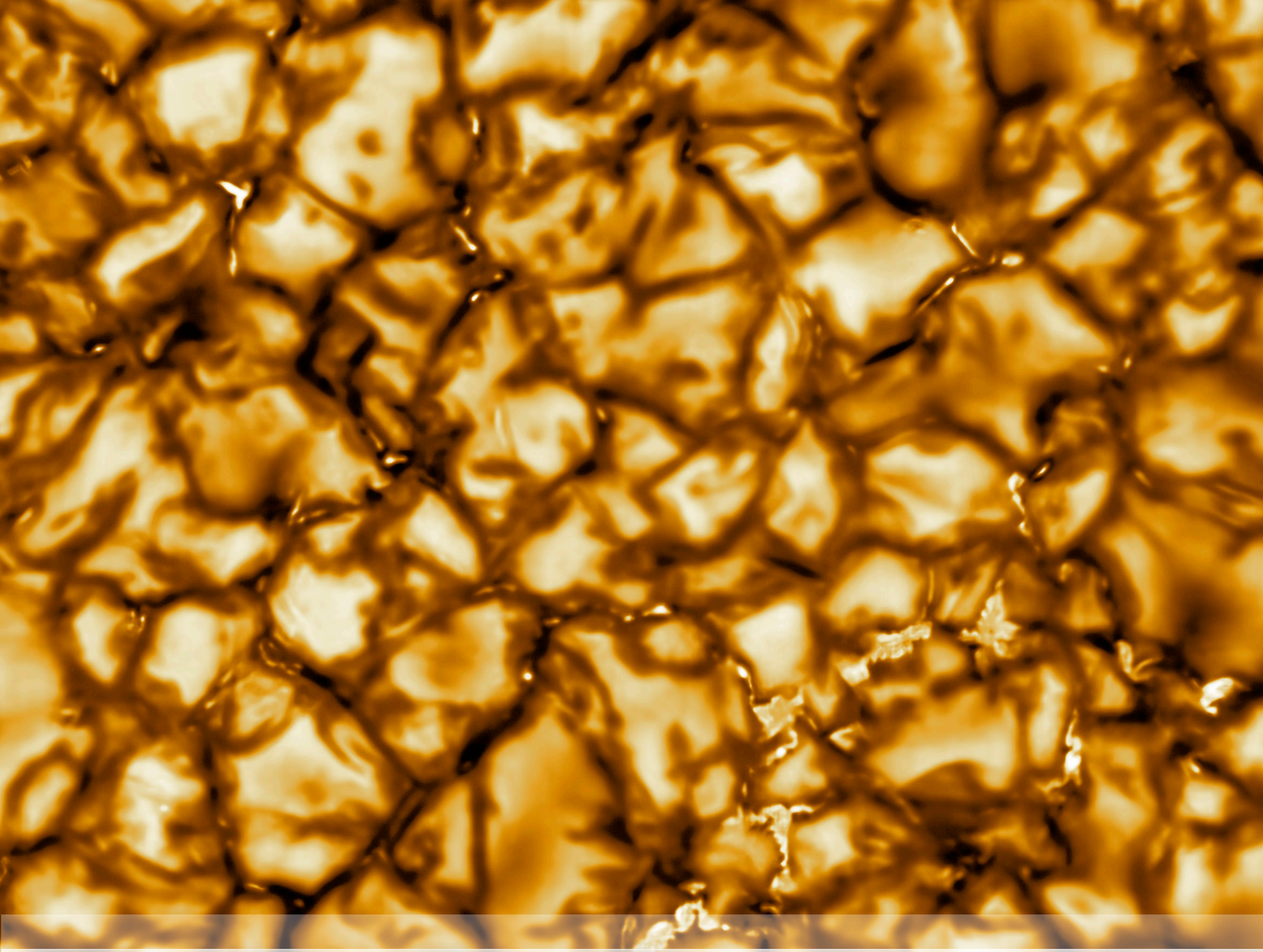

2020
Annual Progress Report

2021
Annual Program Plan

NSF

NSO National Solar Observatory

AURA

Submitted to the National Science Foundation under Cooperative Agreement No. 0946422
and Cooperative Support Agreement No. 1400450

NSO Annual Progress Report covering FY 2020 (10/01/2019 – 09/30/2020) & FY 2021 Program Plan (10/01/2020 – 09/30/2021)

The National Solar Observatory is operated by the
Association of Universities for Research in Astronomy, Inc. (AURA) under
Cooperative Agreement with the National Science Foundation

MISSION

The mission of the NSO is to advance knowledge of the Sun, both as an astronomical object and as the dominant external influence on Earth, by providing forefront observational opportunities to the research community. The NSO operates the world's most extensive collection of ground-based optical and infrared solar telescopes and auxiliary instrumentation, allowing solar physicists to probe all aspects of the Sun, from the deep solar interior, to the photosphere and chromosphere, to the outer corona and out into the interplanetary medium. These assets also provide data for heliospheric modeling, space weather forecasting, and stellar astrophysics research, putting our Sun in the context of other stars and their environs. NSO accomplishes this mission by:

- providing leadership for the development of new ground-based facilities that support the scientific objectives of the solar and space physics community;
- advancing solar instrumentation in collaboration with university researchers, industry, and other government laboratories;
- providing background synoptic observations that permit solar investigations from the ground and space to be placed in the context of the variable Sun;
- facilitating community understanding of the increasingly complex data produced by NSO's facilities;
- providing research opportunities for undergraduate and graduate students, helping develop classroom activities, working with teachers, mentoring high school students, and recruiting underrepresented groups;
- innovative staff research.

RESEARCH OBJECTIVES

The broad research goals of NSO are to:

- ***Understand the mechanisms generating solar cycles*** – Understand mechanisms driving the surface and interior dynamo and the creation and destruction of magnetic fields on both global and local scales.
- ***Understand the coupling between the interior and surface*** – Understand the coupling between surface and interior processes that lead to irradiance variations and the build-up of solar activity.
- ***Understand the coupling of the surface and the envelope: transient events*** – Understand the mechanisms of coronal heating, flares, and coronal mass ejections which lead to effects on space weather and the planet.
- ***Explore the unknown*** – Explore fundamental plasma and magnetic field processes on the Sun in both their astrophysical and laboratory context.

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TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

The National Solar Observatory (NSO) is the primary provider of key ground-based solar facilities to the US solar community. NSO makes available to the community a range of assets that allow solar astronomers to probe all aspects of the Sun, from the deep interior to its interface in the corona with the interplanetary medium. As we enter the DKIST era, NSO provides scientific and instrumentation leadership in high-resolution studies of the solar atmosphere in the visible and infrared, synoptic observations of solar variability, and helioseismology.

Major components of the National Solar Observatory strategic planning include:

- Developing and operating the National Science Foundation's 4-meter Daniel K. Inouye Solar Telescope (DKIST) on behalf of, and in collaboration with, the solar and astronomical community.
- Consolidating and training the DKIST operations team.
- Operating a suite of instruments comprising the NSO Integrated Synoptic Program (NISP). This Program includes the Global Oscillation Network Group (GONG) and the Synoptic Optical Long-term Investigation of the Sun (SOLIS).
- Developing partnerships to establish a future network concept (next-generation GONG, ngGONG) that replaces GONG and SOLIS and provides ground-based solar data adapted to the research community's demands and the Space Weather modeling and forecasting stakeholders.
- An orderly transition to a new NSO structure that efficiently operates DKIST and NISP and continues to advance the frontiers of solar physics. This structure establishes a matrix organization of the NSO that promotes a unified culture at the Observatory and optimizes resource allocations. The NSO's FY 2020–2024 Long Range Plan (LRP) describes the matrix structure. In FY 2021, NSO will complete the administrative and IT common services in Boulder and Maui.

In parallel with these major components, NSO will continue:

- Expanding interagency collaborations for NISP following the guidance in the National Space Weather Strategy and Action Plan and recent legislation.
- Upgrading the GONG network to adapt it to the Space Weather research community's needs, ensuring its competitive continuation in solar Cycle 25.
- Developing multi-conjugate AO (MCAO) and other critical instrumental upgrades for the DKIST.
- Helping the transition of operations of the Dunn Solar Telescope (DST) to a consortium led by New Mexico State University (NMSU). NSO will continue operating the Sacramento Peak site facilities in FY 2021, the final year of the agreement started in FY 2019.
- Increasing diversity of the solar workforce. This FY 2020–2021 APRPP includes a new chapter that summarizes past and future activities at the Observatory to increase diversity within the NSO, its user community, and the undergraduate and graduate student populations, which include geographic, gender, ethnic, and racial metrics.

Some of the programmatic highlights of the NSO Program in FY 2021 include:

- Finalizing the DKIST construction on Haleakalā, while adjusting to delays caused by the COVID-19 pandemic. Subject to the evolution of the pandemic, start of DKIST operations.

- Completing the integration and science verification of DKIST instruments.
- Finalizing the core teams for DKIST operations in Boulder and Maui, including the DKIST Data Center (DC); transitioning staff from the construction project to the operations team.
- Starting the DKIST Operations Commissioning Phase (OCP). Executing the first set of experiments derived from observing proposals prioritized by the DKIST Time Allocation Committee (TAC) and releasing the second call for proposals.
- Resuming operations of the SOLIS suite of instruments at Big Bear Solar Observatory (BBSO).
- Advancing the GONG refurbishment project in its main components; starting deployment of the newly acquired detectors.
- Providing closure to the DKIST Level-2 data products requirements and advancing the interfaces' definition with the DKIST Level-1 data.

A few of the major actions to advance solar physics that NSO will undertake in FY 2021 include:

- Implementing through the NSO Community Science Program (NCSP) a series of activities to prepare the DKIST community on data manipulation and Level-2 data products generation. Continuing the DKIST Ambassadors Program at various US universities to help grow the facility's user base.
- Executing and augmenting the outreach plan to publicize the early science phase of DKIST, building on the highly successful first-light initiative.
- Continuing the integration of NSO research activities into the CU Boulder system. Publicizing the third three-year termed visiting appointment included in the AURA-CU Boulder Cooperative Agreement.
- Strengthening the connections between the in-situ and remote-sensing communities to realize the full potential of multi-messenger solar and heliospheric physics.

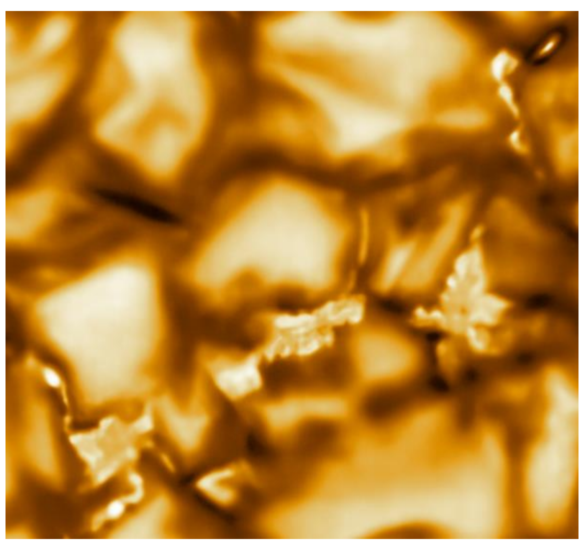


Figure 1-1. An expanded view of the first-light image obtained in December 2019 by the Daniel K. Inouye Solar Telescope at Haleakalā, Maui, Hawaiʻi, that appeared on the front page of the New York Times. The image shows the internal structure of the magnetic ribbon-like bright regions unobserved so far (Rimmele et al., 2020).

In FY 2021, the anticipated observatory funding is $21.79M, split into $17.54M for DKIST operations and $4.25M for base-program actions, including HQ operations and NISP base-funded activities. In past years, NISP has received support for GONG operations from the National Oceanic and Atmospheric Administration (NOAA). For FY 2021, NOAA's annual contribution of $800K has been supplemented with an additional ~$130K to cover the updated costs of running the network. These higher costs have existed in previous years, producing a historical deficit in the GONG operations accounts. In FY 2021, NSO will submit a budget to renegotiate the FY 2022–2026 NOAA/NSF Interagency Agreement (IAA) with an updated GONG operational cost model, including increased site fees at various locations.

NSO received in FY 2020 two supplemental funding actions. The first ($350K) makes the relocatable houses in Sunspot, New Mexico available to an affordable housing program led by the White Sands Habitat for Humanity (WSHFH) in Alamogordo, New Mexico. The second ($481K) enables enhanced DKIST capabilities for multi-messenger research for effective collaboration with the inner heliospheric missions Parker Solar Probe and Solar Orbiter. A third supplement for the DKIST construction project to cover delays created by the COVID-19 pandemic is in process at the NSF.

The demanding but steady path towards the planned completion of DKIST in June 2020 was abruptly interrupted when construction was halted, with work crews following the local stay-at-home orders, due to the spread of COVID-19. On March 17, 2020, all NSO employees began working under an Emergency Telework mode instructed by AURA HR. The majority of the Observatory staff started working from home, guided by their managers. The Observatory defined a set of essential activities that required the physical presence of a few employees at the remote sites or in the offices. All business travel stopped. This phase (Phase 0) lasted until the Observatory performed an AURA internal restart readiness review on May 29. The restart readiness review team included AURA HQ leadership and the safety officers from NSO and NOIRLab. It evaluated two documents, the NSO's Restart Procedure and the AURA Coronavirus Exposure Prevention Plan (CEPP). The successful review allowed the Observatory to move from the lockdown phase (Phase 0) into less restrictive phases. In all of them, NSO has coordinated essential and restart activities as needed with local partner institutions and authorities in Colorado, Hawaiʻi, and New Mexico.

Phase 1 allows for all productive work to occur following strict safety protocols and provides the necessary means for staff contact tracing. In Phase 1, teleworking continued to be the preferred mode of operations (summit construction is described below). High priority and carefully scheduled tasks that require physical presence occur regularly in Phase 1 (IT hardware checks, use of lab space, GONG engineering shelter use, etc.). Authorization to perform these activities requires notification and approval, complete CEPP and site-specific training, access to the site to identified point-of-contact personnel (site managers or safety team), and daily responses to a health questionnaire. AURA HR participates in documenting access to the facilities as needed. During Phase 1, business travel occurs only after approval by the NSO Director or designee and after consultation with the AURA Vice President for Operations.

The phased plan for return describes future phases that evolve to a new normality. At the time of this writing, the Observatory continues in Phase 1, and moving to future phases requires decline in the spread of the virus over time. This improvement of the pandemic situation has not occurred yet. Before moving the Observatory into Phase 2, an additional review exercise will occur. Phase 2 offers more flexible access to the sites by using a web-based calendar that also provides tracking and activity logs. NSO actively coordinates planning for the reopening with other AURA centers and the Corporate office, and participates in revisions of documents providing guidance, including the CEPP.

Due to the pandemic's unprecedented circumstances, the NSO directorate increased the frequency of all-hands meetings to meet with the staff and explain the status of the Observatory as it relates to the COVID-19 situation. NSO transitioned from bi-weekly all-hands in the first part of the pandemic to monthly events, during which leadership explains the contents and modifications of the CEPP and the Observatory's Restart Procedure. Participation in the events is high (more than 80% of the staff), and the regular flow of information has served to maintain staff morale. We will retain the frequency of the all-hands meetings until a new normality is established in CY 2021.

On June 4, a shift schedule with two completely isolated three-day-shift crews restarted DKIST construction at Haleakalā in a relatively constrained mode. After a delta review, construction with the regular (pre-pandemic) single shift resumed on July 6. Construction, however, is occurring inefficiently given the strict safety protocols and procedures implemented—and described in the CEPP. Note also that given the prevailing travel restrictions—that heavily impacted the regular Boulder-Maui transfers of personnel—progress occurs at a slower pace. The project went through a significant schedule revision and the end of construction activities is projected to be April 7, 2021. As a result, the DKIST project submitted to the NSF a Supplemental Funding Request (SFR) of $9.4M to fund the cost of the COVID-19 schedule extension. Additional delays and incurred costs can appear, depending on the evolution of the COVID-19 situation.

Before the pandemic struck and during the first quarter of FY 2020, the Visible Broadband Imager (VBI) and the Wavefront Correction (WFC) were successfully integrated into the facility, making possible the completion of the First Light Initiative (FLI). The FLI milestone produced the most detailed image ever of the solar surface (Figure 1-1). The image was broadcasted in a joint press release by the NSF, AURA, and NSO and achieved major attraction by the press, reaching the front page of the *New York Times* on January 30, 2020.

Progress occurred in FY 2020 with other first-light instruments. The Visible Spectropolarimeter (ViSP) of the High Altitude Observatory (HAO), the Diffraction-Limited Near-IR Spectropolarimeter (DL-NIRSP), and the Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP)—the last two with the University of Hawaiʻi (UH) Institute for Astronomy (IfA)—moved forward, often by readjusting the schedule to accommodate COVID-19 impacts. Following transport to the summit and IT&C work on the Coudé rotator, all three instruments are moving into site acceptance testing and scientific verification in FY 2021. For the ViSP, these latest phases depend on HAO/NCAR personnel's ability to fly to the island. The thermal system will also progress in FY 2021. It will incorporate an improved heat stop assembly that is undergoing final machining and will be installed into the telescope in late 2020. Progress at the summit pending the evolution of the pandemic will dictate the date of the Final Construction Review.

The FY 2020–2021 period has seen the consolidation of DKIST operations teams at all sites. While the priority continues to be finalizing the facility on schedule, the transfer of a majority of the construction staff to the operations team will ensure that the required expertise is available to operate and maintain the DKIST systems for the initial part of operations.

After years of community interactions, the NSO released in May of 2020 the DKIST Critical Science Plan (CSP) document (*https://nso.edu/wp-content/uploads/2020/07/criticalscienceplan_20200602a.pdf*). The CSP provides a snapshot of some of the scientific pursuits that the DKIST will enable as the start of operations nears. The recent DKIST images only hint at the extraordinary capabilities that will follow from the five facility instruments' full commissioning and early operations. The CSP document is an attempt to anticipate some of what those capabilities will enable. The paper relied on contributions from the DKIST Science Working Group (SWG) and CSP community members who participated in a series of activities and workshops organized by the NSO. They all generously shared their experiences, plans, knowledge, and dreams. These workshops have also served as a platform for the community to test the tools needed to define an observing run compatible with the current instrument and telescope capabilities. In that way, they played a vital role in preparing the community for the first call of observing proposals. A shorter version of the CSP document is included in the *Solar Physics* DKIST topical issue, currently in press.

At the end of construction, the DKIST will undergo an Operations Commissioning Phase (OCP). This phase allows for science operations and the Data Center to ramp up and transition into steady-state operations. The expected duration of the OCP is one year. One primary goal of the OCP is to build up complexity from simple instrument configurations to full capabilities (i.e., multi-instrument operations). Similarly, to ramp up towards smooth and successful broad community use of the full capabilities of DKIST, the OCP aims at fine-tuning the proper functioning of all facility subsystems including operational procedures and tools; producing and consolidating instruments' pipelines and data analysis strategies; furthering the scientific validation of the various instruments' modes of operations; and commissioning the DKIST Data Center. During the OCP, NSO intends to make the facility available to the community, albeit with limited capabilities. NSO will release three calls for observing proposals that progressively offer increased instrumental and telescope capabilities. The first such call was released on May 15, 2020. It offered the VBI and the ViSP—forming an early endorsement of the multi-instrument operations of DKIST—and an on-disk configuration of the Cryo-NIRSP. For this OCP call, the submission window was open for three months, providing astronomers with ample time to familiarize themselves with the call's specific capabilities and the tools and services supporting proposal submission. The community's response to this first opportunity was tremendous despite the limitations of the call, and NSO received 101 proposals, with the US as the leading country (46%), followed at some distance by a DKIST project partner, the UK (17%). The proposals are currently subjected to a competitive peer review by the Time Allocation Committee that will produce a ranked list of approved proposals. A second OCP call for DKIST proposals will be released in FY 2021.

In FY 2019, the DKIST Data Center passed its Critical Design Review, which led to some design augmentation and implementation changes based on the review committee report. Following this review, the Data Center is now immersed in performance testing and tuning of infrastructure. In parallel, the team is also working on calibration pipelines for the various instruments and operationalizing the algorithms. The pipelines for the instruments offered in the first OCP call prioritized the ongoing Data Center activities. To have a smooth transition towards full Data Center operations, the OCP planning extends beyond the telescope's commissioning and its subsystems at the summit and includes the Data Center and its infrastructure in Boulder and Maui. During OCP, the Data Center will progressively ramp up to full operations as successive proposal calls offer additional instruments. The first complete test of the transfer of data observed by the telescope from the summit to Boulder HQ will occur in the 2021 spring-summer time frame.

During FY 2020, all three initiatives comprising the DKIST Level-2 data project—channeled through the NCSP—have made significant progress. The Data Product *Initiative* defines the Level-2 data that will be routinely produced by the program. In late FY 2020, the NCSP released the first version of the Level-2 data products requirements. The document describes the Level-1 input data and metadata, the type of analysis that produces the solar atmospheric parameters for each input data product, and the properties of the output Level-2 data and corresponding metadata. By making sensible assumptions based on the CSP science use cases, the requirements document contains a first estimate of the expected Level-2 data rates. As for the Level-1 case, the Kiepenheuer Institute for Solar Physics (KIS) Visible Tunable Filter (VTF) dominates the output data rates, with the Visible Spectropolarimeter (ViSP) as a distant second contributor. In FY 2021, the Level-2 requirements document will serve as the starting point of discussions with the DKIST Data Center about the workforce effort and hardware required to distribute the additional data products.

The DKIST Ambassadors cadre is the fundamental component of the project's University *Initiative*. The NCSP trains a total of 12 Ambassadors, spread within the US university system, who will bring their expertise to their host institutions and broaden the user base. In FY 2020, NCSP had several networking activities with the Ambassadors to help familiarize them with the tools offered by the first OCP call for proposals and to ensure their active participation in this first opportunity to obtain data from DKIST. Finally, and as part of the community oriented *Initiative,* NCSP organized two workshops in FY 2020, one in person in January 2020 at California State University Northridge (CSUN) and another remotely in the summer of 2020. The CSUN workshop provided training to familiarize early-career scientists with the preparatory work often needed before processing the Level-1 data through the Level-2 pipelines (image restoration, feature tracking, etc.). The summer workshop focused on training the participants on Milne-Eddington inversion schemes, which are the most popular inversion technique used to retrieve magnetic field data from observed Stokes profiles.

On March 30, 2020, Dr. Frank Hill retired from the NSO after 35 years in various roles, including his latest as NISP Associate Director. Soon after his retirement, the NSO formed a search committee to replace him. The committee's hiring chair was the NSO Director, who also acted as NISP interim director during the transition. The search committee advertised the position externally to maximize the diversity and expertise of the applicant pool. The committee finally offered the job to a 20-year NSO veteran, Dr. Alexei Pevtsov, who started in this position on June 21, 2020. Alexei's background ranges from solar magnetism to solar-stellar astrophysics; his expertise also includes a substantial understanding of the US Space Weather community's needs, all essential skills necessary for leading a strengthened NISP.

2020 started with a significant and unexpected event impacting GONG operations. The ephemeris tables used by the network had an overlooked expiration date of December 31, 2019. While the network instruments were not dependent on the ephemeris and continued observing the Sun, the software pipelines stopped working. A group formed by NISP scientists and Data Center personnel started working in earnest. Within a month, the team produced a stable solution that automatically generates the necessary ephemeris, preventing similar issues from repeating in the future. The Space Weather Prediction Center (SWPC) at NOAA congratulated the team for finding a long-term solution and a stop-gap approach that minimized data flow interruptions. After the pandemic started, the network lost individual sites for periods of time that were impacted by the local lockdown situation. Teide, Udaipur, and Big Bear stations were down for several weeks, but no more than one at a time was inoperative. Tenerife and India's local teams helped fix the respective site problems as soon as the lockdowns were lifted. The situation in California was slightly more complicated and required an emergency trip by the NISP technical team. NISP has plans for additional travel to the sites in FY 2021 while following the constraints imposed by the evolving COVID-19 restrictions.

The NISP program has two significant ongoing developments, GONG refurbishment and SOLIS construction at Big Bear. The COVID-19 situation has impacted both in different ways. Travel restrictions have prevented the final deployments of new modulators from the refurbishment program to some sites. However, the team, through heavy-use of the GONG engineering units on the CU campus, and adhereing to COVID-19 prevention measures, was able to test a new detector for the network. Deployment of the new cameras—already at the NSO lab—will mark the refurbishment project's most important milestone. COVID-19 also prevented progress on constructing the SOLIS site at Big Bear Solar Observatory (BBSO). However, after the start of Dr. Alexei Pevtsov's appointment as the new NISP AD, progress was made on producing a modified MOU with the New Jersey Institute of Technology (NJIT) (the managing institution of BBSO), clearing the path for construction of the SOLIS site in California. The new MOU establishes a partner framework that will lead to furthering scientific collaborations between NJIT and NSO soon after SOLIS is online at BBSO. Barring any additional constraints imposed by the pandemic, the team expects SOLIS to be back on the skies by summer 2021.

The future of NISP relies on replacing the GONG network and SOLIS with a suite of instruments that fill the needs of the community and provides alternatives to space-based assets. The ngGONG network is the most advanced concept that meets those needs and has broad international and national support. ngGONG is a ground-based network of telescopes capable of precise solar vector magnetic field measurements, primarily designed to enable data-driven models describing the evolving magnetic connectivity between the Sun and the Earth. ngGONG will also ensure the continuity of decades-long helioseismological observations that monitor the solar interior.

In FY 2020, NSO and the High Altitude Observatory (HAO, Boulder, Colorado) continued community engagement to consolidate the requirements for future solar synoptic observations from the ground. The discussions included both Space Weather forecasting agencies and the research community. After a total of three meetings and additional iterations with the interested partners, the two NSF centers have consolidated the science-driven requirements applicable to the future synoptic network and are contrasting requirements with those originated from operational needs. Based on these discussions, NSO and HAO are drafting a concept for ngGONG that incorporates the research requirements but is also compatible with the criteria defined by the Space Weather stakeholders. As a result, ngGONG is the first ground-based synoptic network that considers Space Weather needs from its inception. In FY 2021, NSO and HAO will submit to the NSF a proposal for the definition phase of ngGONG. ngGONG should be seen as the response of the research community to the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act, recently signed into law, that directs the NSF to maintain and improve ground-based observations of the Sun.

In Sunspot, NSO activities concentrate on supporting the New Mexico State University (NMSU) crew operating the Dunn Solar Telescope (DST) and the site's Visitors Center. The NMSU-led consortium continues synoptic observations at the DST. The telescope is accessible to the community for target opportunities such as rocket launches from the nearby White Sands facility, and to coordinate with space-mission observations including NASA's Parker Solar Probe (PSP). CSUN leads, via a NASA Heliophysics System Observatory Data Support grant, a program for coordinating DST observations with PSP science phases, starting with encounter #4. In FY 2021, NSO will continue operating the site as part of the collaborative framework with NMSU that began in FY 2019. In addition to the regular maintenance activities NSO develops on site, FY 2021 will see a significant transformation of the facility by relocating 21 relocatable houses to the nearby city of Alamogordo. This activity is in coordination with the WSHFH non-profit organization. The action is expected to start in early CY 2021 and be completed before the fiscal year. NSO's Sunspot role beyond FY 2021 needs a cost-benefit analysis involving the site consortium stakeholders and the funding partners.

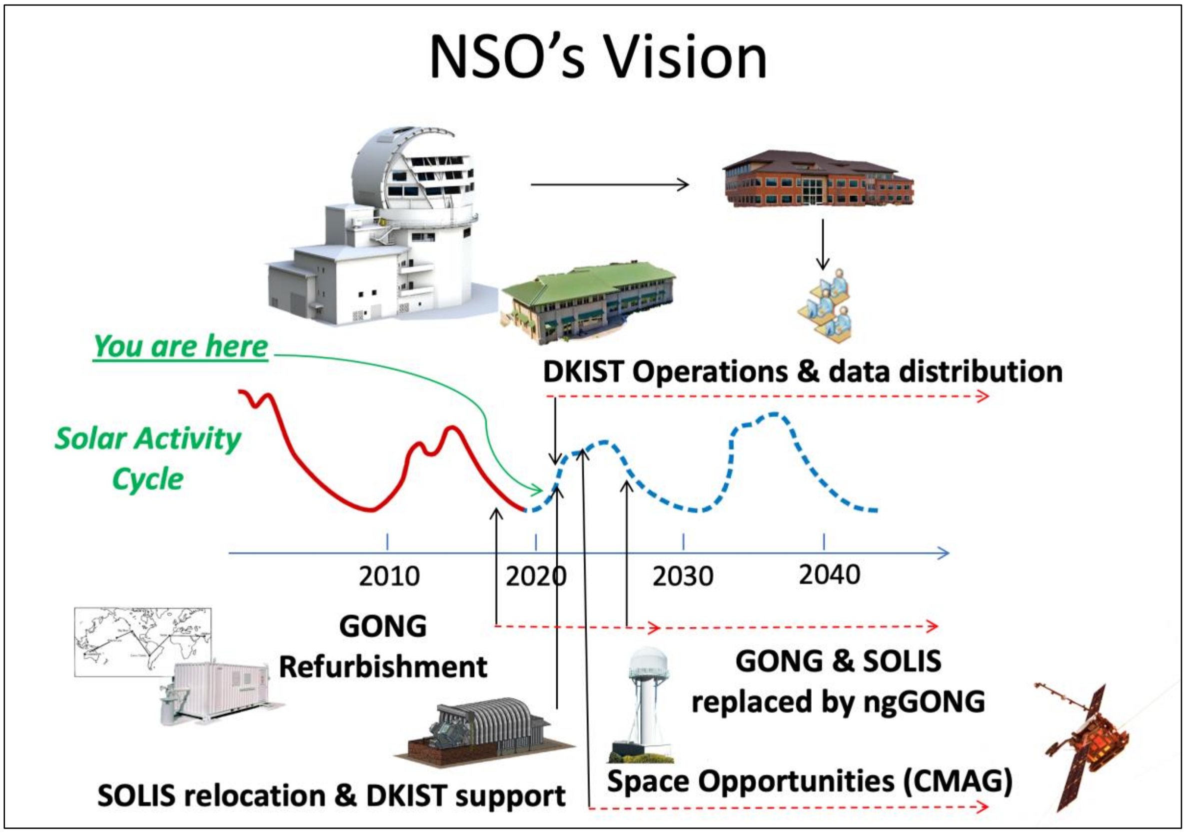


Figure 1-2. The long-term vision of NSO over half the lifetime of DKIST.

COVID-19 also impacted the operations of the NM facility. All activities stopped in mid-March following local stay-at-home orders. NSO and NMSU coordinated the shutdown and met regularly to establish a reopening plan that included cross-training of employees on COVID-19 prevention measures from both institutions. After significant repair work of the DST, the telescope restarted operations in early June following the AURA review. The site manager, Geoff Roberts, acts as site point-of-contact to whom all employees answer the daily health questionnaire before returning to work. The site continues to be operational while monitoring the State of New Mexico guidance on travel and quarantine conditions. Recent State orders excluded Federal sites from going into additional lockdowns, allowing the site to remain open, even in those cases when the telescope operator halted observations. Since March, the site's Visitors Center remains closed, and NMSU is monitoring the local evolution of the pandemic before deciding on its reopening.

After NSO relocated to Boulder and Maui, the Observatory reinvigorated its Education and Public Outreach (EPO) program by hiring a Boulder-based Head of EPO and an assistant in Maui. The team has been augmented with a part-time graphics designer and webmaster. Compared to similar observatories, our EPO team is demonstrably smaller, minimizing the impact the Observatory scientific programs can have on the general public. The FY 2020–2024 Long Range Plan pointed out this concern and requested additional funding for the Program. To adequately promote the DKIST early science phase, the NSO EPO Program is planning to advertise two additional positions originally funded this year from the DKIST Program. NSO is soliciting an increase in the Program's base funding in future years that can sustain these positions. An augmented team will be critical as we move into the DKIST operations phase and as we aim at increasing the user-base by motivating undergraduate students across the country. Key to this task is NSO's involvement in the Boulder-wide Research Experiences for Undergraduates (REU) program, led by our colleagues from the Laboratory for Atmospheric and Space Physics (LASP). The REU program has operated for several years, including FY 2020. The global COVID-19 pandemic mandated a very different approach in the summer of 2020. Still, LASP and NSO program leaders took on the challenge and created a highly successful remote REU experience praised by participants, mentors, and representatives from the funding agency. This online REU program represents a proof of concept for remote mentorship activities in the future. It opens the door for the potential participation of mentors in Maui benefiting from the Boulder-based REU program. In FY 2021, the EPO team plans to leverage this REU experience by supporting higher education via the NCSP and enabling online networking activities, ensuring educational best practices for remote events.

NSO FY 2021 Program

- **Daniel K. Inouye Solar Telescope (DKIST)**
  - Finalize DKIST construction adjusting to the COVID-19 evolving circumstances.
  - Start the DKIST Operations Commissioning Phase (OCP).
  - Start the execution of Experiments from the first OCP call.
  - Execute the DKIST Data Center implementation plan.
  - Release the second OCP call for observing proposals.
  - Continue developing Multi-Conjugate Adaptive Optics.
  - Define DKIST instrumental upgrades.
- **NSO Integrated Synoptic Program (NISP)**
  - Operate the GONG network. Continue the network data distribution.
  - Complete the new SOLIS site at Big-Bear and prepare for operations.
  - Refurbish the GONG network prioritizing new detector upgrades.
  - Submit the ngGONG design phase proposal in collaboration with the broader community.
  - Continue to seek outside funding for operations, including space opportunities.
- **NSO Community Science Program (NCSP)**
  - Consolidate the requirements for the DKIST Level-2 data products.
  - Start the implementation of the Level-1/Level-2 data products interface.
  - Train the community on the generation of DKIST science-ready data products.
- **Sacramento Peak Observatory**
  - Operate the site.
- **NSO Directorate**
  - Implement the first components of the NSO matrix structure.
  - Lead community-based multi-messenger solar physics opportunities.
- **Education and Outreach and Broadening Participation**
  - Disseminate DKIST and Observatory-wide results.
  - Continue local engagement in Boulder and Maui.
  - Train a diverse future generation of solar astronomers.

2 FY 2020 SCIENTIFIC RESEARCH & DEVELOPMENT HIGHLIGHTS

2.1 The Off-Limb Polarized Corona at High-Resolution: New Synthetic Views for the DKIST Era

Diffuse, yet close to the Sun, the solar corona evolves synonymously with its magnetic field, which still remains poorly measured. As remedy to this, DKIST advances large-aperture coronagraphy to enable the unique diagnostics offered by polarized coronal emission lines.

Coronal polarimetry on fine angular scales provides new diagnostic opportunities, but it also requires a deeper understanding of multi-wavelength polarized line formation. To facilitate this understanding, recent work (*SoPh,* 295, 98, 2020) by Tom Schad (NSO Associate Scientist) and Gabriel Dima (DKIST Postdoctoral Research Associate), unites the development of an updated and extended code for polarized spectral calculations, called pyCLE, with the synthesis of coronal polarized spectra through advanced 3D MURaM simulations of the active corona viewed off-limb.

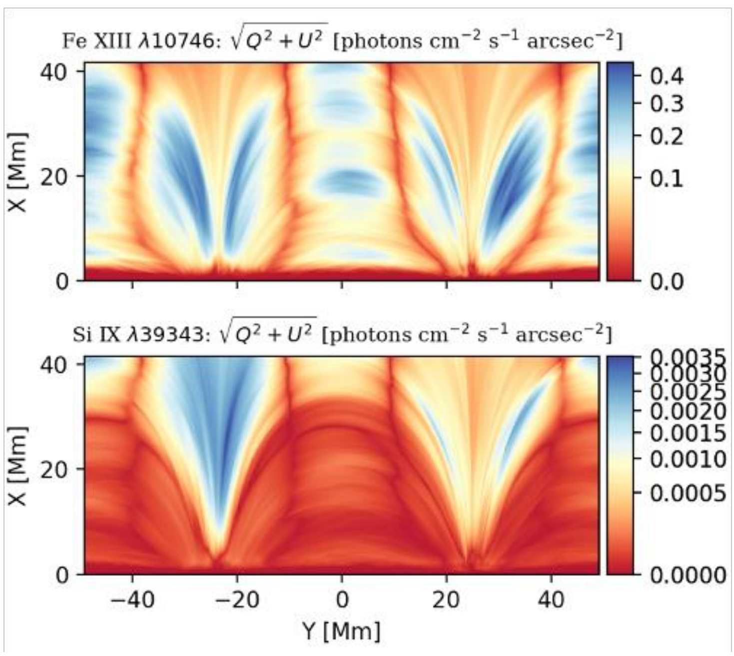


Figure 2-1. Maps of total linear polarization ($\sqrt{Q^2+U^2}$) in radiance units synthesized off-limb for the MURaM active region simulation. The color scale differs for each plot and is power law normalized with $\gamma = 0.5$.

Synthetic maps of the Fe XIII 1074 nm and Si IX 3934 nm linear polarized amplitude are shown (inset, Figure 2-1). Using pyCLE, Schad and Dima showcase the large differences expected between these lines. Locations with near-zero linear polarization have been previously observed in the corona and associated with magnetic topology changes, i.e., the so-called 'Van Vleck nulls'; Schad & Dima, however, also identify a second type of null for specific lines like Si IX 3934 nm, which are due to the density-dependence of the atomic alignment, i.e. "density induced nulls." These have yet to be observed but are within the reach of DKIST observations.

Schad and Dima (2020) further discuss a range of diagnostic pathways making use of DKIST coronal observations, including deriving "single-point" vector magnetic field measurements along coronal loops by adapting background subtraction strategies used in the EUV. pyCLE synthesized maps of polarized intensities do display loop-like features; however, the structure is not strictly coherent amongst the polarized states due to line-of-sight integration effects and the non-linear weighting of polarized signals along the line of sight, which is heavily influenced by density effects. Thus, as we progress toward the interpretation of DKIST observations, we must carefully consider when and how to isolate a feature for a single-point magnetic field measurement.

Through the work of Schad and Dima (2020), we get a glimpse of the richness that DKIST high-resolution coronal observations will provide (Figure 2-2). Much work is needed to realize the full potential of these DKIST coronal diagnostics, and numerical modeling and forward synthesis will continue to be essential tools for this endeavor.

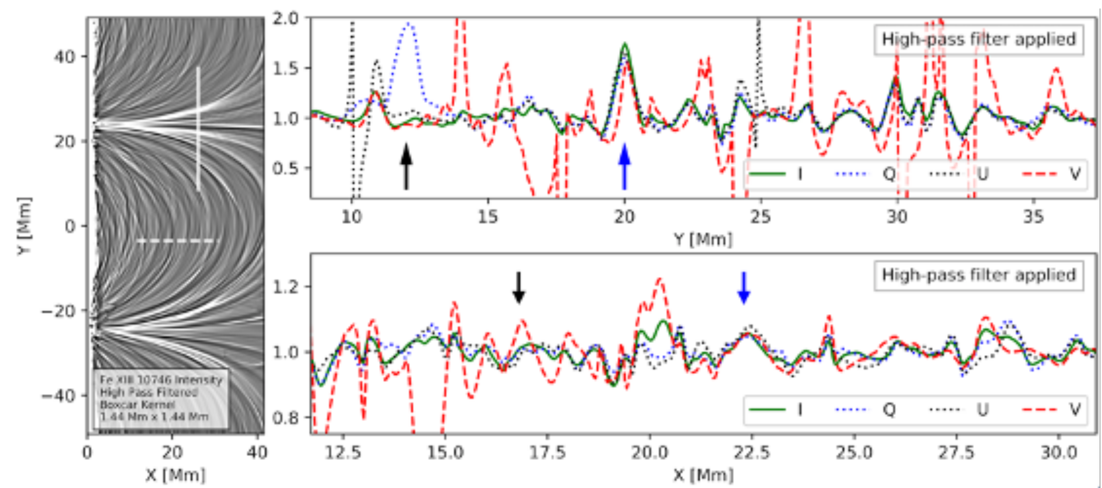


Figure 2-2. A comparison of the spatial structure in maps of line-integrated Stokes I, Q, and U, and the signed maximum Stokes V spectral radiance. Each is high-pass filtered via division by a boxcar convolved version of itself (kernel size in figure). Line cuts along the solid and dashed lines in the left plot are shown in the upper right and lower right plots. Black arrows indicate (as an example) points where a feature is not simultaneously present in all parameters. Blue arrows provide examples where there is some coherence between the structure in all Stokes maps.

2.2 Spectral Signatures of Chromospheric Condensation in a Major Solar Flare

A key question still unresolved in solar flares is the actual spatial and temporal scale on which the lower atmosphere responds to the energy injection from the flaring corona. In many cases, flaring "kernels" have been measured at essentially the diffraction limit of the telescope used, currently of the order of ~0.1"-0.2" (<150 km at the solar surface). Using the popular collisional thick-target model to describe the energy transport, small kernel areas imply very high fluxes of electrons being accelerated in the flare, while reconnection theory still has a hard time explaining their origin and stability.

Graham et al. (*ApJ*, 895, 22, 2020) expand on this problem by analyzing a comprehensive dataset of flare chromospheric spectra, observed at high resolution with the Interface Region Imaging

Spectrograph (IRIS). The spectra were obtained in multiple flaring kernels from the very early phase, allowing a rare insight into the impulsive spectral response of the chromosphere. This is the critical phase when the spectral effects of impulsive heating can be directly compared with numerical simulations.

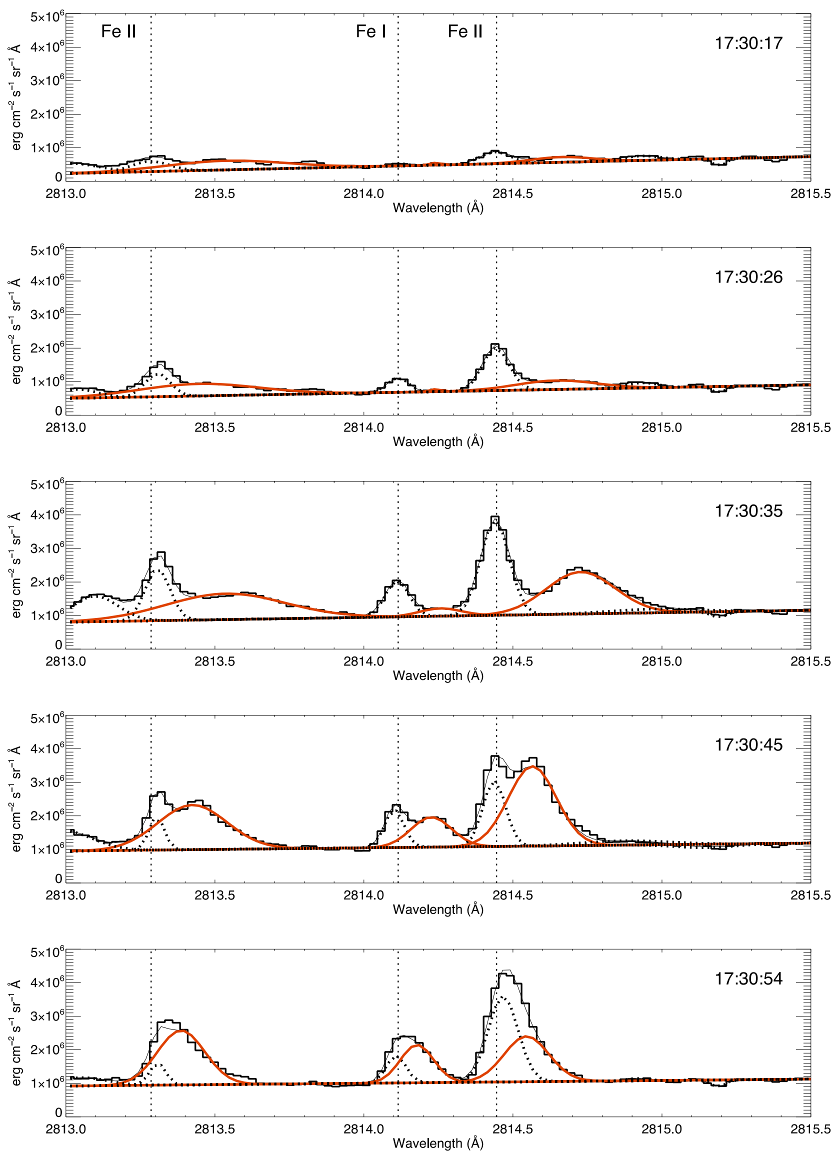


Figure 2-3. Temporal evolution of Fe I and Fe II lines (stepped black lines) during the impulsive phase of a flaring kernel, only 0.3″ wide. The dotted vertical line represents the rest wavelength for each line (labeled in the top panel). Dashed black lines represent the Gaussian fits for the stationary component; red lines the fit for the redshifted components created in the chromospheric condensation. The total fit is given as a solid black line.

The panels in Figure 2-3 show the chromospheric Fe I and Fe II lines observed in one flare kernel, at 9 s cadence. All lines show a rapidly evolving double-component structure: an enhanced, emission component at rest, and a broad, highly red-shifted component of increasing intensity, which rapidly migrates from 25–50 km s^{-1} towards the rest wavelength. Only 30–40 s after the onset, the red-shifted components are mostly blended with the stationary ones, giving rise to apparently single, asymmetric bright lines. (The same behavior is observed for many other chromospheric lines and multiple flaring kernels, only 0.3″ apart.) Using complementary hard-X ray data to guide state-of-the-art radiative hydro-dynamical numerical simulations, Graham et al. could quantitatively reproduce many of the observed characteristics by assuming a high flux electron beam impinging on the plage chromosphere (F ~ 10^{11} erg s^{-1} cm^{-2}). Their analysis demonstrated that the two spectral components of flare lines arise due to the combined heating in different parts of the pre-flare atmosphere; in particular, the rapidly migrating red-shifted component is due to the condensation that develops in response to explosive heating in the upper chromosphere. Graham and colleagues thus confirm that high-flux electron beams appear necessary to explain the thermo-dynamical evolution of chromospheric flare kernels.

The remarkable agreement between simulations and observations in this work has been achieved thanks to the enhanced temporal and spatial resolution of the IRIS spectra with respect to previous instrumentation. Upcoming DKIST observations hold much exciting promise in this respect. Flare imaging will be possible at the highest spatial resolution ever (~3x better than currently), allowing better estimates of the beam flux. The large telescope aperture will be fundamental in providing even faster cadence flare spectroscopy: this is necessary to better characterize the evolution of different spectral components and relate to theories of energy release in the corona. Especially novel is the possibility of obtaining with the ViSP spectrograph these high-resolution data while providing broad range spectroscopy, a feature that has been missing in solar flare studies for decades. Not only is this necessary for constraining the physics of turbulence and shocks in the low atmosphere, but it will also allow for better synergy with the large and growing body of work on flares in cool stars, for which the Sun represents a template.

2.3 Acceleration of Coronal Mass Ejection Plasma in the Low Corona as Measured by the Citizen CATE Experiment

The Continental-America Telescopic Eclipse (CATE) Experiment was designed as a citizen science experiment to capture a time sequence of white-light coronal observations during totality from 17:16 to 18:48 UT on 2017 August 21 across 70 sites. Using identical instruments, the CATE group imaged the inner corona from 1 to 2.1 $R_\odot$ with 1.″43 pixels at a cadence of 2.1 s (Matthew Penn and more than 100 authors, *PASP*, 132:014201, 2020). The white-light images show coronal material escaping from the Sun during the late phase of a slow CME event which occurred before the eclipse.

To take advantage of high cadence of the measurement each image was processed with normalized radial gradient filter to remove coronal background variation in intensity and then a Sobel edge-enhancement procedure was applied to enhance low contrast features. Using cross-correlation between two image pairs local image shifts were computed and a time sequence of these shift provided local velocity vectors. Figure 2-4 below shows spatially filtered image with computed velocity vectors overlaid on the greyscale. The CME outflow was found to lie between two prominent stationary coronal threads.

The average radial velocity inside 0.1 $R_\odot$ bins over the CME region of interest (ROI) versus radial distance is shown in Figure 2-5. Two fits to the CATE data are shown: a constant acceleration model of 15 m s^{-2}, and a model showing a spatially increasing velocity with a slope of 175 km s^{-1} $R_\odot^{-1}$. A spatially changing acceleration is required to explain the observed CME velocities.

Unlike previous studies which report the acceleration of fast CME events by measuring the position of the outwardly moving front as the CME is initiated, we report an acceleration by measuring the velocities of the CME material. The velocities show a change with height in the solar atmosphere. When the CATE measurements are combined with the LASCO C2 data, we find that a uniform acceleration cannot explain the kinetics of this CME, and that the acceleration mechanism must change at different heights in the solar atmosphere.

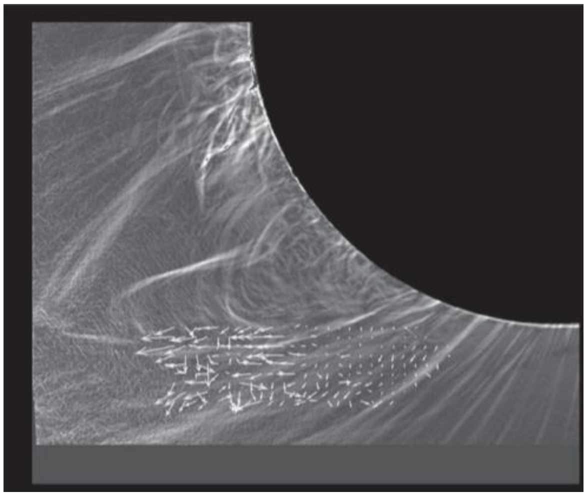


Figure 2-4. A sample frame from the CATE time series showing the SE solar limb with a Sobel filter applied. On top of the gray scale are arrows showing the scaled motions of the coronal plasma measured with a cross-correlation technique in the CME region of interest common to all subswequent images.

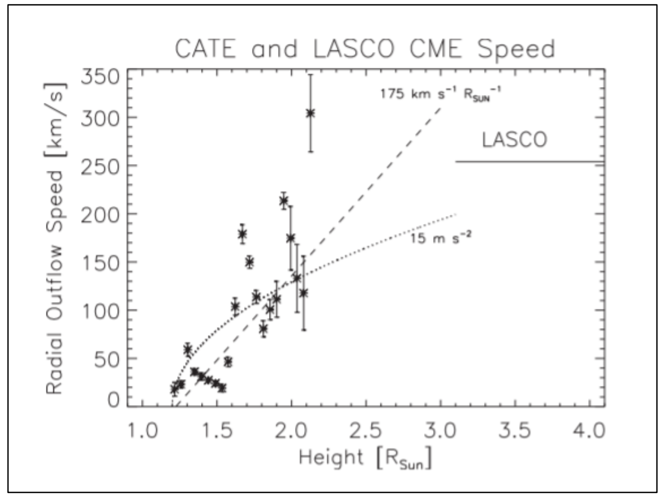


Figure 2-5. The radial outflow speed with height, averaged over the coronal mass ejection region of interest. The points represent averages of the radial outflow in bins of 0.1 $R_\odot$. The error bars are the standard deviation of the mean for the values in that bin. The CATE data extend from 1.2 to 2.1 $R_\odot$, but measurements from LASCO C2 at 3.1 $R_\odot$ and higher are shown by the horizontal line at 254 km s^{-1} .

2.4 Temporal Evolution of the Inverse Evershed Flow (IEF)

The inverse Evershed flow is an inflow of material into the penumbra of sunspots in the solar chromosphere. It occurs along elongated super-penumbral fibrils that extend from about the outer edge of the moat cell to the sunspot's penumbra. The IEF channels exhibit brightenings in the penumbra, where the supersonic IEF descends to the photosphere causing shock fronts with localized heating.

Beck and Choudhary (*ApJ*, 891, 17, 2020) determined the temporal evolution and lifetime of individual IEF channels by analyzing a one-hour time series of observations in the chromospheric spectral lines of He I at 1083 nm, Hα at 656 nm and Ca II IR at 854 nm taken with the Facility Infrared Spectropolarimeter (FIRS) and the Interferometric Bidimensional Spectrometer (IBIS) at the Dunn Solar Telescope (DST) in Sunspot, New Mexico.

Figure 2-6 shows intensity and line-of-sight (LOS) velocity maps of the observed sunspot. The IEF channels appear as bright, elongated, radially aligned or slightly curved streaks in the intensity images of the left column in their reverse grey scale chosen for better visibility, but are in reality darker and denser than their surroundings. The intensity fibrils are matched in the velocity maps of the right column, where the IEF channels show a comet-like head at their inner end point, where the

LOS flow speed increases while the diameter of the IEF channels decreases. The sign of the LOS velocity changes depending on whether the flow channels are on the disk center or limb side of the sunspot.

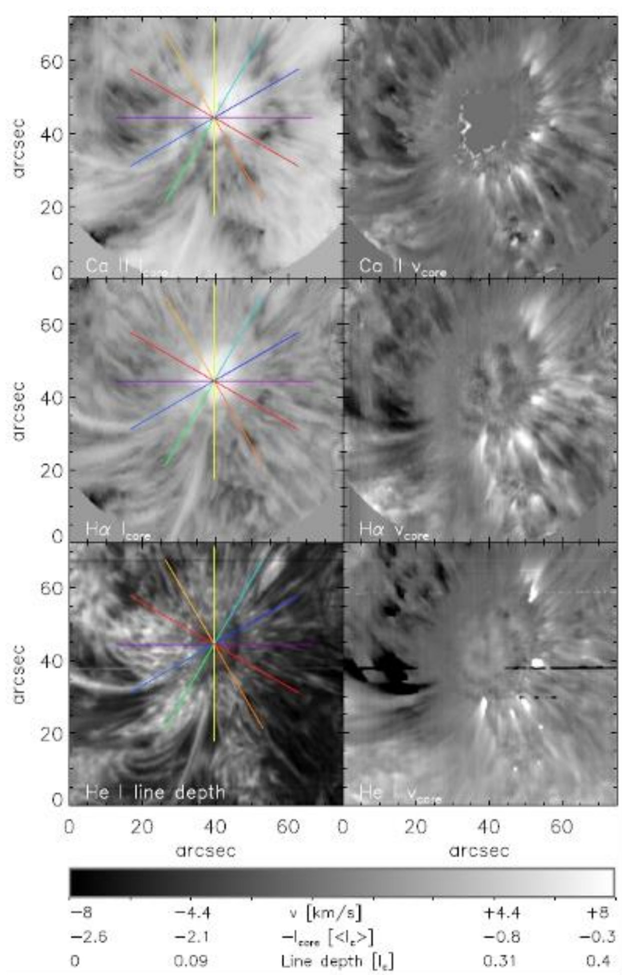


Figure 2-6. Overview maps of FIRS and IBIS data. The IEF channels show up in the intensity images of He I 1083 nm, Hα and Ca II IR in the left column as roughly radial, bright streaks. In the corresponding velocity maps in the right column they appear as comet-like features with a dark or bright head depending on whether they are located on the limb/left or center/right side.

The temporal evolution of the flow speed on an azimuthal path around the sunspot center as derived from the Hα and Ca II IR spectra. Uninterrupted streaks of high velocities above 1 km/s indicate the continued existence of individual IEF channels. Their lifetime is at minimum about 10 min, while some persist for the full duration of the observations of more than one hour.

IEF channels that disappear are often replaced by a new one at about the same location. Initiation and termination of IEF channels take several minutes. The IEF channels exhibit little radial or lateral motion and only small variations in their flow speed during their lifetime. They show no lasting impact from transient or oscillatory phenomena that run along them. Beck and Choudhary could not detect any clear correlation of the location and evolution of IEF channels to local magnetic field properties in the photosphere in the penumbra or moving magnetic features in the sunspot moat.

Figure 2-7 sketches the proposed magnetic topology of the IEF channels in the penumbra, while the super-penumbral fibrils would continue as nearly horizontal field lines at chromospheric heights for several Mm before returning to the solar photosphere at the outer end of the moat cell. The IEF must connect to inclined magnetic field lines that ascend from the photosphere to the chromosphere at the inner end point. These cannot be identical to the horizontal field lines in the photosphere that host the regular Evershed flow in the opposite direction. Beck and Choudhary's findings support a so-called "uncombed" penumbral structure with two magnetic components of different inclination, whose existence was predicted from observations of net circular polarization in photospheric spectral lines.

From their current observations, Beck and Choudhary were not able to trace back the temporal evolution, especially the formation and cessation of individual IEF channels, to any changes of the magnetic topology inside the penumbra. They thus suggest that this part of the evolution of IEF channels is controlled by changes of the magnetic field at their outer endpoint instead, which governs the difference in field strength and subsequently gas pressure between the inner and outer endpoint that drives the IEF.

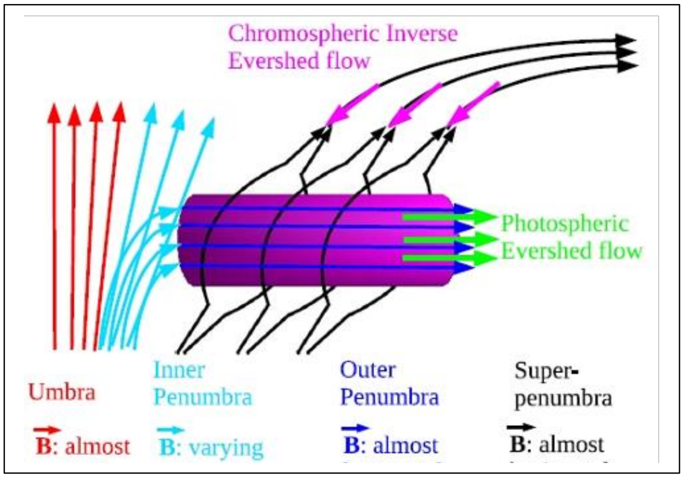


Figure 2-7. Sketch of the IEF magnetic topology. The chromospheric IEF follows inclined magnetic field lines in the inner and outer penumbra showing an inflow towards the sunspot that turns downward at the end. The photospheric Evershed flow in the opposite direction follows nearly horizontal magnetic fields lines in the lower atmosphere.

With the intensity and velocity information as presented in Figure 2-6 one can, however, not reliably determine where those locations are as the IEF channels blend into the background of the chromospheric structure in the moat far away from the sunspot. Beck and Choudhary will thus use magnetic field extrapolations of the observations used here to identify the outer endpoints of individual IEF channels to follow the evolution of the magnetic topology at the outer end in a future study.

2.5 Spatially Resolved Ultraviolet Spectroscopy of the Great Dimming of Betelgeuse

Experience from modeling the Mg II h and k lines in the context of understanding the information contained in IRIS observations of these lines in the solar atmosphere (e.g., Leenaarts et al., *ApJ*, 772, 90, 2013) guided the interpretation of spectra of the magnesium lines in a very different object. In December 2019 and the first quarter of 2020, the bright supergiant Betelgeuse (Alpha Orionis; HD 39801) experienced an exceptional visual dimming, reaching an historic minimum in brightness in 2020 February 7–13. This led to widespread speculation that the star was about to explode as a supernova. At the same time, as the severe dimming occurred, spatially resolved ultraviolet spectra using the Hubble Space Telescope/Space Telescope Imaging Spectrograph revealed a substantial increase in the ultraviolet spectrum and Mg II line emission from the chromosphere over the southern hemisphere of the star.

The shape of the brightened Mg II h and k lines, with an enhanced blue peak was reminiscent of the signature of acoustic waves passing through the chromosphere in the Sun. From experience at NSO studying the excitation of these acoustic waves and modeling of the Mg II lines in the context of IRIS observations, it is known that the strongest shockwaves in the solar atmosphere occur when granular upflows coincide with upward motion in the five-minute oscillation. This prompted the suggestion that the exceptional outflow event might be a coincidence of the regular pulsation of Betelgeuse with a strong super giant convection cell. The generated, combined, out flow generates a strong acoustic wave growing into a shock that heats the chromosphere and leaves a significant expansion cooling event in its wake. In this cooling event, a sizeable molecular and dust cloud can form that would explain the extreme darkening as well as simultaneous brightening of the chromosphere. Thus, experience from solar physics was able to inform and explain a series of seemingly diverse events in a very different environment (Dupree et al., *ApJ*, 899, 68, 2020).

Figure 2-8. Recent observations of Betelgeuse have revealed that the star's unexpected and significant dimming periods in late 2019 and early 2020 were most likely caused by the ejection and cooling of dense hot gases, and that the star may be going through another dimming period more than a year early.

2.6 Polarization Modeling and Predictions for DKIST: Fringe Mitigation with Polycarbonate Modulators and Optical Contact Calibration Retarders

Interference fringes are a major source of systematic error in astronomical spectropolarimeters. In this work (*JATIS*, 6, 3, 2020), D. Harrington et al. applied the Berreman formalism along with recent aperture averaging estimates to design and fabricate new fringe-suppressed polarization optics for several DKIST use cases. Harrington and colleagues successfully performed an optical contact bond on a 120 mm diameter compound crystal retarder for calibration with wavelength-dependent fringe suppression factors of one to three orders of magnitude. Special rotational alignment procedures were developed to minimize spectral oscillations of retardance, which they show represents a calibration stability limit under retarder thermal perturbation. This oil-free retarder has improved thermal stability and should improve DKIST calibration accuracy substantially.

Harrington and colleagues developed new fringe-suppressed modulators for DL-NIRSP and VISP (Figure 2-9). They collaborated and funded a new fabrication technique to deliver low beam deflection for small and large aperture polycarbonate retarders. Modulators have some spatial variation of retardance (Figure 2-10) but they showed the efficiency losses from spatial variation of retardance is less than 5%. As part of this effort, they delivered multiple modulators with minimal beam deflection and bandpass-optimized anti-reflection coatings achieving estimated fringe suppression factors of at least two orders of magnitude. They confirmed experimentally that polycarbonate retarders do indeed fringe as expected when low-deflection fabrication is achieved.

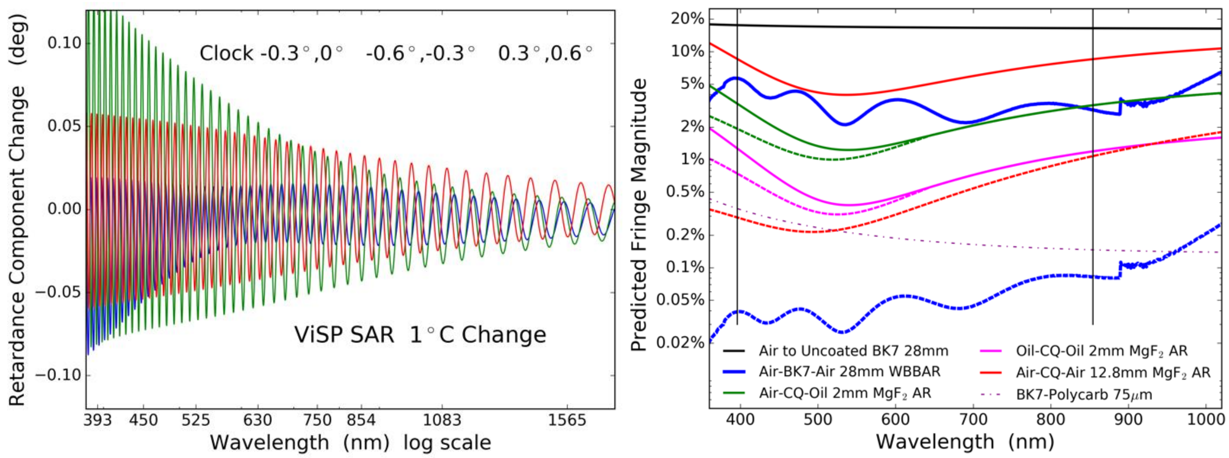


Figure 2-9. The top left graphic shows thermally forced spectral retardance oscillation changes in a scenario where five of the six compound retarder crystals are perturbed to produce clocking errors of magnitude 0.3 degrees in each pair. Blue, green and red show the three axis-angle elliptical retardance parameters linear1, linear2, and circular respectively. Top right shows fringe magnitudes predicted from coating reflectivity measurements for both coated sides of the ViSP modulator optic. Solid lines show fringes in a collimated beam. Dashed lines show fringe magnitudes for each optic reduced by the marginal ray path estimates. Comparing solid to dashed lines of the same color shows fringe magnitude reduction. Blue shows 28 mm of BK7, the full thickness of the polycarbonate modulator with cover windows. Red shows 12.8 mm thickness of crystal quartz, the nominal six crystal modulator and calibrator thickness. Black shows 2.1 mm of crystal quartz representing the thickness of an individual crystal within the original six crystal modulator. Vertical dashed black lines show common ViSP observing wavelengths of 396 nm, 589 nm and 854 nm.

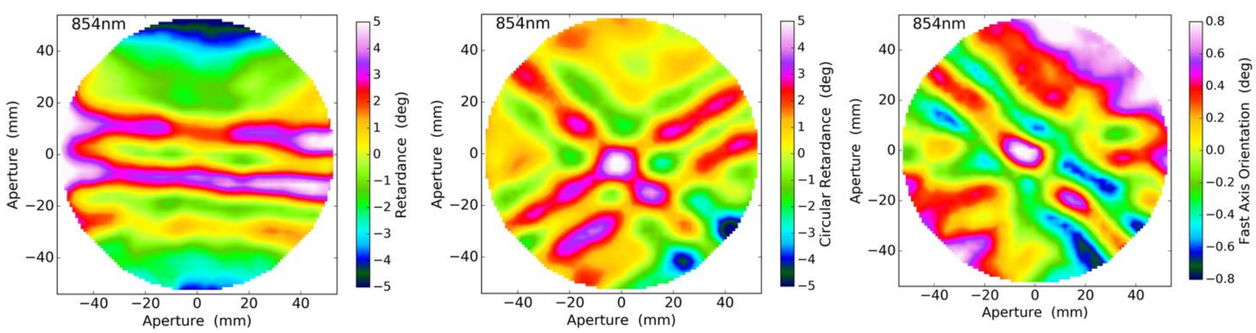


Figure 2-10. The bottom row shows spatial variation of retardance across the ViSP polycarbonate three-layer retarder at 854 nm wavelength measured by the manufacturer. Left shows spatial variation of elliptical retardance magnitude. Middle shows the spatial variation of circular retardance. Right shows spatial variation of the fast axis of linear retardance.

2.7 70 Years of Chromospheric Solar Activity and Dynamics

Historical databases are crucial for understanding the long-term variations in solar activity and the mechanisms that drive the solar cycle. In this study (*ApJ*, 897, 181, 2020), L. Bertello et al. have analyzed multiple decades of full-disk Ca II K observations to investigate two important aspects of solar variability: possible cycle variations and north-south hemispheric asymmetry in the profile of solar differential rotation and in chromospheric activity. More than 14,000 daily Ca II K observations from The Mount Wilson solar photographic archive of the Carnegie Observatories, acquired from 1915 August to 1985 July, were used in the study (Figure 2-11).

A novel and improved procedure for calibrating and rescaling these images into a consistent and homogeneous dataset is introduced. From the rescaled images Bertello and colleagues have defined two separate plage indices, matching each other very well, and produced sets of Carrington synoptic maps covering the entire period under investigation. Their Ca II K emission indices clearly show the signature of the different cycles of activity, with Cycle 19 being the most active recorded.

Although temporal variations in chromospheric activity are clearly visible in their generated synoptic charts, Bertello et al. found no evidence for a statistically significant difference in activity between the northern and southern hemispheres. Using a feature- tracking technique they were also able to obtain the average solar rotation profile. They find no indication of any detectable periodicity in the temporal behavior of the orthogonalized rotation rate coefficients, suggesting the global chromospheric dynamics has not changed during the 70 years investigated in this work. They also found no significant evidence in their analysis for a hemispheric asymmetry in rotation rates.

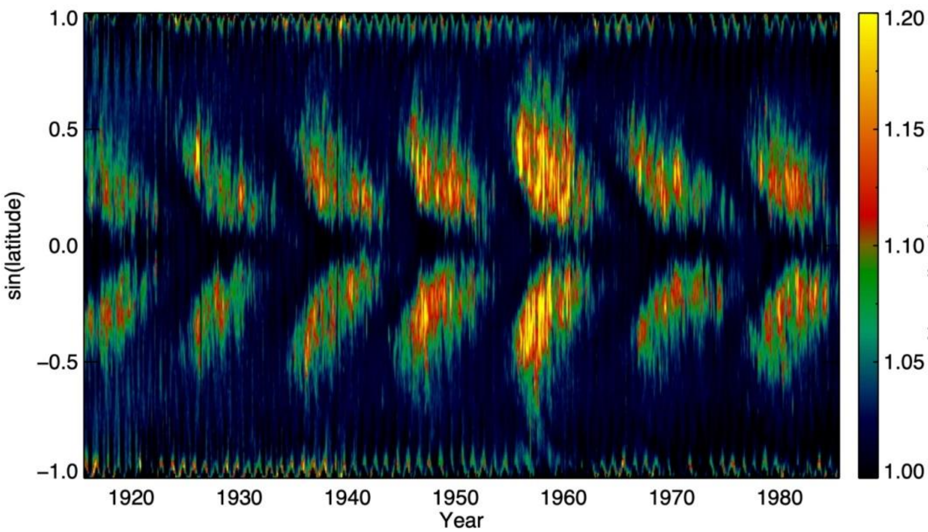


Figure 2-11. This chart shows the typical butterfly pattern representing the latitude drift of chromospheric activity during each solar cycle cycles, beginning in 1915 (Cycle 15) and extending to 1985 (Cycle 22). Solar Cycle 19 (1954 to 1964) is clearly the strongest cycle, with significant chromospheric activity extending to higher latitudes as compared to the other cycles. The chart shows also the gradual progression of plages associated with active regions from high latitude at the beginning of each cycle to the equator at the end of cycle.

2.8 Solar-Cycle Variation of the Subsurface Flows of Active- and Quiet-Region Subsets

The rotation rate and the meridional flow vary with the solar cycle. Both show bands of faster- and slower-than average flows moving from mid-latitudes toward the equator during a solar cycle. Are active regions the only contributors to these flow patterns? R. Komm et al. (*SoPh*, 295, 47, 2020) derived the flows of active and quiet regions and found that the solar-cycle variations are present in both subsets. They are thus not unique to locations of active regions. The contribution of active regions to the meridional flow pattern is strongest in shallow layers (Figure 2-12). This implies that these flow patterns are caused by a near-surface effect and are disconnected from activity below.

Komm and colleagues used GONG ring-diagram flows covering Solar Cycles 23 and 24 together with SoHO/MDI and SDO/HMI data. They used NSO synoptic magnetograms (Kitt Peak, SOLIS, GONG) to create subsets of active and quiet regions. The solar-cycle variations of the zonal and meridional flows are present in both subsets with somewhat larger amplitudes in the active-region subset. The meridional flow is poleward in both hemispheres in the depth range covered. After subtracting the mean flow, the residual meridional flow converges near the mean latitude of activity (poleward residual flows at lower latitudes and equatorward flows at higher latitudes). Using the quiet-region flows as a baseline, Komm et al. showed that the additional meridional flows near active regions converges and that the convergence is strongest in shallow layers. Such a rapidly declining meridional flow is expected from a theoretical model that explains the solar-cycle variation of the rotation rate as a geostrophic flow (Spruit, 2003). In this model, the flow is driven by temperature variations near the surface due to the enhanced emission of radiation by the magnetic field of active regions. Since the meridional flow of quiet regions does not rapidly decline with depth and the bands of fast and slow flows appear years before a solar cycle is noticeable in surface magnetic activity, Komm and colleagues conjecture that a second mechanism causes the solar-cycle variation of flows in the absence of active regions.

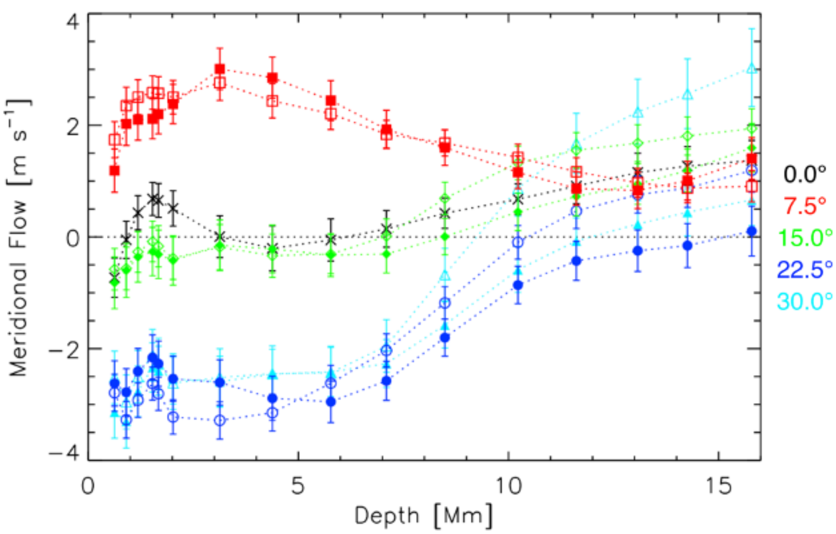


Figure 2-12. The meridional flow associated with active regions converges near the mean latitude of activity (at 15.0°) with a maximum near a depth of 3 Mm. The flow differences between active and quiet regions are poleward at 7.5° and equatorward at 22.5° latitudes. Open symbols represent flows in the northern hemisphere, while filled symbols indicate values in the southern one. Positive values indicate poleward flows, while negative values represent equatorward flows.

2.9 Comparing Radiative Transfer Codes and Opacity Samplings for Solar Irradiance Reconstructions

Spectra are the most important, and often the only observable data available for the estimate of physical properties of astronomical objects. Nevertheless, detailed comparison with observations reveals that different codes reproduce observed spectra with different degrees of accuracy. In the specific case of stellar energy distributions (SEDs), differences of 1-2% between syntheses and observations are found in the Visible and IR, while in the Blue and UV differences up to several tens of percent. This is not entirely a surprise, as spectral syntheses are known to critically depend on the atomic and molecular parameters adopted, as well as on approximations used for the computations of the opacities and in the solution of the radiative transfer equations. S. Criscuoli et al. (*SoPh*, 295, 50, 2020), compare synthetic spectra obtained with radiative transfer codes widely employed for solar irradiance reconstructions, using different atmosphere models representing different types of quiet and magnetic features.

Criscuoli and colleagues first compared spectra obtained under Non Local Thermodynamic Equilibrium (NLTE) using the Code for Solar Irradiance (COSI) (Haberreiter et al., 2008) and RH (Uitenbroek, 2001). Given that NLTE syntheses are computationally expensive, for this comparison they employed a set of 1D, static atmosphere models widely used for solar irradiance reconstructions (i.e., Fontenla et al., 1999). They found that, in agreement with previous studies performed with other radiative transfer codes, the SEDs obtained using a quiet Sun model compare very well between themselves and observations in the Visible and IR, while in the Blue and UV discrepancies are up to 20%; features are also visible in correspondence of certain molecular bands (e.g., OH and Gband). However, different trends are found when comparing the contrasts (ratios with the quiet Sun model SED) synthetized for different atmosphere models. Overall, with the exception of model E (network), contrasts are similar in the region 250–400 nm, but are rather different (several percent) at longer wavelengths.

Criscuoli and colleagues then compared syntheses obtained using MURaM 3D MHD simulations and opacity tables computed with RH and with the ATLAS9 package. The radiative transfer is performed using the MURaM solver, which allows focusing the comparison only on differences stemming from the opacity computations. In particular, with the aim of investigating effects of using opacity binning techniques on the synthetized spectrum, Criscuoli et al. compared four sets of syntheses:

- *RH_full_avg*: the intensity is computed using opacity tables from RH at a spectral resolution of 0.01 nm. The emergent intensity and flux are spatially averaged over each snapshot and the spectrum is binned over 1 nm-wide spectral regions.
- *RH_harmonic*: the intensity is computed using opacity tables from RH averaged over 1 nm spectral bins. The emergent intensity and flux are spatially averaged over each snapshot.
- *Atlas_full_avg*: the intensity is computed using ATLAS9 opacities. The emergent intensity and flux are spatially averaged over each snap-shot and the spectrum is averaged over the 12 opacity steps of the wavelength intervals over which the ATLAS9 ODFs are defined. The resulting spectrum is sampled over a non-uniform grid, with resolution ranging from 1 nm at wavelengths shorter than 300 nm to 10 nm at wavelengths in the 2000 nm range.
- *Atlas_harmonic*: the intensity is computed using opacity tables from ATLAS9 averaged over the 12 opacity steps in each opacity bin. The emergent intensity and flux are spatially averaged over each snapshot.

Criscuoli and colleagues found that the use of mean opacities instead of the full resolution produces an excess of opacity at wavelengths shorter than 300 nm and a deficit of opacity at longer wavelengths (see Figure 2-13). The flux is therefore underestimated by several tens of percent in the UV and overestimated by up to about 10% in the Visible. At longer wavelengths, differences are within a few percent. In the range 250–290 nm RH reproduces the observations better than ATLAS9 at full resolution, while in the range 290–340 nm RH presents an excess of opacity. At longer wavelengths, RH seems to reproduce better the observed spectrum, while ATLAS9 systematically underestimates the flux. Note, however, that most of these differences are within the uncertainties of measurements and that some uncertainty may arise from using only one HD snapshot. Contrasts obtained using the four syntheses and (M)HD snapshots (snapshots with no magnetic field, and snapshots with average field of 100G and 200G were analyzed) present discrepancies that are larger at wavelengths shorter than 350 nm and that increase with the magnetic flux. Such differences might critically affect estimates of UV variability. One should also keep in mind that the description of energy exchange between gas and radiation in the simulations themselves requires methodological improvements to achieve sufficiently accurate radiative transfer.

In conclusion, Criscuoli and colleagues found that the synthetic contrasts, which are the relevant quantities for irradiance modeling, can differ by several tens of a percent, and therefore critically affect estimates of solar irradiance variability, even though the codes and approximations investigated for the comparison reproduce the observed spectrum reasonably well.

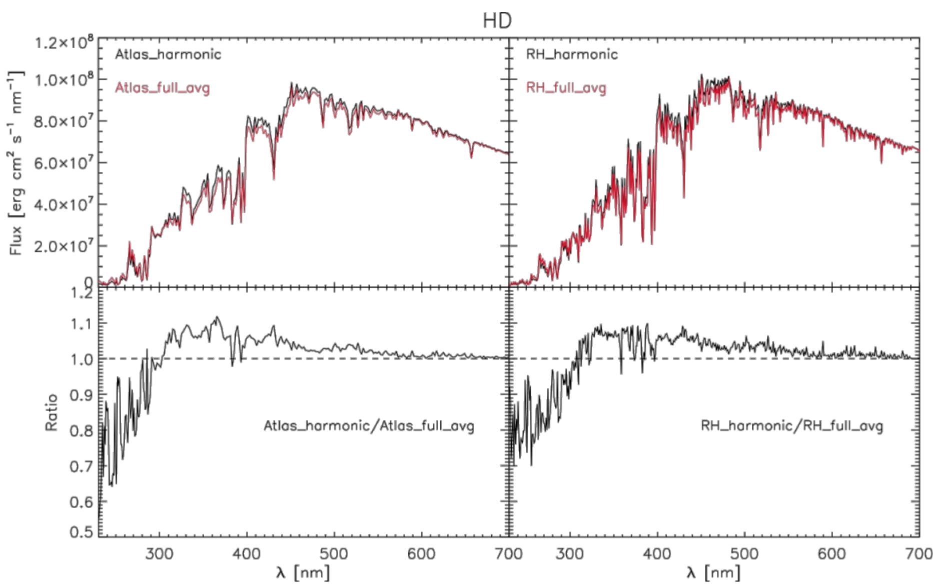


Figure 2-13. Comparison of synthetic flux obtained for the HD snapshot using harmonic means of the opacities with the flux obtained using the full resolution table of opacities and averaging the intensities over 1 nm-wide bin.

2.10 Solar Disk Center Shows Scattering Polarization in the Sr I 4607 Å Line

Probing the small-scale magnetic fields in the solar photosphere is an observational challenge. One issue is that the sizes of the structures are at the limit of our spatial resolving power, which means it is difficult to gather enough signal to get highly precise measurements. Additionally, the diagnostic solar physicists most commonly used to probe the magnetic field, the Zeeman-effect line splitting, becomes less sensitive when observing the turbulent, unresolved fields we expect in the region of convective overshoot in the solar atmosphere. Instead, the Hanle-effect linear polarization signal due to resonance scattering in certain atomic lines can be a sensitive probe of the magnetic structures in the photosphere. However, the signal is relatively weak and previously has been detected primarily by integrating the signal over an extended portion of the solar surface to improve the signal-to-noise ratio. But this summing of the signal limits our ability to use this effect to characterize the underlying magnetic field topology. Spatially resolved observations of the scattering should show the imprint of the granulation pattern due to the anisotropic radiation field and can be used to derive the statistical distribution of magnetic field strengths at small scales.

A group of researchers from the Max Planck Institute for Solar Physics, in Göttingen, Germany, working with NSO scientists Kevin Reardon and Valentin Martinez Pillet, were able to make some of the first measurements of the spatially resolved scattering polarization signal at NSO's Dunn Solar Telescope (DST) in August 2017 (*ApJ*, 893, 44, 2020). Led by PI Franziska Zuener, they combined their Fast Stokes Polarimeter, which can image at rates of up to 800 frames per second, with a custom-built optical setup using a Fabry-Perot interferometer and prefilter, to spectrally sample the Sr I 4607 Å line in the quiet Sun at disk center. Good seeing conditions combined with the AO system allowed them to achieve nearly diffraction-limited spatial resolution, even after integrating several minutes of data. The combination of many accumulated frames allowed them to reduce the noise in their linear polarization measurements to a few parts per 10000 or less. This is perhaps the highest precision ever achieved in such spatially and spectrally resolved measurements.

After a careful data reduction, they were able to recover the scattering polarization signal, which was found to be strongest where the anisotropy of the radiation field was most pronounced, as was theoretically predicted (Figure 2-14). This confirms that the Hanle-effect measurements, combined with predictions from advanced magnetohydrodynamic simulations, are indeed an excellent diagnostic for the complex magnetic fields intertwined on small scales. These measurements were compatible with either a distribution of weaker, primarily vertical fields or a prevalence of stronger, more horizontal fields. Future observations using this technique, combined with Zeeman effect measurements, will be needed to distinguish these two possibilities. This will be a prime target of the Daniel K. Inouye Solar Telescope, with a collecting area 25 times greater than the DST, and will allow an even better signal-to-noise even at subgranular scales. The key instrument for such measurements will be the Visible Spectro-Polarimeter (ViSP), a slit-based spectrograph built by the High-Altitude Observatory. The goal is to map the scattering polarization signals at even higher precision and at different positions (i.e., viewing angles) on the solar disk, allowing a much better understanding of the generation and structuring of the magnetic field in the turbulent photospheric flows.

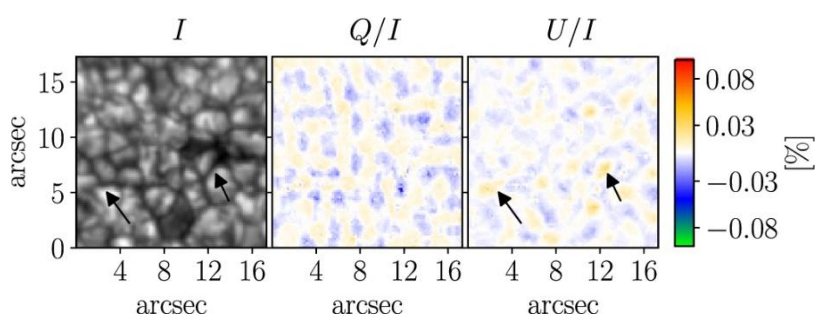


Figure 2-14. Stokes I and "reconstructed" linear polarization maps in the Sr I line core. From left to right: temporally averaged observed intensity image, reconstructed Q/I and U/I spatial maps. The reconstruction can be considered to be equivalent to a clever way of denoising the observations.

3 DANIEL K. INOUYE SOLAR TELESCOPE (DKIST)

3.1 DKIST Project

3.1.1 DKIST Construction Status

3.1.1.1 DKIST Development Time Line and Major Milestones

The DKIST project got its start back in the mid-1990s with work on the Clear concept studies. This work helped lead to prioritization of the project in the 2000 Decadal Survey. Beginning in 2000, high-level Science Requirements were established, technical design concepts generated and analyzed, and cost, schedule, and risk estimates were developed. This led to a funded Design and Development (D&D) phase that began in 2003 and ultimately resulted in a full construction proposal submitted to the NSF. In parallel with this work, a detailed site survey of potential locations for the telescope was undertaken, with the result being the selection of Haleakalā, Maui, Hawaiʻi as the preferred location for the telescope. The construction proposal was accepted by the NSF, and in January 2010, the Project was authorized and funded, and construction activities began.

Delays in permitting on Maui lingered for the first two years of construction, but eventually were resolved and ground-breaking at the construction site took place in late CY 2012. This was followed immediately by site clearing and initial construction activities. Since 2010, the project has progressed steadily on schedule and budget in all major technical areas (e.g., telescope, wavefront correction, instrumentation, high-level software and controls, enclosure, and buildings).

Key recent milestones over the past few years include:

- 2017: Support and Operations (S&O) Building made weathertight.
- 2017: Primary mirror delivered to construction site.
- 2018: Telescope Mount Assembly (TMA) site acceptance testing successfully passed.
- 2018: Integration, Test & Commissioning (IT&C) plan established and approved.
- 2018: Primary mirror successfully aluminized and readied for integration.
- 2019: System Integration Module (SIM) #1, Telescope Pointing, successfully completed.
- 2019: SIM #2, Primary Integration, successfully completed.
- 2019: SIM #3, M1+M2 Integration, successfully completed.
- 2019: SIM #4, M1-M6 Integration, successfully completed.
- 2019: SIM #5, Coudé Optics Integration, successfully completed.
- 2019: SIM #6a, Visible Broadband Imager (VBI), successfully integrated.
- 2019: SIM #6b, Wavefront Correction (WFC), successfully integrated.
- 2020: SIM #7, First Light Initiative, successfully completed.
- 2020: SIM #8, Gregorian Optics Station (GOS) Integration, successfully completed.
- 2020: SIM #9a, Cryo-NIRSP Instrument, Lab Acceptance Testing (LAT) successfully completed and instrument delivered and installed onto the Coudé rotator.
- 2020: SIM #9b, DL-NIRSP Instrument, Lab Acceptance Testing (LAT) successfully completed and instrument delivered and installed onto the Coudé rotator.
- 2020: SIM #9c, ViSP Instrument, Lab Acceptance Testing (LAT) successfully completed, instrument delivered and installed onto the Coudé rotator, Site Acceptance Testing (SAT) started.

- 2020: SIM #10, Polarization Calibration, NSO Coudé Spectropolarimeter (NCSP) successfully integrated.
- 2020: Primary mirror successfully re-aluminized.

The DKIST project continues its construction and IT&C efforts toward full completion and handover of the observatory to operations; this handover is expected to occur in mid-2021.

3.1.1.1.2 Telescope

During this past year, the telescope was fully integrated with its optics and control systems, and began functioning per key technical requirements. This allowed the First Light Initiative (FLI) effort to proceed. Following FLI, the primary mirror was removed from the telescope to receive a science-grade aluminization coating. Additionally, an improved heat stop assembly is undergoing final machining and will be installed in to the telescope in late CY 2020.

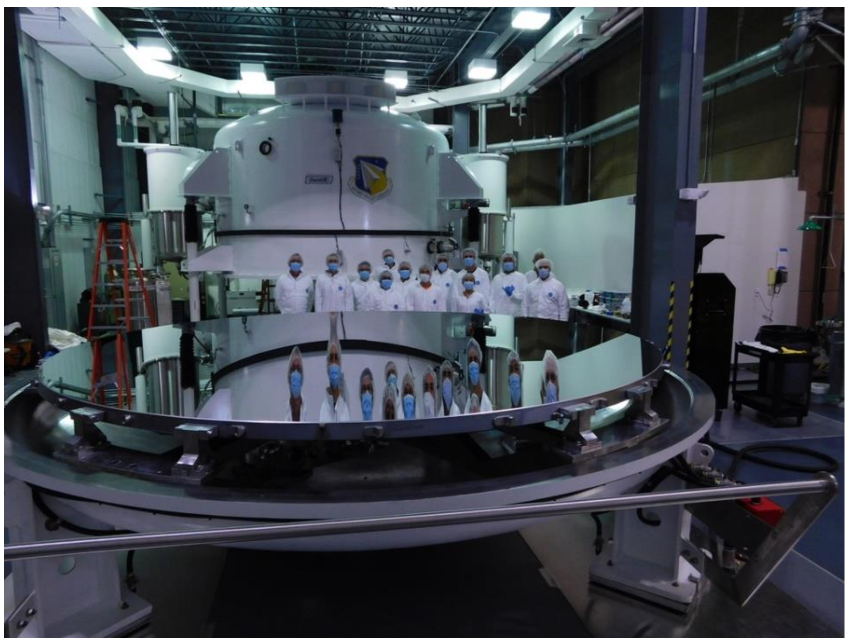


Figure 3-1. The primary mirror immediately after re-coating and removal from the coating chamber.

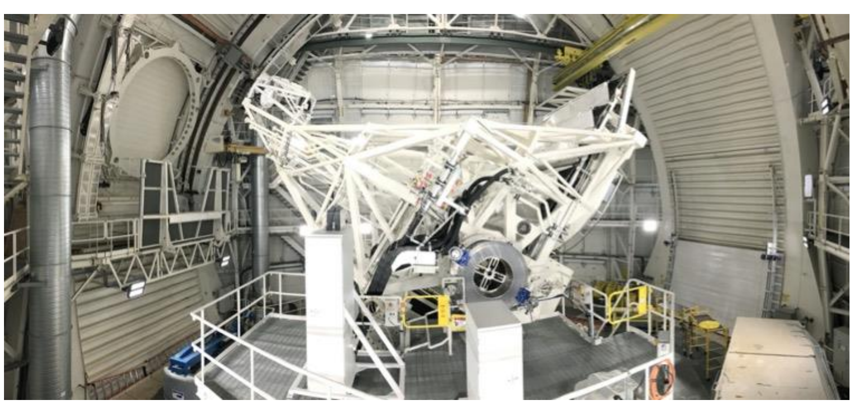


Figure 3-2. The telescope ready for an on-Sun observation.

3.1.1.1.3 Wavefront Correction

The Wavefront Correction (WFC) system was fully integrated into the observatory this year. It has passed the majority of its site acceptance testing requirements, and the remaining tests are expected to be completed in late CY 2020.

3.1.1.1.4 Instrumentation

The Visible Broadband Imager (VBI) was installed onto the Coudé rotator this past year. Subsequently, it passed its Site Acceptance Test (SAT) and then was used in the First Light Initiative (FLI) effort. The results of the FLI campaign exceeded the project's expectations, with extensive and very positive media coverage throughout the world.

The Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP) project with the University of Hawaiʻi (UH) Institute for Astronomy (IfA) made significant progress over the past year, including successful completion of its Laboratory Acceptance Tests (LAT) and subsequent disassembly, packaging, and transport the summit. The assembly of the instrument onto the Coudé rotator is nearing completion and will be followed by Site Acceptance Testing and Science Verification (SV) in the coming months.

The Diffraction-Limited Near-IR Spectropolarimeter (DL-NIRSP) project with the University of Hawaiʻi Institute for Astronomy also made significant progress over the past year. This included completion of its LAT, disassembly, packaging, and transport to the summit for IT&C work. The initial assembly onto the Coudé rotator is nearing completion, and both SAT and SV are scheduled early in CY 2021.

The Visible Spectropolarimeter (ViSP) project with the University Corporation for Atmospheric Research (UCAR) High Altitude Observatory (HAO) has also made excellent progress this past year. This included assembly and integration onto the Coudé rotator. Further, the majority of SAT work was performed, and the few outstanding elements of the testing are expected to be completed in early CY 2021. This will be followed by SV in spring of CY 2021.

The Visible Tunable Filter (VTF) project with the Leibniz Institute for Solar Physics (KIS) in Freiburg, Germany continued with laboratory assembly efforts. The instrument is expected to be delivered to the DKIST observatory in late CY 2021.

Finally, the Polarization, Analysis and Calibration (PA&C) system was completed in this past year, including installation, test, and commissioning of both the upper and lower Gregorian Optic Stations. The SATs for these elements is largely finished, requiring only a few closeout activities to formally complete their acceptance.

3.1.1.1.6 High-Level Software

The High-Level Software (HLS) infrastructure has advanced this year from the construction-level release system to the integration-level system, which allows for more rapid update and problem response during final integration. All summit software, Hawaiʻi and Boulder end-to-end systems now use a distributed release push system. The Observatory Control System (OCS) is ready for Site Acceptance Testing (SAT) and is working with the DKIST Operations Group to upload and execute the first set of user experiments. The Data Handling System (DHS) has completed SAT and has been upgraded for additional data storage and processing capability. All network and Global Interlock System Software (GISS) are complete. The HLS team continues to work in close collaboration with the summit team and instrument partners on performing the final instrument integrations.

3.1.1.1.7 Site, Buildings and Enclosure

The major focus this past year on the exterior site infrastructure and buildings has been on completion of punch list items and the demobilization and cleanup of the site, per Conservation District Use Permit (CDUP) requirements. This work is now complete and awaiting inspection by the Department of Land and Natural Resources (DLNR) authorities.

Inside the buildings, tenant improvement (TI) activities have proceeded, including installation of flooring, painting, and the installation of ceilings and lights. This work will continue over the next few months as access permits.

Finally, the installation of the exterior cooling system on the enclosure (i.e., the plate coil system) was started this year and is expected to complete in the next few months.

3.1.1.1.8 Facility Thermal Systems (FTS)

Progress continued on the FTS this year, including completion of the secondary loops, installation of insulation on the primary and secondary loops, and startup of the system. The latter item was crucial to achieving First Light.

The Coudé Environmental System (CES), which has been operating nearly continuously for the past twelve months, was balanced and tuned this year.

Finally, the plate coils were delivered to the site and the installation of them onto the enclosure has started.

3.1.1.1.9 Integration, Test & Commissioning (IT&C)

As stated above, the First Light was achieved this past year with spectacular results. While much remains to be done to wrap up both the WFC and VBI subsystems, there don't appear to be any remaining significant challenges to complete this aspect of the observatory.

Similarly, significant progress has been made integrating the three partner instruments into the overall observatory. The ViSP is nearly completely integrated and ready for final SAT and SV work. The Cryo-NIRSP instrument is installed and final alignment activities are underway in advance of its SAT. And the DL-NIRSP instrument is also nearly fully assembled and aligned.

A science-grade recoating of the primary mirror is currently underway, with the telescope ready for on-sky observations expected to happen within the next few weeks. A series of on-Sun campaigns are planned for the coming months, primarily to allow completion of SATs and SVs of the partner instruments.

3.1.1.1.10 Schedule Status

A subsystem view of intermediate milestone highlights is shown in Table 3-1 and in Figure 3-3.

Completion of the project was delayed approximately 6+ months due to the impact of the COVID-19 pandemic. All site construction was halted for 2.5 months (mid-March 2020 through May 2020) and then restarted, albeit in a very inefficient manner.

Training of operations staff will occur during the extended Integration, Testing and Commissioning phase. A science verification period performed by the DKIST teams, supported by the instrument partners, will demonstrate the scientific validity of delivered data products. With the conclusion of instrument science verification, the facility will be handed over to operations.

Table 3-1. DKIST Major Construction Milestones (Fiscal Year 2020-2021)

DKIST Major Construction Milestones (Fiscal Year 2020-2021)		
Site Construction & Support Facilities	2020-Dec	FMS Tracking Ambient
	2021-Feb	Tenant Improvement Fit and Finish Complete
	2021-Feb	Plate Coil Install - Complete
	2021-Feb	FTS Primary Loops Commissioning Complete
	2021-Feb	Final Close-out of Construction and A&E Services Contract
	2021-Apr	Facility Thermal Systems Complete
	2021-Apr	Site Close-out Complete
Instruments	2019-Dec	ViSP - Delivery to Site Complete
	2019-Dec	DKIST First Light (VBI Red FLI Achieved)
	2020-Feb	Cyro-NIRSP - Delivery to Site SP & Warm Optics and Frame (DKIST Labor)
	2021-Mar	Cryo-NIRSP - Science Verification - On Disk & Coronal
	2021-Mar	ViSP Science Verification Complete
	2021-Apr	DL-NIRSP Science Verification Complete
	2021-Apr	DL-NIRSP Science Verification - On Disk
	2021-Apr	VBI Science Verification
Integration, Test, & Commissioning	2019-Nov	SIM #3 M1-M2 Integration Complete
	2020-Aug	SIM #5 Coudé and M7+ Feed Optics Complete
	2020-Oct	M1 Verification Coating
	2020-Nov	M1 Re-alignment & Optical Path Verification
	2020-Nov	SIM #4 M1-M6 Integration Complete
	2021-May	Start of Operations

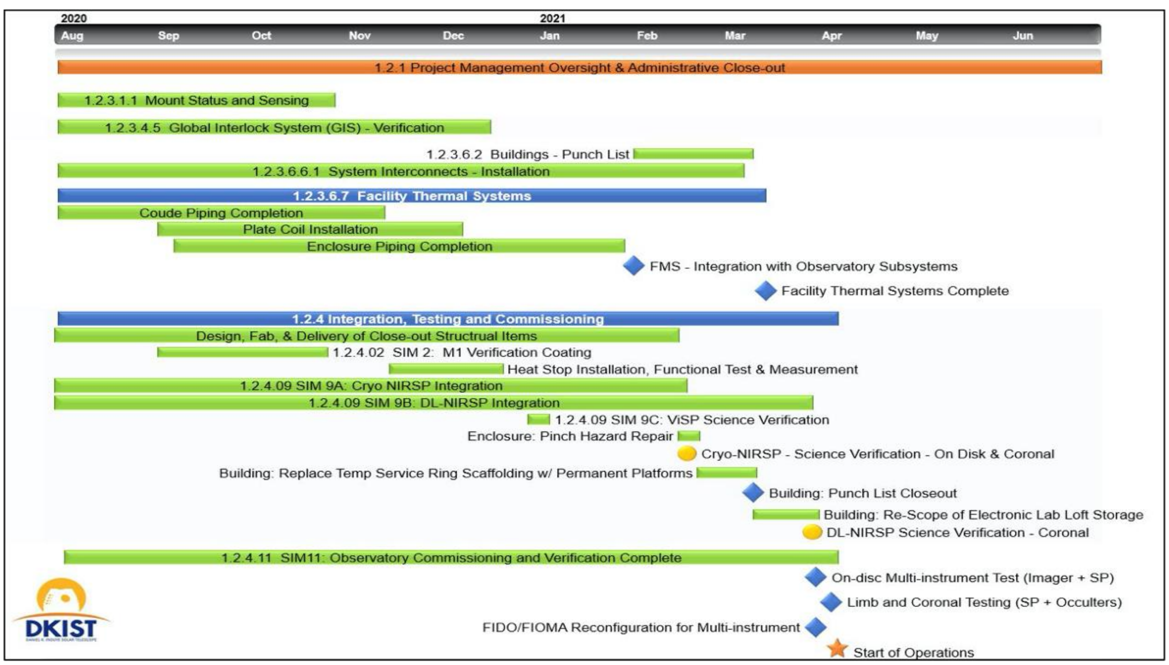


Figure 3-3. DKIST Summary Schedule.

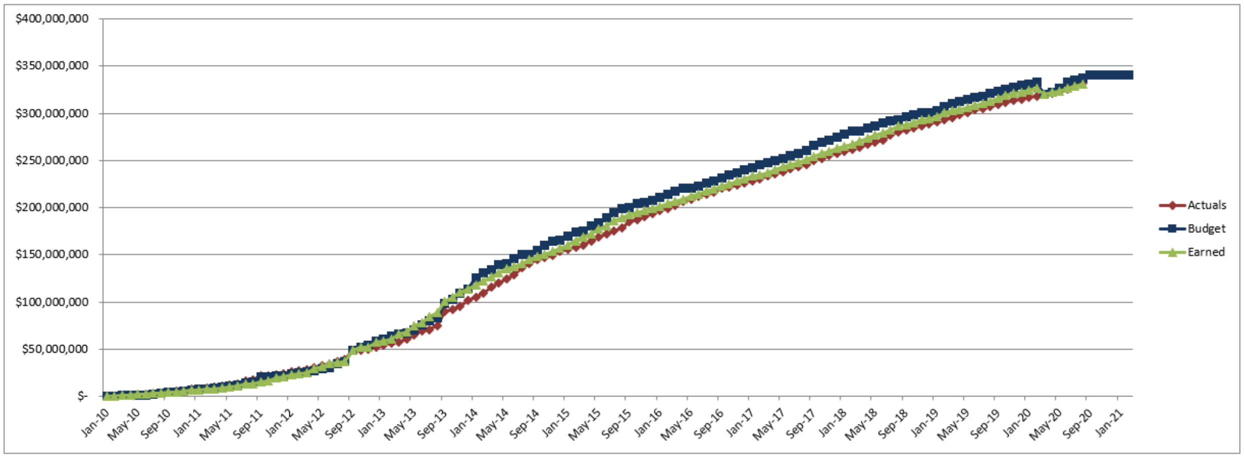
3.1.1.1.11 DKIST Financial Status

Following the Project Re-baseline, the Total Project Cost was established as $344.1M. To date, the project has received all of this amount; $146M from the American Recovery and Reinvestment Act (ARRA) of 2009 and the remainder from the Major Research Equipment and Facilities Construction (MREFC) Program. The ARRA funding was provided in January 2010 and expired at the end of FY 2015. The MREFC funding was provided annually.

Due to the delays caused by the COVID-19 pandemic, the project has requested supplemental funding to cover these unplanned expenses. This request is currently under review by the NSF.

EVM Status Report	**$M**	**Description**
EVM Reporting Date	Aug-20	Date of the report
Total Project Cost (TPC)	$344.1	Performance Baseline + Contingency
NSF Funding To-Date	$344.0	Amount of funding received to date
Budget at Completion (BAC)	$341.0	Approved Budget
Planned Value ($M)	$337.2	
Earned Value ($M)	$331.0	
Actual Costs ($M)	$331.5	
% Complete (Planned)	99%	PV/BAC*100%
% Complete (Actual)	97%	EV/BAC*100%
% Complete (Spent)	97%	AC/BAC*100%
Cost Variance (CV)	-$0.4	EV-AC
Schedule Variance (SV)	-$6.1	EV-PV
Forecast Estimate at Completion (EAC - $M)		
EAC$_1$: AC+(BAC-EV)	$341.4	
EAC$_2$: AC + Lagging invoices + (BAC – EV + Anticipated future negative cost variances that would increase the ETC for the work package)	$349.4	
Date of last EAC update	Aug-20	Date of last update of the EAC
Unencumbered Funds	$3.2	TPC-BAC
Liens	$0.3	Risks with probability >80% and pending change requests
Contingency Balance	$3.17	Contingency Log Value
Estimate to Complete (ETC)	9.9	EAC$_1$-AC
	17.9	EAC$_2$-AC
% Budget Contingency of ETC	31.9%	(BC/ETC$_1$)*100%
	17.7%	(BC/ETC$_2$)*100%
Risk Exposure		
Risk Confidence Level	80%	Confidence level of Risk Exposure
Project Baseline Completion	Sep-20	NSF funded and approved
Estimated Project Completion	May-21	Unofficial Projected Completion
Project Award Expiration Date	Dec-20	CSA expiration
Schedule Contingency	1 month	

	CPR REPORT MONTH ENDING AUGUST 2020 (ALL VALUES IN $K)												
	CURRENT PERIOD					CUMULATIVE TO DATE							
WBS	PLANNED	EARNED	ACTUAL	SV	CV	PLANNED	EARNED	ACTUAL	SV	CV	BAC	EAC	VARIANCE
1.2.1 Project Management	421	361	264	(59)	97	48,596	48,439	48,091	(158)	348	49,680	51,554	-1,875
1.2.2 Systems Engineering	64	64	51	-	13	5,819	5,819	5,856	-	(37)	5,883	6,149	-266
1.2.3 Telescope Systems	976	1,554	995	577	559	242,680	237,467	238,412	(5,213)	(945)	244,175	245,841	-1,667
1.2.4 Integration, Test, and Commissioning	729	653	554	(76)	99	21,748	20,981	20,990	(768)	(10)	22,626	26,994	-4,368
1.2.5 Science Support	91	91	52	-	39	6,278	6,278	6,201	-	78	6,369	6,693	-324
1.2.8 Support Services	110	110	108	-	2	12,047	12,047	11,917	-	130	12,228	12,820	-592
SUBTOTAL	2,390	2,832	2,023	442	809	337,169	331,030	331,466	(6,139)	(436)	340,961	350,052	-9,091
RISK ADJUSTED TOTAL PROJECT COST	2,390	2,832	2,023	442	809	337,169	331,030	331,466	(6,139)	(436)	344,129	353,220	-9,091



	BUDGET	EARNED	ACTUAL	SV	CV	TOTAL BUDGET	SPI	CPI	% COMPLETE PLANNED (PV/BAC)	% COMPLETE EARNED (EV/BAC)	% COMPLETE SPENT (AC/BAC)
PREVIOUS CUM TO DATE	334,779	328,198	329,443	-6,580	7,659	340,961	0.98	1.00	98%	96%	97%
CURRENT PERIOD	2,390	2,832	2,023	442	809		1.18	1.40			
CUMULATIVE TO DATE	337,169	331,030	331,466	-6,139	-436	340,961	0.98	1.00	99%	97%	97%
RISK ADJUSTED TOTAL COST	337,169	331,030	331,466	-6,139	-436	344,129	0.98	1.00	98%	96%	96%

Figure 3-4. DKIST Schedule and Cost Variance.

3.1.2 DKIST Project Closeout

Successful completion and closeout of the DKIST project is governed by the requirements in two key documents: a) the NSF's Large Facilities Manual; and b) the Project's own PMCS-0100 Project Execution Plan document. The former dictates the requirements of two final closeout reports (Final Project Report and Project Outcomes Report) and also calls out the need for a Final Construction Review. The latter spells out specific handover information, including verification of technical compliance (i.e., all Level-0, Level-1, and Level-2 requirements), primarily in the form of compliance matrices, scope delivery compliance (as defined in the DKIST Work Breakdown Structure (WBS)) and all project files.

Additionally, the project is required to formally close out all financials. The project is also required to document compliance with all environmental and site-related compliance obligations. These obligations include:

- Federal Aviation Administration (FAA).
- Final Environmental Impact Statement (FEIS) – NSF.

- Programmatic Agreement (PA) – State Historic Preservation Office/Federal Historic Preservation Office.
- Conservation District Use Permit (CDUP) – DLNR.
- Special Use Permit (SUP) – National Park Service (NPS).
- Biological Opinion/Incidental Take License (BO/ITL)– U.S. Fish & Wildlife Service.
- Habitat Conservation Plan (HCP) – State Division of Forestry & Wildlife.
- National Pollutant Discharge Elimination System (NPDES) – EPA/Hawaii Dept. of Health.
- Project Labor Agreements (PLA) – Unions.
- Land Lease – University of Hawaiʻi.

The project fully intends to document full compliance with all of the aforementioned obligations at the time of handover to operations.

3.2 DKIST Science Case: The DKIST Critical Science Plan (CSP)

3.2.1 General Descriptions and Goals and Role of the Science Working Group (SWG)

Community participation in and support of the DKIST effort occurs through the DKIST Science Working Group (SWG). The SWG is currently chaired by Mark Rast of the University of Colorado, Boulder, and members include non-project scientists, project co-investigators, and instrument PIs (Current membership Table 3-2).

Table 3-2. Membership of the DKIST SWG

DKIST Science Working Group

Count	Last Name	First Name	Affiliation	Status	Start of term
1	Bello-Gonzales	Nazaret	KIS	Member	2014
2	Cao	Wenda	NJIT	Member	2013
3	Cauzzi	Gianna	AO	Member	2005
4	DeLuca	Ed	Harvard	Member	2017
5	dePontieu	Bart	Lockheed	Member	2015
6	Fletcher	Lyndsay	U. Glasgow	Member	2002
7	Judge	Phil	HAO	Member	2003
8	Katsukawa	Yukio	NAOJ	Member	2014
9	Kazachenko	Maria	CU	Member	2018
10	Khomenko	Elena	IAC	Member	2018
11	Landi	Enrico	Michigan	Member	2017
12	Petrie	Gordon	NSO	Member	2017
13	Rachmeler	Laurel	NASA Marshall	Member	2019
14	Qiu	Jiong	MSU	Member	2011
15	Rast	Mark	U. Colorado	Member	2013
16	Rempel	Mattias	HAO	Member	2015
17	Rubio	Luis Bellot	IAA	Member	2002
18	Scullion	Eamon	Northumbria	Member	2014
19	Sun	Xudong	IfA	Member	2017
20	Welsch	Brian	Wisconsin	Member	2017
21	Goode	Phil	NJIT	Co-I	
22	Knoelker	Michael	HAO	Co-I	
23	Rosner	Robert	U. Chicago	Co-I	
24	Kuhn	Jeff	IFA	Co-I & Instrument PI	
25	Rimmele	Thomas	NSO	Ex-Officio	
26	Casini	Roberto	HAO	Instrument PI	
27	Lin	Haosheng	IFA	Instrument PI	
28	Schmidt	Wolfgang	KIS	Instrument PI	
29	Woeger	Friedrich	NSO	Instrument PI	

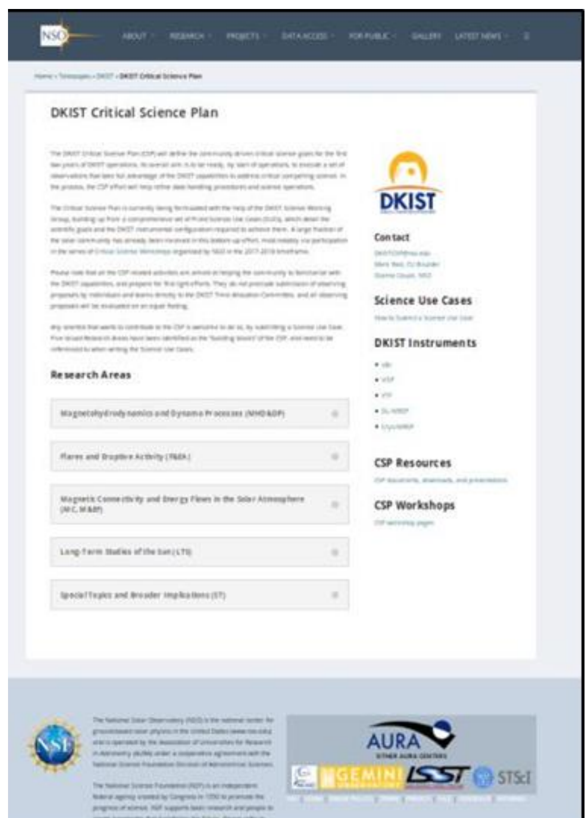


Figure 3-5. The DKIST Critical Science Plan website with links to documentation and tools.

With construction well underway and instrument capabilities well defined, the focus of the SWG has shifted largely to the development of the Critical Science Plans (CSP). The CSP serves to both define early science goals and inform the project of likely use scenarios that help clarify expected operation modes, data handling and processing requirements, and data product dissemination needs.

The CSP is being developed with broad community involvement, facilitated by two websites: *https://www.nso.edu/-telescopes/dkist/csp/*, which describe the science objectives and instrument capabilities and include links to the documentation and tools required to construct a CSP Science Use Case (SUC) (Figure 3-5) and *https://nso-atst.atlassian.net/*, a collaborative site for the development of Science Use Cases by the community. These Science Use Cases not only serve as the basis for the critical science describes in the CSP document, but also as first drafts of the Observing Proposals users of the DKIST will be required to submit to the DKIST Time Allocation Committee (TAC) to acquire observing time on the telescope. The JIRA DKIST Community development site is password protected, and there are currently 387 members and 260 Use Cases in various stages of development. Of these Science Use Cases, 97 are assessed to be well developed by their PIs, ready to be converted into Observing Proposals in response to early calls for proposals by the project. The completion of remaining Science Use Cases and their conversion to DKIST Proposals will be essential to meet the broad early critical science goals.

In order to facilitate these activities, the NSO supported a series of Critical Science Plan workshops. The first of these followed the 2016 Solar Physics Division meeting in Boulder. It hosted over 50 participants and resulted in 21 Science Use Cases being started. Following this, the NSO called for workshop proposals, with matching funds required for non-US participation. Between November 2017 and October 2018, 11 workshops were held covering nine science themes (Magnetic Reconnection and Reconfiguration, Magnetic Connectivity, Photospheric Magnetic Fields, Joint Science with Solar Orbiter and Parker Solar Probe, Wave Generation and Propagation, Flares and Eruptive Phenomena, Coronal Science Frontiers, Broader Implications, and Long-Term Studies). About 200 scientists were involved, and of the 260 Science Use Cases on the JIRA site, 229 were worked on at one or more of the CSP workshops (84 of the 97 well developed Use Cases were worked on at one or more of the CSP workshops). More details about the individual CSP workshops can be found at *https://www.nso.edu/telescopes/dkist/csp/dkist-csp-workshops/*.

The DKIST Science Working Group has met to evaluate the scientific completeness of the Science Use Cases submitted, their “criticality,” and the degree of overlap among them.

Two rounds of feedback have been provided to the Science Use Case PIs, first to all contributors and then subsequently to those PIs who flagged their Use Cases as complete.

The DKIST SWG has completed and published the Critical Science Plan document via the NSO website and as a refereed journal publication. Previously a living document on the internet, the SWG has consolidated and expanded upon the community input provided by the Science Use Cases to articulate the critical science to be addressed during the first one to two years of regular DKIST Operations. The current topics addressed in the CSP document include:

Magnetoconvection and Dynamo Processes

- Small-Scale Photospheric Magnetic Fields: Formation, Structure, Dynamics.
- Wave Generation and Propagation.
- Magnetoconvective Modulation of the Solar Luminosity.
- Active Region Evolution and Sunspot Fine Structure.

Flares and Eruptive Activity

- Flare and CME Precursors.
- Changes in Magnetic Field associated with Flares and Coronal Mass Ejections.
- Energy Deposition during Flares.
- The fundamental structure and evolution of flare ribbons.

Magnetic Connectivity through the Non-Eruptive Solar Atmosphere

- Mass Cycle in Low Solar Atmosphere.
- Solar wind origin and acceleration.
- Magnetic Reconnection throughout the Solar Atmosphere.
- Waves in the Solar Atmosphere.
- Impact of Flux Emergence on Non-Eruptive Solar Atmosphere.
- Multilayer Magnetometry.
- Large-scale Magnetic Topology, Helicity & Structures.

Long-Term Studies of the Sun, Special Topics, and Broader Implications

- Long-Term Studies of the Sun.
- Sun-Grazing Comets.
- Turbulence and Reconnection Processes.

As start of operations approaches, the SWG will keep the CSP document up-to-date and provide input to the DKIST Time Allocation Committee on CSP objectives and scientific priorities. Execution of the Critical Science Plan will likely occur over the course of several years in response to DKIST calls for observing proposals. During this period, the SWG will support the execution and analysis of the Critical Science Plan observations, assist in the coordination of publications in special topical journal volumes, aid in the advocacy and outreach for DKIST science, and provide input into second-generation instrumentation definition.

During the first year of operations, it is anticipated that DKIST calls for observing proposals will define an Observatory Commissioning Phase (see Section 3.5.9 Operations Commissioning) with participation of community members on a shared-risk basis, during which refinement of instrument calibration and facility operation procedures will occur in conjunction with early science investigations. These early calls will thus focus on subsets of the available instruments. Since the Science Use Cases underlying the CSP were developed based on the full suite of first-light instruments, they will have to be adapted to meet the early calls.

Nevertheless, the early and detailed training provided by the CSP workshops has prepared the community for submission of proposals. The large number of proposals submitted as well as the very low rejection rate due to incomplete or non-compliant proposals are at some measure the result of the community preparedness.

3.3 DKIST Operations

3.3.1 Introduction

The technical complexity of the Daniel K. Inouye Telescope and instrument systems significantly exceeds that of the older facilities. In addition, operations of the DKIST include a newly developed service mode and data processing, long-term storage and dissemination not available for the previous generation of National facilities. The previous generation of high-resolution ground-based facilities were and continue to be operated in PI mode. The PI is awarded a certain amount of observing time at the telescope and to a large extent is able to guide and direct the use of the observing time, including instrument and instrument-mode selection, real-time target selection, as well as definition and execution of calibration sequences. The raw data collected during an observing run, including all calibration data, are simply provided to the PI on hard disk or tape. It is the PI's responsibility to perform all necessary data processing, including calibrating the data. In some cases, the NSO and its partners have provided calibration and reduction software to aid in the data processing. Due to the limited assistance that could be provided, every user essentially was required to become an expert user of the facility's complex instrumentation. When multiple imaging and spectro-polarimetric instruments are observing simultaneously, as is often the case at the DST and elsewhere, users must master the many intrinsic details of instrument and facility calibrations in order to have a reasonable chance of achieving their scientific goals. It often takes many years of experience for a user to arrive at the necessary proficiency and, with limited support, build an individually owned tool box for performing calibrations. Furthermore, the carefully calibrated data usually remain with the PI and are not generally available to the community for other scientific investigations. Because of this approach, which was a consequence of resource limitations, science productivity was significantly limited due to the lack of any data handling support or any broader scheme to provide a unified collection of the high-resolution data.

From a science productivity and general user perspective, DKIST Operations will be much more efficient compared to the operations of the previous NSO facilities or similar facilities. This statement applies to both the production of raw data at the DKIST facility as well as the processing and dissemination of calibrated data products. Observing modes such as Service Observations will make more efficient use of the available observing time. These concepts build on the lessons learned from nighttime telescopes, such as Gemini, specific Service Mode campaigns at the DST but also recent spacecraft operations such as TRACE, *Hinode* and SDO. However, the effort to design and implement the new DKIST operational concepts as well as data handling and distribution is substantial.

The NSO is able to draw on decades of experience with operating National facilities such as the Sunspot and Kitt Peak observatories and its flagship facilities (DST, McMath). Operations plans and experience of nighttime and radio facilities of similar size and complexity were studied and folded into the DKIST planning were possible. Site visits of Gemini Observatory (North), VLA NRAO, and the Hobby-Eberly Telescope (McDonald Observatory), and discussions with the respective science operations teams provided significant insight into specifically service oriented operations and its demands. Significant time during these visits was spent on introductory lessons and demonstrations of operations tools needed to support science operations. Practical experience into service-oriented operations was gained through service mode experiments performed at the Dunn Solar Telescope (DST), Sunspot, New Mexico. These experiments, where telescope time was offered to the community in full service, deeply corroborated the lessons learned in nighttime and radio astronomy and resulted in tremendous progress at identifying operational requirements for DKIST.

We note that there are distinct and substantial differences in how solar and nighttime telescopes are operated. These differences are not only driven by the fact that solar telescopes (obviously) operate during the day but also by how solar instruments are designed (e.g., laboratory environment) and operated (multiple instruments sharing the light and running in parallel). Nevertheless, operational concepts are often similar and with some adaptation or modification can be transferred to some extent.

The DKIST Operations development "project" includes a sizable effort to develop and operate a Data Center that ingests, processes, stores and distributes to the user community an average of 3 PB per year of calibrated data.

Previous solar facilities, due to their limited time horizon and cost constraints, were operated with a minimalistic approach to maintenance. The facilities were able to accommodate a minimal set of maintenance activities during the day in parallel or interlaced with observing tasks. This approach is not viable for DKIST. A maintenance plan for long-term and sustainable operations has to be developed and implemented.

The NSO Long Range Plan provides a summary overview of all DKIST Operations activities. The APRPP summarizes operations activities and plan. During the course of construction and during the ongoing operations ramp-up phase, operations concepts and procedures were developed and documented. In many cases, these documents were required to guide the development of subsystems but also contain valuable concepts and detailed information needed to plan and implement the DKIST Operations. For example, SPEC-0036, the Operations Concepts Definition document (OCD) is one of two Level-0 documents that has guided the construction project subsystem development (in particular, High Level Software systems). Subsystems such as wavefront correction and instruments have developed subsystem OCDs that describe the user interactions with the subsystem and provide information for development of user manuals. Operations tools such as the proposal architect and the experiment architect are guided by OCDs and the Data Center has developed operational concepts descriptions, just to mention a few examples.

3.3.2 Deliverables and Objectives

The main deliverables of the DKIST Operations ramp up include the following major items:

1. Development and implementation of Science Operations concepts and procedures, including service and access mode operations, TAC procedures, proposal and experiment cycle.
2. Implementation of Science Operations, including supporting tools, staffing plans, shift schedules and budgets. This includes the Science Operations Specialists (SOSs), Resident Scientists, the Operations Tools, and the Help Desk.
3. Development and operations of infrastructure, such as the DKIST Science Support Center (DSSC) on Maui, office, lab and shop space in Boulder.
4. Concepts, plans and implementation of Technical Operations of the DKIST facilities on Maui, including staffing plans, shift schedules and budgets. This includes the engineering

support and maintenance activities involved in operating the Maui facilities, including the summit facilities and the DSSC.

5. The development and operations of the DKIST Data Center (DC), which will handle processing, archiving, and distribution to the community of calibrated DKIST data.
6. Development and integration into DKIST of new instrumentation or capabilities, such as MCAO, instrument upgrades and enhancements to be implemented during operations in FY 2020 – FY 2024.
7. Support of the community in order to prepare for DKIST science by developing a Critical Science Plan (CSP).
8. NSO Research – NSO science staff will participate in CSP science activities and scientific publications, including NSO staff led CSPs. NSO science staff will serve as the PI of individual DKIST Proposals. NSO science staff will continue to play a leading role in working with the community to develop new instrument capabilities. Science staff document their research with publications and presentations. (Ongoing effort).
9. For operations, the DKIST will adapt the safety program developed during DKIST construction.
10. Development and implementation of an effective organizational structure, including staffing plans, schedules and budgets.

We emphasize that operations planning and ramp up to operations, including the implementation of the DSSC and the Data Center are outside the scope of the DKIST MREFC construction project. The initial DKIST Data Center will deliver calibrated data for all first-light instruments. Enhanced capabilities, such as higher-level data products and inversions, will be developed initially through recently awarded supplemental NSF funding (Section 5.1 DKIST Level-2 Data Efforts) and, as funding and available resources allow, during operations. Distribution of Level-2 data products has been added to the DKIST Data Center scope and is funded through the Level-2 effort.

The planning and implementation of DKIST Operations began at significant levels with the approval of the current CA in 2015 and subsequent funding. During FY 2015 and FY 2020, significant progress has been made in all areas listed above. Milestones achieved as well as milestones to be achieved in the second half of the CA are addressed in the individual sections below. In particular, significant progress was made with the planning and implementation for the Operations Commissioning Phase. The first proposal call for OCP1 was successfully executed (see Section 3.5.9.1.1).

The team involved in the operations planning and ramp up consists of staff dedicated to the operations effort and small fractions of full-time equivalents (FTEs) from construction staff. The team covers all areas of relevant expertise needed to plan and implement the DKIST Operations. Obviously, at this phase of the DKIST project, resource contention exists, in particular, for contributions of members of the construction engineering team. The top priority remains the completion of the construction of DKIST on schedule. Hence, construction staff availability for operations planning is very limited, which affects primarily the planning of technical operations on the summit.

During FY 2020, a large fraction of the construction engineering staff has been formally offered transfers to operations. The majority of staff has accepted these offers. In this way, it is ensured that the required expertise and experience to operate and maintain DKIST systems is available for operations.

<u>FY 2020 Milestone Summary and Status:</u>

1. **Science Operations Concepts and Procedures:** Preliminary versions in June 2020; full implementation at the end of OCP.

   Working groups for the development of concepts, procedures and Operations Commissioning Modules (OCM) have been formed during FY20. Preliminary concepts and procedures were developed and documented for the Proposal Cycle, including OCP TAC procedures. With the first proposal call released in May 2020, many of the procedures were implemented and tested.

2. **Help Desk:** Preliminary versions in June 2020; full implementation at the end of OCP).

   A help desk to support the Proposal Call and submission of proposals was implemented and successfully rolled out during OCP1.

3. **Infrastructure:** DSSC, lab and machine shop were completed during the first half of the CSA. Solution for long-term equipment storage space on Maui, rent or build, at the end of CSA.

   Cost estimates for building a suitably sized storage facility on Maui were developed. A lease vs. build cost comparison analysis was performed.

4. **Concepts, Plans, and Implementation of Technical Operations:** Initial planning complete; full implementation at the end of OCP.

   Staffing plans for Technical Operations have been updated and finalized. Initial shift schedules for technical support staff were developed.

5. **Development and Operations of the DKIST Data Center (DC):** DC infrastructure implemented at the beginning of the OCP. First iteration of instrument calibration pipelines implemented at the end of OCP. Calibration pipelines for additional instrument modes and some Level-2 products developed at the end of the CSA.

   Data Center infrastructure implementation was completed. Testing of infrastructure performance is ongoing. Prototype calibration pip3lines for several instruments were delivered to the Data Center by the construction team and implemented at the Data Center. Initial testing with simulated data and with available real (VBI) data has begun.

6. **Instrument and MCAO Development:** Major components manufactured by the end of FY 2021. Lab integration and testing in FY 2022 – FY 2024.

   MCAO: A contract for fabrication of a deformable mirror for the 4km conjugate is progressing. Delivery of the device is expected in early FY 2021. A design and feasibility study for the 11km conjugate DM has been concluded. A design and fabrication contract has been prepared. The award of a fabrication contract for DM11km, originally planned for FY 2020, has moved to FY 2021.

Instrument upgrades: Development of the second etalon for the final dual-etalon VTF is progressing well at the Leibniz Institute, Germany. Specification development and vendor interaction to identify upgrade and replacement options for infrared detectors. Development of image slicer technology.

7. **Community Support and Critical Science Plan:** Ongoing effort. CSP document complete by FY 2020.

   The CSP document has been completed and published via the NSO website and as a refereed journal publication.

8. **Research**

   In spite of significant service commitments, the DKIST science team continues to pursue research projects, including research in instrumentation development. The team has published 10 papers.

9. **Safety Program:** Transition to operations, staffing. Adaptation to operations phase complete by the end of OCP).

   The construction safety team has received and accepted transfer offer letters. The adaptation of construction safety procedures for operations is progressing well.

10. **Organizational Structure, Staffing Plans, Budget, Schedules:** Complete by the end of OCP.

    The organizational structure, staffing plans, budgets and schedules have been updated and in many areas finalized. The COVID-19 situation has caused a significant delay of the construction schedule. The construction end date has slipped to April 2021, with a high probability of further delays due to the dynamically evolving COVID-19 situation. The start of operations has slipped accordingly. The impact on operations staffing plans, schedules and budgets has been taken into account in the development of the FY 2021–2024 budget.

3.4 Management Structure and Staffing

During FY 2020, a focused effort was made to prepare transition offers for construction staff. During FY 2020, the majority of construction staff received offers for transfer to an operations position. A number of key positions were defined and filled. Staff were transferred into all areas, including data center, instrumentation development, technical operations, science operations specialists, and science support. Several recruitments of personnel were conducted. Figure 3-6 shows the top-level organizational chart (org-chart) for the DKIST Program in operations.

DKIST is organized into functional areas including:

- DKIST Associate Director.
- Science Support and Research.
- Science Operations.
- Maui Technical and Facility Operations.
- Instrument Development Program.
- Safety Program.

DKIST draws on NSO and AURA provided support for its administrative, business, Human Resources, and IT needs. The funds for the corresponding FTEs for administrative and IT support are included in the DKIST Operations budget. As indicated in the org-chart, accountability of these services will be ensured via the Director's office. And, however, given the geographical distribution of DKIST Operations, local delegation of authority to (co-)manage these resources will likely be implemented on Maui.

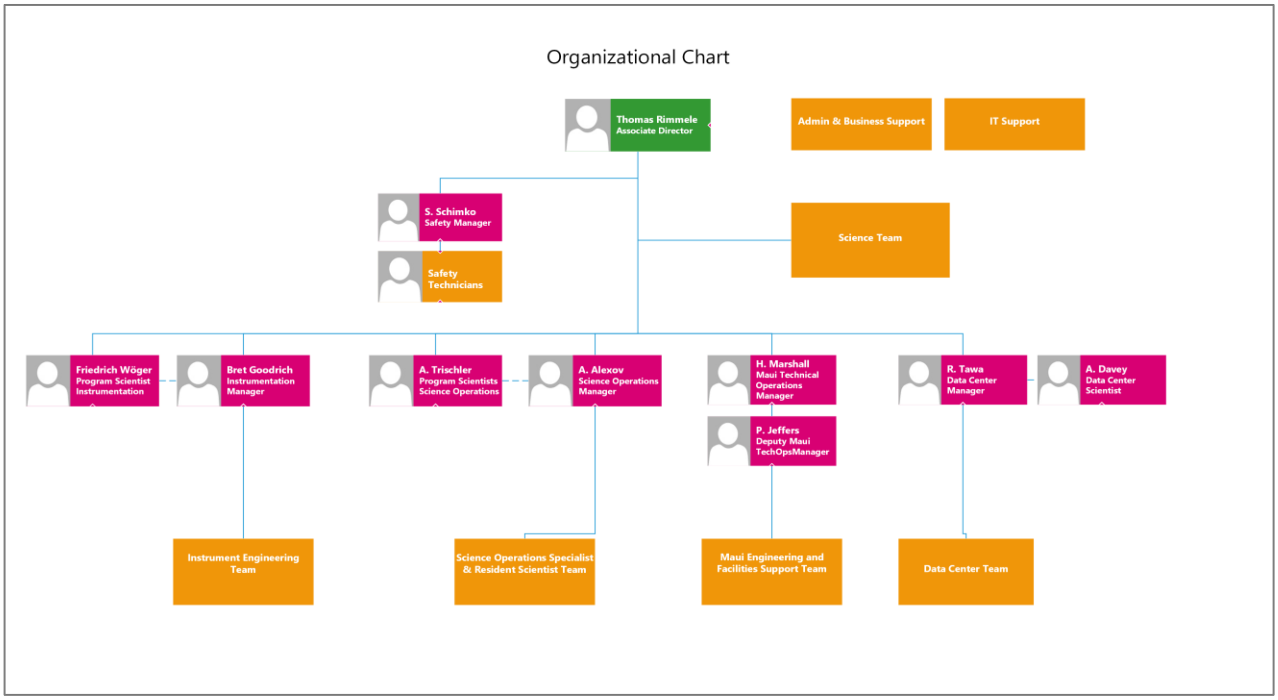


Figure 3-6. DKIST top-level organizational chart.

Key functional areas and management positions are defined as follows:

1. **DKIST Associate Director**
   The Associate Director for DKIST, in addition to directing the DKIST construction effort, has responsibility for DKIST Operations planning, ramp up to operations and upon completion of construction, regular operations of the DKIST facility. The position is currently located in Boulder and reports to the NSO Director. The plan is to add the position of Deputy Director toward the end of FY 2021 or at the beginning of FY 2022.

2. **Science Support and Research**
   The DKIST **Science Team** consists of scientists, post-doctoral researchers and students. The DKIST Science Team supports all areas of DKIST Operations, including service as Resident Scientists, leadership and support of new developments and instrument upgrades, EPO, data services, service on committees such as the TAC or SWG, and mentoring of students and post-docs. According to AURA policy, scientists have a fraction of their time available for personal research, which in many cases will be directly related to DKIST science objectives. The Science Team supports and collaborates with users of DKIST. The joint NSO/CU faculty positions engage in teaching, undergraduate, and graduate student training as well as research and support activities. The Science Team is distributed between Boulder and Maui.

3. Science Operations

The DKIST **Program Scientist for Operations** is the Lead Scientist for development and implementation of DKIST Science Operations and provides scientific guidance to the Science **Operations Manager.** This position coordinates and guides the team of Resident Scientists. This position provides training to Science Operations Specialists. This position leads or guides the development of operations procedures and tools. This position works closely with and provides scientific guidance and direction to the Science Operations Manager. The position is located in Boulder.

The DKIST **Science Operations Manager** supports the DKIST Director in the development and efficient operation of the DKIST facility. This position manages the development and execution of science operations plans, management of staff supporting the science operations, communication with the solar physics/astronomical community on DKIST capabilities and planning, and development and management of the telescope time allocation and user support programs.

The **Chief Science Operations Specialist** supervises the team of Science Operations Specialists (SOS). This position is responsible for developing and implementing work schedules for the SOS team including support of regular science observations, maintenance and technical development activities. As part of the telescope operations team, the Chief SOS performs regular observing support. The Chief SOS reports to the Science Operations Manager and works closely with the Operations Scientist and the team of Resident Astronomers.

The **Science Operations Team** includes **Science Operations Specialists and Resident Scientists**. The roles of the team members have been described in detail in other sections of this LRP.

The Science Operations group will participate and support observing proposal evaluation, planning and execution of daily observations. Resident Scientists will be drawn from the pool of DKIST and potentially all NSO Scientists, including postdocs and students, scientists from partner institutes as feasible and community members. Coordination of science support resources will be the main challenge. Providing travel and other support to community members will be considered to incentivize broad participation in the Resident Scientist service.

4. Maui Site Technical and Facilities Operations

The Maui **Technical Operations Manager** supports the DKIST Director in the development and efficient site and technical operation of the DKIST facility. This position is responsible for the development and execution of technical, engineering, and maintenance operations plans, management of staff supporting the technical operations, communication with the observatory science and engineering community on DKIST capabilities and planning. Responsibility for management of summit facilities on Maui is included in this position.

The **Deputy Technical Operations Manager** coordinates and manages prioritized daily work schedule for technical staff and provides overall management of predictive, preventive, and corrective maintenance on telescope systems. The Deputy Technical Operations Manager coordinates with the Technical Operations Manager and Technical Engineering team to plan and schedule strategic projects, such as DKIST development activities, new instrument integration and commissioning, and Observatory upgrades plan and schedule supporting infrastructure and resources to current and future facility instruments. This position prepares technical operations staff shift patterns, coordinates with discipline leads to make assignments, and oversees technical staff training and development.

The **Engineering and Facilities Support Group** consists primarily of engineers and technicians. The group covers a broad skill set, required to support operations and maintenance of the complex DKIST facility. This group includes optical, mechanical, electrical engineering, systems engineering aspects and minimal facilities support personnel. This includes the Technical Operations management positions. Even though major new developments are planned to be pursued by the Boulder instrument development team using the Boulder facilities, the combined pool of Boulder and Maui engineering resources will participate in new developments and upgrades to existing instrument and telescope systems, including software. Similarly, the Boulder instrument engineering team will contribute remotely and via campaigns to the operations and maintenance of summit systems. In particular, instrument systems, such as PA&C, WFC and software systems, including the Camera software (CSS) that during construction were developed by the Boulder instrument team can be effectively supported with participation by Boulder-based personnel that are expected to transition to operations.

5. **Instrument Development Program**

The **Program Scientist for Instrument Development** provides the scientific guidance and leadership for all new instrument development, upgrades to existing instruments, including current and future collaborations with instrument partners. The Program Scientist interfaces and works with the community, including the NSO Science Team, to provide guidance on priorities of new developments. The Program Scientist works closely with the Instrumentation Program Manager and the leads of other branches, including Science Operations, Technical Operations, and Data Center.

The **Instrument Program Manager** is responsible for managing scope, budget, and schedule of new development and upgrade efforts. The Instrument Program Manager takes scientific direction and guidance from the Program Scientist and coordinates closely with the leads of the other branches.

6. **Safety Program**

The **DKIST Safety Officer** is responsible for adaptation and continuation into operations of the safety program that was developed and implemented during construction of DKIST. The intention is to transfer highly qualified safety personnel and thus corporate knowledge from construction to operations.

3.4.1 Advisory Committees

DKIST regularly reports to NSO and AURA advisory and oversight committees. The DKIST Science Working Group (SWG) was formed to provide scientific advice and guidance to the construction project. Main objectives of the SWG included participation in development of the top-level science requirements (SRD, ISRDs) and operational requirements (OCD). The SWG has developed the Critical Science Plan that will define the majority of observing programs for the approximately first two years of DKIST full operations (following the operations commissioning). We anticipate that with the start of full operations, the SWG will cease to exist or "merge" with the long standing NSO Users' Committee.

3.4.2 DKIST Staffing Summary FY 2021 – FY 2024

Labor constitutes about 58% of the overall operations budget (Figure 3-7). The staffing plan for FY 2021–2024 is summarized in Figure 3-8. The figure shows staffing numbers (FTEs) as a function of WBS element and fiscal year. Due the delay of construction completion due to COVID-19, in FY 2021 a significant fraction of the staff will transfer to operations approximately six months later than previously anticipated. The operations staffing for FY 2021 is 59 FTE compared to 108 FTE projected for FY 2022 and 103 FTE for FY 2024 (steady state).

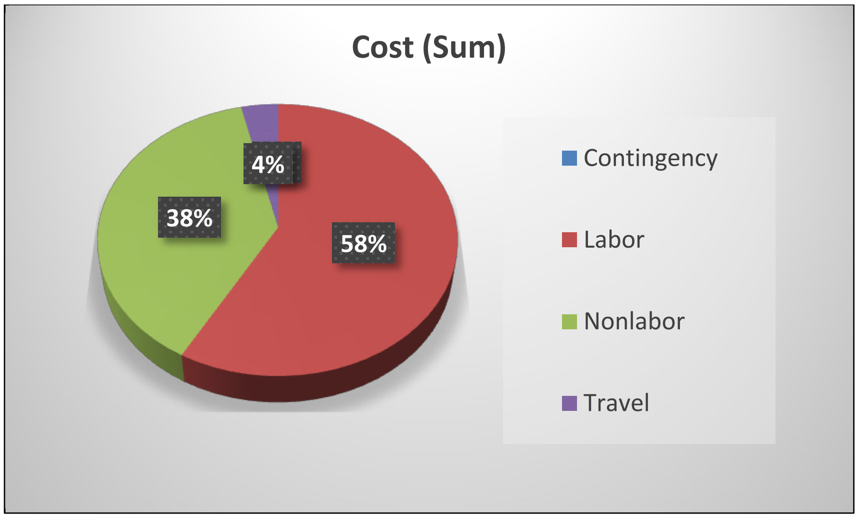


Figure 3-7. Overall operations budget distribution.

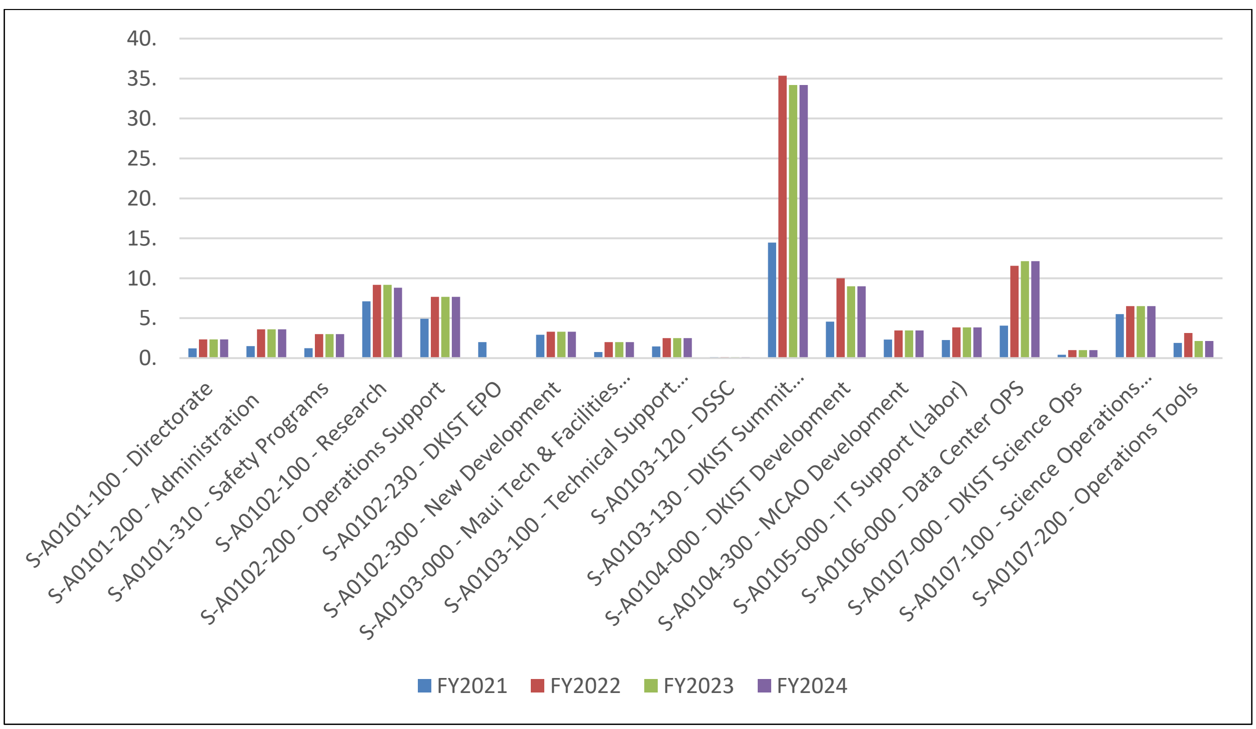


Figure 3-8. DKIST Operations staffing plan for FY 2020 – FY 2024.

3.5 DKIST Science Operations

3.5.1 Scope Summary

The deliverables and objectives, i.e., the program scope of DKIST Operations was summarized in Section 3.3.2 Deliverables and Objectives. DKIST Operations at the top level is organized into the following work breakdown elements: Science Operations, Technical Operations, Data Center, New Developments, and Science Support and Research. In this section, we describe the Science Operations Work Breakdown Structure (WBS) element. In summary, the Science Operations WBS element includes the labor and supporting non-payroll to support the science-observing process. The main function of Science Operations is collection of science, meta- and calibration data and delivery to the Data Center. Science Operations will be performed in either service mode via dynamic scheduling or access mode via fixed-block scheduling.

At the front end, Science Operations supports the user community in their efforts to generate and submit DKIST Proposals. Science Operations manages the proposal review process by the TAC, including the scientific merit and technical reviews. Approved proposals are translated to experiments using software tools, such as the Experiment Architect. Science Operations staff tests, verifies experiments, plans and supports execution of daily observations (science and calibration) in either service or access mode. Science Operations develops and maintains software tools that support users and staff in performing the required functions. DKIST Science Operations includes a Program Scientist for Operations, a Science Operations Manager, Scientists in their support role as Resident Scientists, the Science Operations Specialists (SOSs), the Operations Tools development effort, and the Help Desk.

Science Operations and Technical Operations (described in Section 3.6 DKIST Technical Summit Operations) will be working together on a daily basis to ensure both are conducted efficiently and with guaranteed long-term technical viability of the facility. It is anticipated that the oversubscription of science observing time will put pressure on minimizing maintenance efforts; this will be mounting early on in operations while at the same time failure rates and the need for technical work on the facility will still be high.

The primary documents guiding Science Operations are the "Operational Concepts Definition" (OCD) document (SPEC-0036) and the "Day In the Life (DIL) of DKIST". OCDs specific to software tools provide additional, detailed guidance.

The OCD captures the primary overall operational philosophy needed to operate the DKIST. The goal is to operate the telescope as efficiently as possible, while at the same time retaining the capacity for flexible operations, one of the strengths of ground-based facilities, and ensuring reliability and availability. The DIL document outlines the details of day-to-day operations for observing typical experiments, which fulfill proposals.

As the IT&C project matures and more of the DKIST subsystems are brought online and integrated, our DIL document and procedures will be updated. Processes and procedures described in the DIL will be tested and vetted during the Operations Commissioning Phase.

The Science Verification of instruments during DKIST construction will produce initial data towards the Data Center's development effort. These first raw data from actual DKIST instruments will be used to the extent possible for testing the end-to-end data flows, processing, archiving and distribution. It will help with calibration pipeline development, with calibration pipeline workflows and with all aspects of end-to-end processing, archiving and distribution.

3.5.2 Summary of Operational Concepts

3.5.2.1 General Guidelines and Considerations

- Science: The DKIST will adopt a fixed-length Proposal Cycle with cyclical solicitation for Proposals (Proposal Call) governing science operations.
- Operational Model: The DKIST will offer two different observing modes for Investigators: Service Mode Observing (SMO) and Access Mode Observing (AMO). Observing modes specify how observations are scheduled.
- Proposals and Experiments: All Science Operations and their related observations are based on and directly traceable back to an approved DKIST Proposal. Proposals provide enough detail to allow a science merit review and a technical feasibility review. Proposals also specify which instruments in what configurations or modes are requested for the observations. Proposals will be implemented through Experiments. Exactly one Experiment is generated per Proposal (i.e., translated into instructions that can be automatically executed). An Experiment contains a sequence of Observing Programs (OPs). Each OP fulfills an Observing Program Task and defines what the telescope, its subsystems and individual instruments have to do when the Observing Programs script is executed at the summit to acquire data.
- Synergies: The DKIST allows and supports co-observing efforts. Current solar ground-based observatories regularly support and co-observe with other observatories and missions, often referred to as coordinated observations. These co-observing efforts benefit the science goals, specifically if additional wavelength information and/or time coverage is needed. It is expected that the DKIST will be requested to co-observe with other observatories or missions on a regular basis.
- Multi-Instrument Operations: The DKIST supports the parallel operation of multiple instruments to obtain larger wavelength coverage and/or make use of different instrument capabilities. The Proposal and its respective Experiment define which instruments in what configurations are participating during an observation and the data acquisition process.
- Standard Calibrations: The DKIST complements each Experiment with calibrations. Each instrument participating in the Experiments observation will be supported by standard calibration measurements. Instruments are combined during those calibrations measurements as much as possible.
- The software systems on DKIST are designed to be extensible and scalable. All DKIST software control systems build on the same common software framework (called the Common Services Framework, CSF).
- The DKIST supports instrument development as well as visitor instruments.

3.5.2.2 Observing Modes

The DKIST is offered in two different observing modes: Service-Mode Observing (SMO) and Access-Mode Observing (AMO). SMO observations are planned and executed by DKIST science operations staff on behalf of a Proposal PI when observing and solar conditions are suitable, and technical readiness is assured. AMO is performed when close communication with, and overviewing and guidance by, the PI is necessary (either remote or present at the DSSC).

For efficient Science Operations, the DKIST will implement service-mode observing. It is assumed that the DKIST is operated for a significant fraction of the available observing time in this service mode.

Service mode is allocated in blocks of time (scheduled around access time or any other time-constrained operations) during which individual experiments are executed on a dynamic basis. The observatory staff is responsible on a daily basis for deciding what experiments are executed and what instruments are operated. Service mode renders the physical presence of the PI and/or Co-I's difficult to plan and therefore they will not be present. Remote participation of the PI and/or the Co-I's, however, may be desired or even necessary (depending on the complexity of the program) although difficult as the scheduling is by definition dynamic. Service mode allows making efficient use of target availability, weather conditions and technical readiness, and supports a broad range of different programs. Particularly, this mode is amenable to target-of-opportunity observations and can be used to perform surveys spanning multiple days and (long-term, solar-cycle scale) synoptic programs. During Service-Mode Observing (SMO), DKIST offers the following proposal program types from which the Investigator can choose: regular/standard, synoptic, and Target of Opportunity (ToO).

To fully support service-mode observing, the observatory staffing level requires substantial support from Resident Scientists and Instrument Scientists in addition to the normal staffing with Science Operations Specialists (aka telescope operators), a wave-front correction specialist, and engineers and technicians.

Access-Mode Observing (AMO) time for Science Operations is granted when real-time or very close interactions with the PI and/or Co-I's are necessary and/or special time constraints are given. AMO time is granted on a scheduled basis, i.e., a fixed block of time is allocated for the Proposal and its associated Experiment. Access time can be shared and can be granted to more than one PI during the same time period if no conflicts arise from this and non-interference is guaranteed. During access time, the PI and/or Co-I's participate remotely, or from the DSSC, or in some cases they may be granted physical access to the summit facility. During AMO the DKIST offers the regular/standard and Target of Opportunity (ToO) programs.

The implementation of service-mode observing time versus access-mode observing time (i.e., the respective percentage of the available observing time) will be subjected to periodic changes and adjustments (i.e., per solicitation cycle) depending on the experience gained at the DKIST and community demands.

We note that, while expected to be significantly more efficient, service mode requires significantly more resources, including investment in software and other supporting tools and, in particular, daily support from Resident Scientists (as described below). Although, service mode was experimented with and tested at the DST, the implementation of service mode at DKIST will require a commissioning and test phase in early operations. All DKIST science staff or potentially NSO science staff in general are expected to serve as Resident Scientists. Training of scientists in the use of operations tools, DKIST instrumentation and calibration procedures will accelerate until the start of operations in spring of 2021 and continue into the second half of the CA. Resident Scientists support is also an area where international partner contributions, financial or in-kind, could be integrated into the DKIST Operations effort and thus help alleviate resource constraints. Discussions with a few potential contributors are ongoing.

3.5.2.3 Science Operations Lifecycle

The DKIST is projected to be the major future resource for solar research and as such needs to provide access and attract not just the traditional ground-based solar scientists, but new users as well. DKIST is expected to increase the user base significantly by drawing and pulling in non-traditional users that currently rely mostly on space-based missions and/or come from other astronomical communities (e.g., the ALMA community is the most prominent recent example undergoing this user experience). As a consequence, DKIST observing time is expected to be in high demand with significant contributions from very different users with varying experience and familiarities with the complex instrumentation and the data handling thereof. The DKIST Operations staff needs to be able to accommodate new users to the field who are not as familiar with ground-based solar astronomy and non-PI-driven observing practices.

In order to identify common concepts that can be decomposed to derive operational requirements through use cases, the larger astronomical environment in which the DKIST will operate, was carefully examined. As a result, the DKIST Science Operations Lifecycle (see Figure 3-9) was developed, embracing and incorporating many of the important operational concepts that most modern large facilities share and from which the DKIST will benefit. On the overall scale, the DKIST Science Operations Lifecycle decomposes into a Proposal and an Experiment Lifecycle during which either Proposal- or Experiment-related tasks are performed (Experiments for the most part are the implementation of Proposals, i.e., their executable counterpart).

Figure 3-9. The DKIST Science Operations Lifecycle.

The Proposal Lifecycle separates the following phases:

- Preparation: Principal Investigators in collaboration with their Co-I's prepare Proposals to apply for observing time at the DKIST.
- Submission: Principal Investigators submit prepared DKIST Proposals.
- Review: The technical review committee (TRC) reviews and assesses technical feasibility of all submitted Proposals, the science review committee (SRC) scores and ranks Proposals for scientific merit, and the Time Allocation Committee (TAC) prioritizes the submitted Proposals and produces the final list of ranked proposals.
- Finalization: The TAC amends Proposals with approved TAC changes and notifies PIs of the results of the review.
- Completion: DKIST Proposals complete when their respective DKIST Experiment completes.

The Experiment Lifecycle separates the following phases:

- Generation: DKIST Scientists generate an Experiment for each approved and finalized DKIST Proposal.
- Quality Assurance: DKIST Scientists and Science Operations Specialists subject generated Experiments (i.e., their Observing Programs and Instrument Programs) to a three-step acceptance process: (1) component verification (qualification); (2) integrated verification (simulation through an end-to-end facility); and (3) validation (testing at the summit on real hardware).
- Planning and Monitoring: DKIST Scientists monitor, plan and dynamically schedule daily science operations at the summit.
- Execution: Science Operations Specialists execute Experiments' Observing Programs at the summit as directed by DKIST Scientists.
- Completion: DKIST Scientists assess executed Observing Programs by inspection of Observing Program information acquired during its execution (operator log, execution status, percent complete, light level and Fried parameter, calibration data status, etc.) and manually confirm completion.

3.5.3 Science Operations Software Support Tools

During each of the Science Operations Lifecycle's phases, actors in their specific roles are supported through a suite of integrated software tools, all of which have graphical user interfaces (GUIs). These tools are shown as small gray bubbles in Figure 3-10. Principal Investigators use an integrated Proposal Tool facilitating proposal preparation and submission (called the Proposal Architect). The TAC and its members will use a Proposal Review Tool for reviewing and scoring of submitted Proposals. The tool also has the capability to assist in creating a ranked list of approved Proposals DKIST Scientists will use an Experiment Generation Tool (called the Experiment Architect) to generate Experiments, Observing Programs, and their Observing Program scripts which control the telescope during an observation. DKIST Scientists will subject each Experiment and its Observing Programs to a quality-assurance process using an End-to-End testbed and the summits' Observatory Control System. DKIST Scientists will use an Operations Planning and Monitoring Tool to plan, and dynamically schedule Experiments and their Observing Programs for execution at the summit. The same tool also allows assessing the Observing Programs that have been run at the summit and tag them and their Experiments as successful (i.e., status = completed). Science Operations Specialists will execute Observing Programs at the summit using the Observatory Control System.

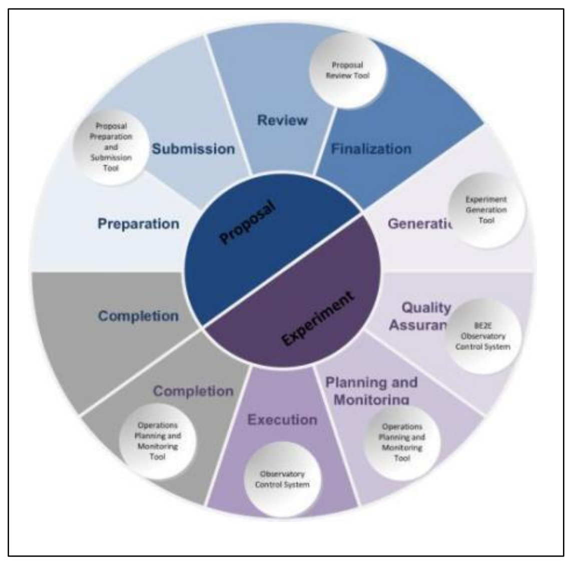


Figure 3-10. Science Operations Lifecycle phases; tools which support the phases are indicated in the small bubbles.

In summary, the main Science Operations tools are as follows:

- Proposal Preparation and Submission Tool (Proposal Architect).
- Proposal Review Tool.
- Experiment Generation Tool (Experiment Architect).
- Boulder End-To-End Testbed (BE2E).
- Observatory Control System.
- Operations Planning and Monitoring Tool.

These tools form an interconnected system that allows creating and directing the flow of information and data from Proposal generation by a PI to Observing Program execution and data acquisition by a Science Operations Specialist, as well as the manual completion confirmation of successful data acquisition by a DKIST Scientist. These tools are crucial for Science Operations and data acquisition. The Boulder End-to-End Testbed and the Observatory Control System (OCS) are DKIST Higher Level Software (HLS) deliverables and reliant on the software infrastructure at the summit. The Proposal Architect, Experiment Architect, Operations Planning and Monitoring Tool, and the Proposal Review Tool are science operations deliverables. Those tools form the core Operations Tool set and are built independently utilizing a "serverless" approach making heavy use of Amazon's Web Services (AWS) for economical ease of development, and long-term maintenance advantages. The entire software support tool suite is complemented by a Help Desk service.

Proposal Architect Tool

The Proposal Architect Tool allows Principal Investigators (PIs) to generate, edit, save, and submit DKIST Proposals. The Proposal Architect facilitates the preparation of DKIST Proposals with sufficient detail necessary for eventual Proposal review and for Experiment design while still accommodating a diverse and partially un-experienced and novice user base. The Proposal Architect makes available templates to provide guidance and support for the preparation of a science justification and an observing strategy. In more detail, this tool allows input of general information (title, abstract, PI and CoI details), program information (e.g., observing mode, program type, coordination request), observing condition details (e.g., seeing, sky, spatial resolution), target details (e.g., solar structure, location on the Sun), and instrument information (e.g., what instruments and their modes using which wavelengths) (Figure 3-11).

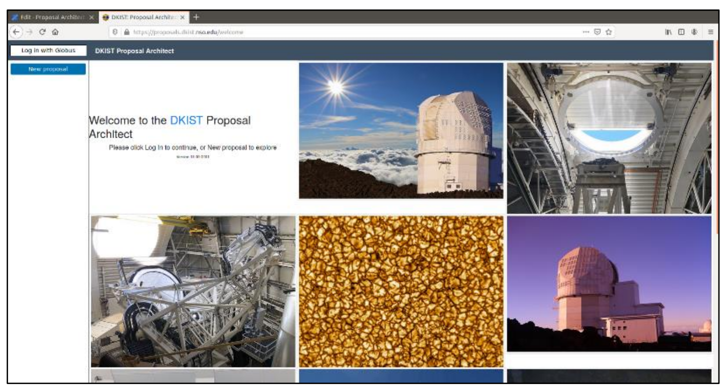


Figure 3-11. Proposal Architect Portal.

Proposal Review Tool

The Proposal Review Tool will support Proposal Reviewers to comment and individually score submitted DKIST Proposals. The tool will allow prioritizing and approving, or rejecting submitted proposals. Additionally, the tool will assist with generating a ranked list of approved and prioritized.

The Proposal Review Tool will allow finalizing Proposals, which involves amending the Proposal with TAC approved changes and notifying PIs about the status of their Proposal.

Experiment Architect Tool

The Experiment Architect Tool will allow DKIST Scientists to generate Experiments from approved Proposals and facilitate the generation of Experiments' Observing Programs and Instrument Programs (Figure 3-12). Observing Programs define the configuration of the telescope (pointing, Coudé orientation, etc.), the Gregorian Optic Station (GOS) (which FOV, dark, pinhole, target, etc.), and WFC (mode, offsetting and lockpoint details). Instrument Programs define the configuration of the instruments specified by the PI in the Proposal. Instrument Programs are part of the Observing Program. The Experiment Architect will support DKIST Scientists in creating Observing Program scripts for each Observing Program. All science observations are obtained through the OCS by executing an Observing Program script.

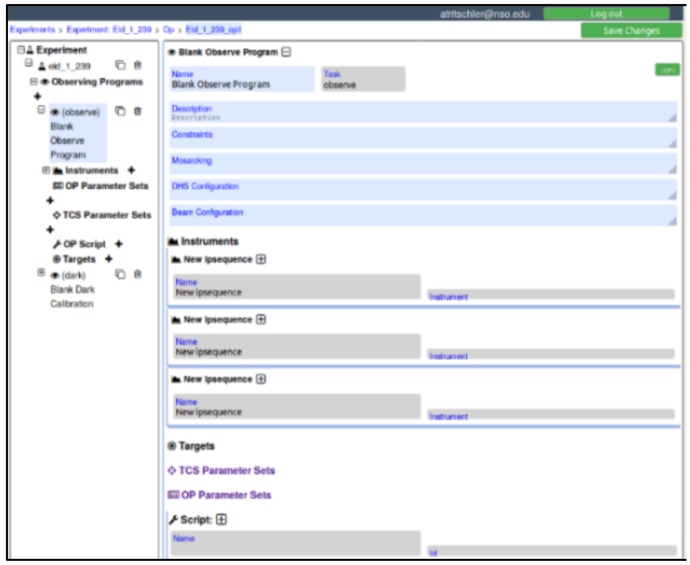


Figure 3-12. Experiment Architect GUI.

Only data that are obtained during the execution of an Experiments' Observing Program are transferred to the Data Center for calibration and distributed to the end-user. Script generation will be automated as much as possible, alleviating the need for handwritten scripts. These scripts will be tested against the (Boulder) End-to-End Testbed prior to being forwarded for test execution against real hardware.

Operations Planning and Monitoring Tool

The Operations Planning and Monitoring Tool will allow planning and monitoring of the daily activities at the summit through communication with the OCS. The tool will allow DKIST Scientists to generate Experiment Lists (aka priority lists) and potentially exact time lines (which is an eventual tool functionality goal) that are made available for ingestion by the OCS. The OCS will send status information and observing program execution reports back to the planning tool. This will allow scientists to assess and flag the completion of Experiments and Observing Programs. Moreover, the tool will facilitate the association of calibration measurements with science measurements which is crucial information for the DKIST Data Center.

3.5.3.1 Operations Tools during Operations

As the DKIST Operations Tools (Ops Tools) transition into operations, which under the current Cooperative Agreement with NSF extends until FY 2024, the focus will shift from development of the Ops Tools suite towards maintenance of the infrastructure and software developed during the previous years.

The DKIST Ops Tools programming staff will be responsible for implementing new, and modifications to, the Proposal Architect, Experiment Architect, Operations Planning and Monitoring, and Proposal Review Tool modules. New and/or modified functions are expected as users become familiar with the various tools, and their capabilities and shortcomings, and begin providing suggestions for improvement of the applications.

In addition, Ops Tools staff will be performing debugging and manual manipulations (movement, retrieval, posting, etc.) of entered data until the suite of applications is mature enough that human intervention is reduced. These manual interventions will likely result in code modifications to implement functionality that may not have been correctly implemented or to add necessary functionality that may not have previous been envisioned.

3.5.3.2 Operations Tools Development Status and 2021 Outlook

The Operations Tools development schedule is presented in Table 3-3. The Operations Tools are well along the development path. A Graphical User Interface (GUI) for the Proposal Architect (PA) was completed, tested, and released for PIs to prepare and submit Proposals in response to the first DKIST Call for Proposals on May 15, 2020 (aka Cycle 1 Proposal Call). The tool was extensively used for a duration of three months during the proposal submission window. Feedback from the Proposers was very positive regarding the ease of use of the PA as well as the documentation provided. Any issues discovered during the proposal call will be worked on prior to the release of the PA for the second Call for Proposals in 2021.

The Experiment Architect GUI has been prototyped and is undergoing heavy development and integration into the DKIST systems. The Experiment Architect Tool will be tested prior to and during the translation of the Cycle 1 proposals into experiments starting in the first quarter of 2021. The team has initiated development of the Operations Planning and Monitoring Tool's GUI in winter 2020. Testing of the Operations Planning and Monitoring Tool will be done towards the end of IT&C and during the Operations Commissioning Phase.

The Proposal Review tool assisting with the Proposal Review process has been conceptually specified but is not yet under development. Therefore, during the Operations Commissioning Phase, some aspects of the Proposal Review process are being done manually.

As the OT systems are used by scientists, an assessment of the OT suite will be conducted, and a suite of Key Performance Indicators (KPI) will be generated, captured, and analyzed as a means to enhance both the utility of the OT as well as the functioning of DKIST operations as a whole.

3.5.3.3 Help Desk

The DKIST project has been using the issue/bug tracking Atlassian product called Jira for several years. This Jira software tool can be used to track project management items, software bugs/tasks, project review material, test procedures, as well as to run a Help Desk. The Jira Service Desk software tool suite is specifically geared for Help Desk request tracking and is an expansion to the Jira product already used by most staff.

Table 3-3. Operations Tools Development Schedule

ID	Task Name	Start	Duration	Finish
1	**Ops Tools**	**Mon 4/13/20**	**469.5 days**	**Mon 1/31/22**
2	EA Phase 1 complete (VBI VisP, Cryo)	Fri 11/27/20	0 days	Fri 11/27/20
3	EA Phase 2 complete (DL)	Fri 11/27/20	0 days	Fri 11/27/20
4	EA Phase 3 complete (VTF)	Fri 11/27/20	0 days	Fri 11/27/20
5	OPMT complete	Mon 1/11/21	0 days	Mon 1/11/21
6	Proposal Finalize complete	Thu 11/19/20	0 days	Thu 11/19/20
7	**Overhead**	**Mon 4/13/20**	**230.75 days**	**Tue 3/2/21**
33	**Proposal Finalize**	**Tue 4/14/20**	**156.06 days**	**Thu 11/19/20**
40	**EA Development**	**Tue 4/14/20**	**203 days**	**Fri 1/22/21**
70	**OPMT Development**	**Tue 4/14/20**	**193.29 days**	**Mon 1/11/21**
142	**Email Notifications (EA, OPMT)**	**Mon 1/11/21**	**10.52 days**	**Mon 1/25/21**
148	**User Help Functions**	**Thu 10/29/20**	**27 days**	**Fri 12/4/20**
151	**System Verification**	**Mon 5/11/20**	**150.25 days**	**Tue 12/8/20**
159	**Display OPMT information/Status in PA**	**Thu 6/25/20**	**147.12 days**	**Mon 1/18/21**
165	**Post MVP Enhancements**	**Mon 11/30/2**	**27.5 days**	**Wed 1/6/21**
171	**TAC Tool Development**	**Mon 12/7/20**	**220 days**	**Mon 10/11/2**
175	**KPI Developmenet**	**Mon 3/1/21**	**240 days**	**Mon 1/31/22**

3.5.3.3.1 Help Desk Status

Science operations evaluated and tested a number of Help Desk software tool options, including the Jira Service Desk. The DKIST project decided on Jira Service Desk as the best option, purchased, implemented and configured the new tool set in 2019–2020 based on the initial design specification. The Help Desk Working Group encompassed all the entities which likely need to work using the Help Desk: Scientists, the Data Center, NSO IT, Ops Tools development, and potentially the Science Operations Specialists and Technical Operations. The workflow of tickets was designed and configured so that tickets/issues entering the Help Desk are farmed out to the correct subsystems; are assigned to the correct workflow, are followed up on within a reasonable period of time, and are resolved/closed. A significant amount of resources were used to create the Help Desk user portal and documentation for users as well as for the staff responding to tickets. Science staff were then trained on how to respond to questions/issues on the Help Desk (aka Help Desk Agents) and a staffing schedule was drawn up and managed by the DKIST Science Operations Manager. The DKIST Help Desk was released in conjunction with the Cycle 1 DKIST

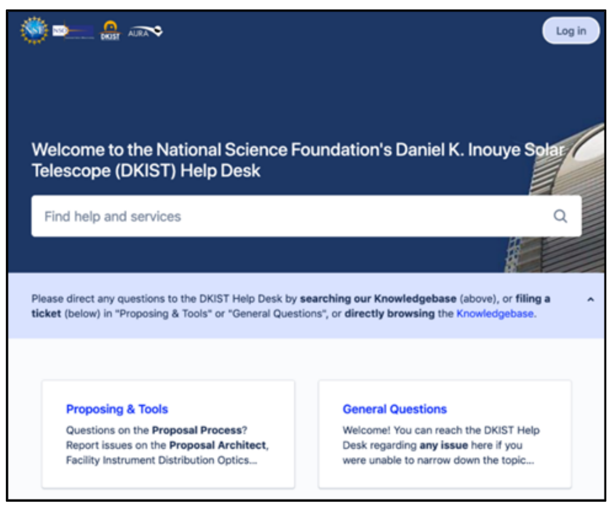


Figure 3-13. DKIST Help Desk screen.

Call for Proposals. Weekly Help Desk triage meetings were held during the three-month proposal call to ensure user tickets were being moved through the workflow and resolved by Help Desk Agents.

The advantage of having chosen Jira Service Desk is that the NSO staff have been using Jira for a number of years and are already well versed with configuring and using it. NSO IT was instrumental in helping setup and configure the DKIST Help Desk. Even though the Help Desk aspect of the Jira tool was new for DKIST, the foundation of having used Jira across the team significantly shortened the ramp-up time in learning how to use the Service Desk software tool.

3.5.3.1.2 Help Desk 2021 Outlook

Lessons learned during the Cycle 1 Call for Proposals are planned on being incorporated into Help Desk upgrades prior to the Cycle 2 Call for Proposals. Some effort is being spent on implementing the extended design to add DKIST entities, who will also be using the Help Desk in the future (i.e., internal Help Desk).

The DKIST Help Desk will continue to build on its current documentation and support the DKIST community by answering questions during proposal planning and assisting with data-related issues (after the release of the DKIST Data Center).

3.5.3.4 Observatory Control System (OCS) and Boulder End-To-End Testbed

The Observatory Control System is responsible for the overarching and centralized management, monitoring and control of all routine observatory operations (except for engineering). The OCS accomplishes this task partly through other systems of the DKIST. Three major functions of the OCS are (1) the efficient support of science observations; (2) support of routine facility tasks; and (3) the monitoring of the systems' health and alarms. The OCS also has managerial responsibilities for the DKIST software systems. The TCS, ICS and DHS (as well as the OCS itself) are resources managed by the OCS.

The OCS acts as the primary interface and tool for DKIST control during routine operations. The OCS imports and ingests lists of Experiments and their Observing Programs and Instrument Programs. This process will likely be done on a daily basis—information will be loaded into the summit data bases for testing, modification, and execution

The OCS executes Observing Programs that control the telescope and its subsystems (i.e., upper and lower GOS part of PA&C, WFC, TEOA, TMA, enclosure) through commanding the TCS, and the instruments (including cameras) through commanding the ICS. Some of this functionality is captured in Figure 3-14. Specifically, the OCS supports multi-instrument operations. To guarantee traceability of all science observations, the OCS provides and ensures a unique and unambiguous association between an Experiment, its Observing Programs, and all products of the observation. In other words, all data that are produced during an Observing Program execution, are associated with its source Proposal.

The Boulder End-To-End (BE2E) simulator is a full test bed for the Observatory Control System and its functionality. The BE2E integrates and incorporates all DKIST control systems ranging from the enclosure and mount, through the Gregorian Optical System and Wave-Front Correction system down

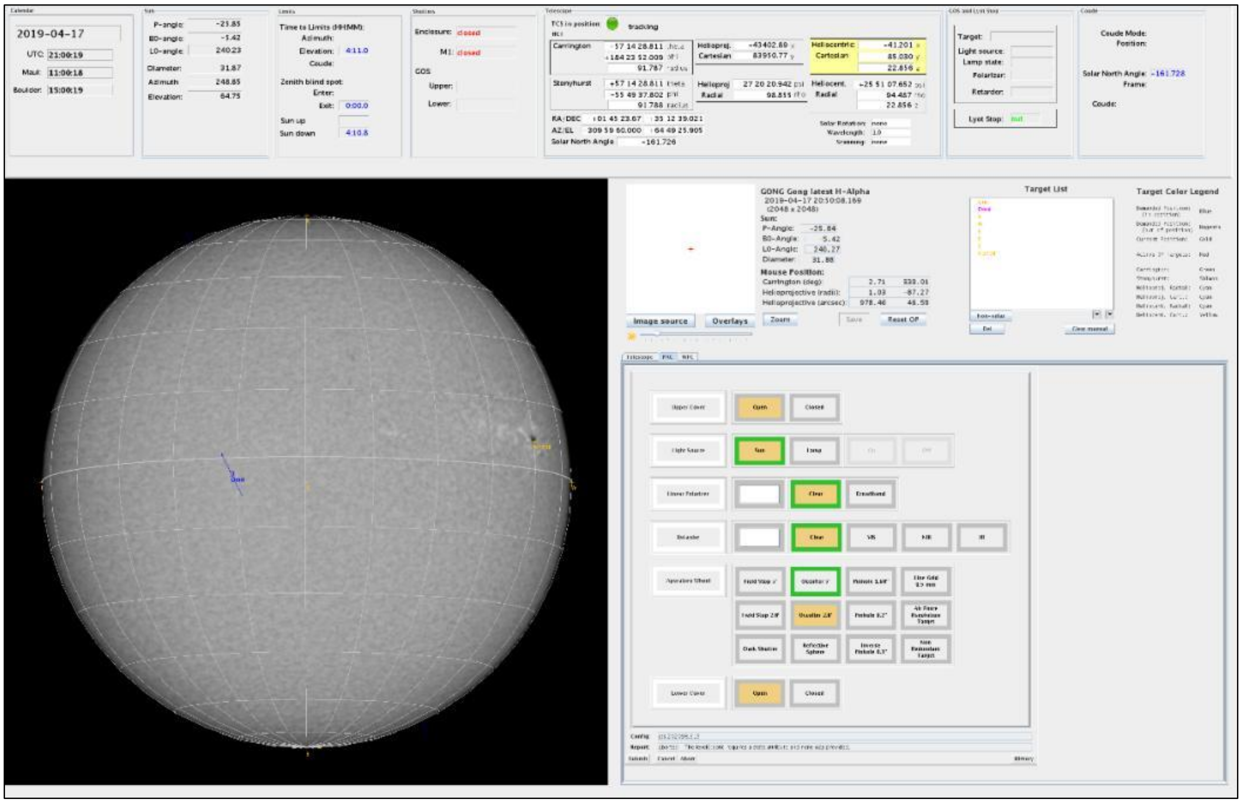


Figure 3-14. OCS screen.

to individual instrument controls using simulators wherever any of the control systems are connected to real hardware. The BE2E is a multi-purpose software tool used by DKIST system developers, instrument developers, science operations specialists, as well as scientists. This test bed allows for the testing of up-dates and new releases to software prior to integration at the summit. Most importantly, it allows for the testing of workflows through the systems using its graphical user interfaces, and as such, provides unique training opportunities for the operations staff.

3.5.4 Proposal Process

The community and its members directly guide DKIST science and thereby indirectly all observations performed at the observatory. This guidance will be facilitated through the implementation of a fixed-length Proposal Cycle that governs the planning and scheduling of all DKIST Science Operations. The DKIST will ask for community input through solicited observing requests (Proposals) which will be prepared by community members (Proposal Investigators, PIs) at least on a biannual basis via a Proposal Call. It is likely that the solicitation cycle will be six months. Investigators will use an integrated Proposal Tool (called the Proposal Architect, see earlier sections) consisting of a graphical user interface facilitating proposal preparation and submission.

The DKIST will accept Proposals during a defined submission window. All proposals submitted in response to a Proposal Call are subjected to a competitive peer review. Proposals will be evaluated for technical feasibility and for scientific merit. The results of this technical and science review will then be forwarded to a Time Allocation Committee (TAC) weighing the relative merits of different proposals in light of operational, technical, scheduling, and programmatic constraints and policy guidelines. The outcome of this review will be a ranked list of prioritized approved DKIST Proposals (a.k.a. master proposal list).

The DKIST Proposal Cycle during steady-state operations will be composed of the following time line windows, as depicted in Figure 3-15.

Proposal Submission Window: one month; opens with a call for proposals and closes one month later. In this submission window, Principal Investigators prepare and submit DKIST Proposals for the upcoming Proposal Cycle.

Proposal Review Window: two months; opens when submission window ends, and closes two months later. In this review window, all science merit and technical feasibility assessment has been completed including consensus meetings, the TAC has convened and generated the final ranked list of approved and prioritized Proposals, Proposals are finalized,, and PIs of submitted Proposals have been notified of the results of the Proposal Review process.

Experiment Generation Window: three months; opens when the Review window ends and closes three months later. In this experiment generation window, DKIST Operations staff creates DKIST Experiments from all approved and finalized DKIST Proposals; DKIST Operations staff performs Quality Assurance on created Experiments (simulation testing as well as testing at the summit).

Experiment Execution Window: six months. At the time the execution of cycle N starts, ideally all Experiments should have been created and tested. Therefore, each Experiment has the same chance and time available to be executed as any other competing Experiment. Caveats to this include target availability, requested observing conditions, and perhaps additional constraints that will limit when the Experiment can be executed.

This specifically means that a Proposal Cycle N is broken up as follows:

- Call for Proposals for Cycle N and Opening for Proposal submission.
- Submission Deadline for Cycle N: one month after Call.
- Results of Review of Cycle N Proposals: two months after closing of Submission Phase.
- Start of Execution of Cycle N: three months after Results of Review announced.
- End of Execution of Cycle N: six months after start.

The time line allows for enough time to organize the proposal review, assign Proposals for review, organize review meetings, produce the final ranked Proposal queue, but most importantly generate Experiments from approved Proposals and perform Quality Assurance of those Proposals.

For comparison, the average time frame between Proposal Call and Submission deadline of other facilities is between one and one-and-a-half months. Results of any peer proposal review are announced to Investigators on average typically three months after the submission deadline. Execution of observations starts on average two-and-a-half months after the results of the review have been announced. The DKIST leaves slightly more time for Experiment generation and its quality assurance process than other ground-based observatories.

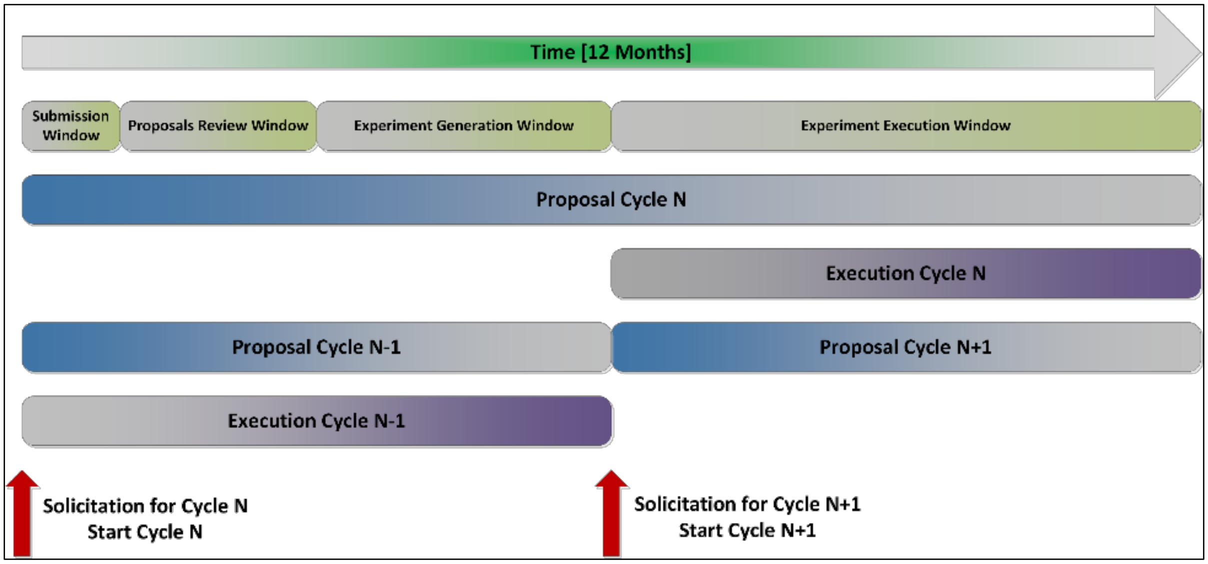


Figure 3-15. The DKIST proposal cycle time line during steady-state operations.

3.5.5 Science Operations Planning Time Line

The DKIST plans Science Operations on a long-term (six months), medium-term (one-to-three months), and short term (days to week(s)) basis. The long-term planning is driven by the length of the solicitation cycle. The medium-term planning is driven by co-observing (see Synergies in Section 3.5.2.1 General Guidelines and Considerations), access mode, Coudé laboratory preparations (see Standard FIDO and DHS Configurations), and specific calibration planning. The short-term planning is driven by the Sun (solar changes) and weather conditions.

3.5.6 (Limited) Remote Participation and Operation

Remote operations are possible from the DSSC only. Remote operations support at a minimum the monitoring of observatory operations via the replication of operations and quality assurance displays. Remote operations from the DSSC are limited by safety, by certain procedures that are being developed during Integration, Testing & Commissioning, and possibly by the available bandwidth to the summit.

During approved AMO time, the DKIST supports remote participation of Investigators (the PI and/or his/her designees and Co-I's) from the DSSC (or otherwise as regulated by policy). Remote participation support during approved SMO time is very limited and challenging; this will be done on a best effort basis only, at the DSSC only, and not at the summit, due to the inherent dynamic nature of the scheduling. DKIST policy will regulate the AMO and SMO remote participation support. All remote participation is passive and will be for monitoring and target verification purposes only (or as regulated by policy).

3.5.7 Overview of "Day In the Life" (DIL)

DKIST Science Operations embeds into the larger context of daily observatory operations. This involves procedures and activities that are performed every day, just as at every optical ground-based facility, allowing the observatory to transition from a high-level Housekeeping state (for the DKIST this is its Nighttime state) into other high-level states like Open or Closed or possibly Standing-By. Figure 3-16 conceptualizes these high-level states, the transitions between them, and activities that are likely to occur during those states. Transitions can occur at any time during the day, and are mostly constrained by weather (i.e., likely humidity, temperature and wind speed), and are guided by safety as well as by technical aspects.

The site survey predicts less atmospheric stability for the middle part of most days. Periods of good or excellent seeing are rare when the Sun is more than 50 degrees above the horizon (Rimmele et al., 2005). Therefore, the DKIST plans for on-disk diffraction-limited observing with post-WFC instrumentation at wavelengths up to 2 microns in the morning hours. Later times during the day and the afternoon will be used for observing at larger wavelengths.

During routine operations and under normal conditions, most Experiment-related activities are facilitated through the Observatory Control System (OCS) and its Operations GUIs. Those activities are complemented with manual procedures and activities that involve handboxes. Under special circumstances only and not under routine operations, Engineering GUIs are used in order to make specific changes that are not possible through the OCS's Operations GUIs. If experience shows that Engineering GUIs are used routinely for specific operations, then those responsibilities can be transferred to the OCS's respective Operations GUIs. Conversely, responsibilities of Operations GUIs can be removed if these are utilized very infrequently.

Figure 3-16 describes a daily workflow scenario, outlining what work is accomplished to transition the observatory and what work is performed when in a specific high-level state. In particular, the latter is kept generic and not tied to the specific details of an Experiment or the context within which it is executed. Most activities are executed from the Summit Control Room (SUCR) with a few exceptions where procedurally it is disallowed.

In the following, it is assumed that the operations staff have an understanding of what experiments are likely to be executed. These choices are made the day before by the Resident Scientist based on the weather forecast, the seeing prediction models (if available), the current solar conditions (such as target availability) and using knowledge about what has been executed on the current day. All these factors play in the decisions regarding what sort of operations should be conducted and specifically which Experiment or Experiments should be executed on the following day. One prerequisite is that all selected experiments and all observing programs that are part of the chosen Experiments have undergone a quality assurance process where they have been tested and verified on the Boulder End-to-End (BE2E) simulator.

A typical work day starts officially when the duty staff arrives at the workplace at least one hour and 30 minutes before sunrise. Summit support for operations will be provided by two groups, a Technical Operations group ("TOPs") and the Science Operations group (SOPs). The TOPs group includes technicians and engineers with different backgrounds, working in two shifts for morning activities (AM) and afternoon activities (PM), covering almost the entire day supporting operations. The Science Operations group ("SOPs") provides three or four Science Operations Specialists (SOS) who will perform observations in between sunrise +10 degrees and sunset -10 degrees of the position of the sun every day at the summit in two shifts. The morning (AM) shift with two SOSs arrives at the summit 1.5 hours before sunrise with the TOPs crew to perform the activities to prepare the observatory for

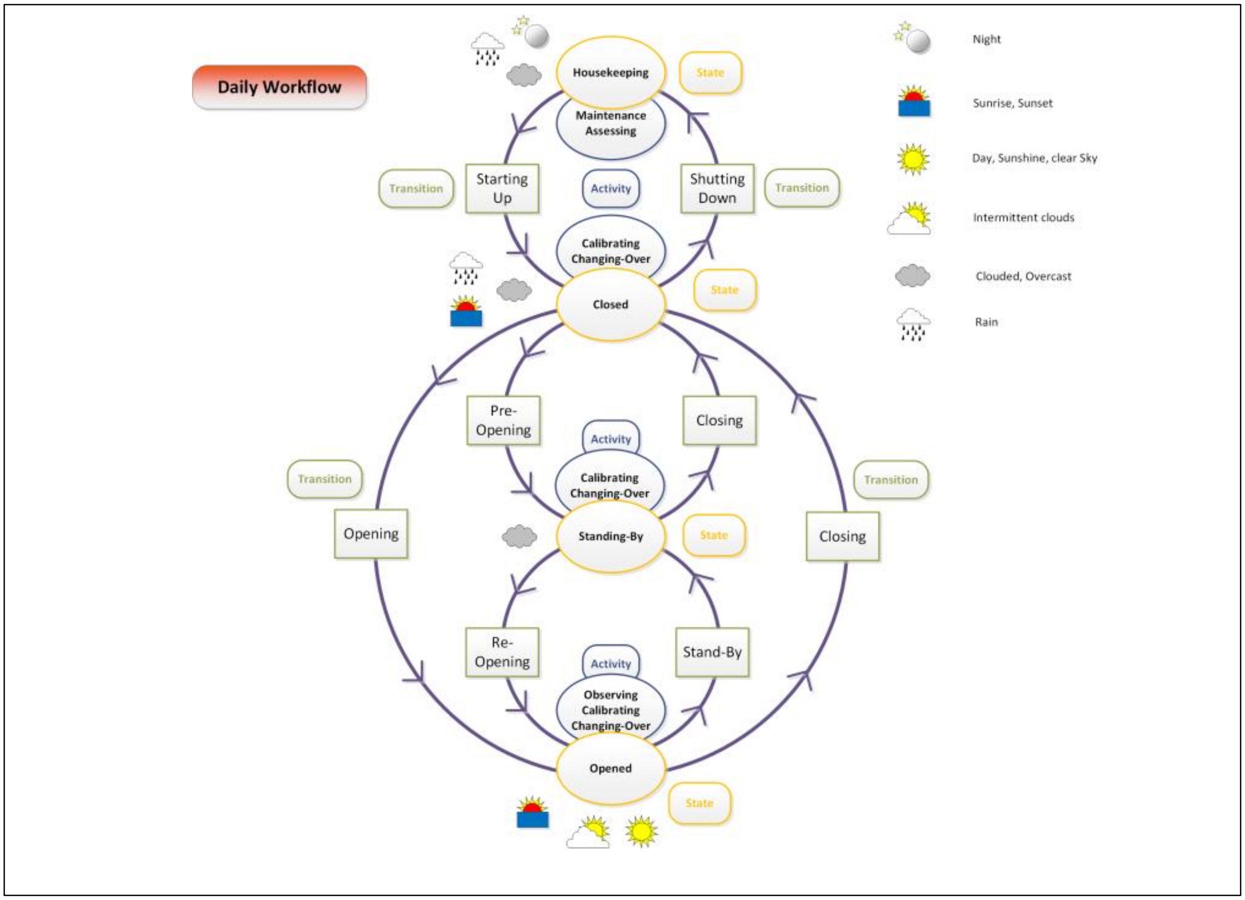


Figure 3-16. DKIST Daily Workflow, depicting the observatory to transition from a high-level Housekeeping state into other high-level states like Open or Closed or possibly Standing-By.

observations and provide observation support in the first part of the day. The second shift, the afternoon (PM) shift, with one or two SOSs depending on the day to support and the schedule, will arrive at the summit to continue the observations in the afternoon and close the telescope at the end of the day details in Section 3.5.8.1 Science Operations Specialist (SOS Schedules).

There is only one entity responsible for the facility at a time for daily operations, which can change depending on the phase of the day. The responsibility of the facility will be designated to the TOPs group led by one of the duty Engineer (designated by a schedule) or in the hands of the SOPs group led by one of the SOS on duty (designated by a schedule). In this scenario, any activity in the facility must be coordinated and approved by the person responsible at that moment; all aspects must be communicated and coordinated centrally between the SOPs and TOPs.

A standard set of checklists with a list of tasks will be provided to both groups (TOPs & SOPs) to perform activities in parallel to save time in preparation of the facility for observations (or in some cases maintenance activities). The handover section (with signatures) will be added into the checklists for each specific phase that includes this process.

Milestones FY 2020

The SOSs were included in the first on-Sun campaigns in FY 2020 before the DKIST summit was shutdown due to the coronavirus. During these early-year on-Sun campaigns, the SOSs were supporting some of the functions specified in the DIL, including inspections, telescope support and VBI instrument support. Checklists provided by IT&C were exercised by the SOSs in real-time, supporting on-Sun activities and observations. The SOSs then converted those checklists into draft operational procedures; lessons learned while on the summit were added into the SOS knowledge base; the wealth of experiences at the summit added to the training material for the SOS group and for SOS future hires.

The SOSs hired their fifth group member in winter 2020 from the DKIST construction project; this new group member gradually transitioned, over a six-month period, from the High Level Software DKIST project to the SOS group. Additionally, the SOS group went through a large-scale job search for their sixth team member, starting with the job posting in March 2020 which kicked things off with 63 applicants, nine shortlist candidates and eventually three finalists. Due to the coronavirus, the finalists were not able to visit Maui for typical two-day interviews across the various DKIST teams along with a summit visit; therefore, an extensive effort was made to have a series of nine interviews/discussions for each finalist with many staff from operations and IT&C, to mimic a multi-day interview process (had they visited the project on Maui). After five months, with nearly 40 interviews in total from start to finish, the sixth member of the SOS team was finally hired.

Milestones FY 2021

FY 2021 will be a critical year for the SOS group as Construction and IT&C come to a close and the Operations Commissioning Phase starts. The team needs to fully train two new operators, one of whom is very junior, coming from nighttime observing using small telescopes. The SOS group will create the procedures that describe in detail the transitions indicated in Figure 3-17 as starting up, shutting down, opening, preopening, closing, and standby. The SOS group will create the documentation that define the constraints to change the observatory in between the different states indicated in Figure 3-17 as opened, standing-by, and closed (calibration/change over).

Finally, the major milestone will be the support of Cycle 1 observations of accepted proposals. That will be the first operational test fully involving the SOSs. Procedures will be updated to address issues encountered during operations as well as to improve efficiency where possible.

3.5.8 Operator and Resident Scientist Schedules and Training

3.5.8.1 Science Operation Specialist (SOS) Schedules

The Science Operation Specialist (SOS) is the person responsible for performing and executing all aspects of science operations at the summit under direction of the Resident Scientists. The SOS works in conjunction with Technical Operations staff. The SOS is responsible for making sure that all observatory systems are functional for executing observations.

At the summit, a day of operation will include three or four SOSs who will support two shifts in operations: the morning (AM) shift and the afternoon (PM) shift.

The full staff schedule is shown in the Figure 3-17. The schedule includes six SOSs without planned or unplanned leave for a period of four weeks. During these 28 days DKIST is expected to be open for 25 days for solar observations and closed for three days for maintenance activities where no observations can be performed because the facility will be in a shutdown state. During maintenance time, the SOS group will be assigned to work at the DSSC to create/update the documentation and procedures for operations, but they will always be available to perform summit activities if needed.

There are three or four SOSs scheduled daily at the summit depending on the day in the week. In this schedule, there is full coverage with three or four SOSs at the summit where two SOSs support morning and the other one or two SOSs support afternoon observations, covering 100% of the possible observing time. For the days with three SOSs at the summit, the afternoon observing will be executed by one SOS most of the time. In the 25 science operations days with all SOS staff available for operations (without leave), we can support operations with four SOSs for 12 days (48%) and with three SOSs for 13 days (52%) at the summit.

Colored boxes indicate on-shift hours and the numbers in the boxes depict the number of working hours.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	WEEK1							WEEK 2						
	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa
SOS1	0	10	10	10	10	0	0	0	10	10	10	10	0	0
SOS2	0	0	10	10	10	10	0	0	0	10	10	10	10	0
SOS3	0	0	0	10	10	10	10	0	0	0	10	10	10	10
SOS4	10	0	0	0	10	10	10	10	0	0	0	10	10	10
SOS5	10	10	0	0	0	10	10	10	10	0	0	0	10	10
SOS6	10	10	10	0	0	0	10	10	10	10	0	0	0	10

	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	WEEK 3							WEEK 4						
	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa
SOS1	0	10	10	10	10	0	0	0	10	10	10	10	0	0
SOS2	0	0	10	10	10	10	0	0	0	10	10	10	10	0
SOS3	0	0	0	10	10	10	10	0	0	0	10	10	10	10
SOS4	10	0	0	0	10	10	10	10	0	0	0	10	10	10
SOS5	10	10	0	0	0	10	10	10	10	0	0	0	10	10
SOS6	10	10	10	0	0	0	10	10	10	10	0	0	0	10

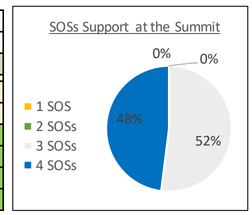


Figure 3-17. SOS staff schedule.

The goal is to have two SOSs to support the morning preparation activities and start the observations for the day. Depending on the availability on a specific day, one or two SOSs will support the observations in the afternoon and close the telescope to complete the observing day.

Each SOS shift (AM & PM) will arrive at the summit at different times to work at the summit for ten working hours in total (two hours travel + eight hours operations). The AM shift will arrive at the summit before sunrise to prepare the telescope to open at sunrise +10 degrees when the Sun can be observed with the DKIST.

The main activities defined for the AM shift are:

- Starting Up – Assess.
- Starting Up – Transition.
- Opening.
- Morning Observations.

The PM shift will arrive at the summit three or four hours after sunrise, depending on the length of the day through the year. Once the PM shift arrives, there will be a handover in operations between the AM and the PM shifts. Important information regarding activities performed during the AM shift, such as science observations, calibrations, problems, and various reports will be transferred to the PM shift in a well-defined standard procedure.

The main activities defined for the PM shift are:

- Afternoon Observations.
- Closing.
- Sending Day Report.

3.5.8.2 SOS Training 2020: Looking Back

Many training activities have taken place in the last several years in order to prepare the SOS group to have a better understanding of the DKIST Operations model as well as other important technical features of the different systems, all of which will impact the future definitions for operations in different ways.

2020 SOS Training Activities

With the lack of operations at the summit due to COVID-19, the group's main goal was to start creating the training process and learning material for new SOSs being hired in 2020 and beyond. The main activity was to create content in the SOS Confluence wiki space all critical information for future operations and flag relevant aspects which needed to be included as part of the training process for new hires.

The main activities of the year are highlighted in Figure 3-18.

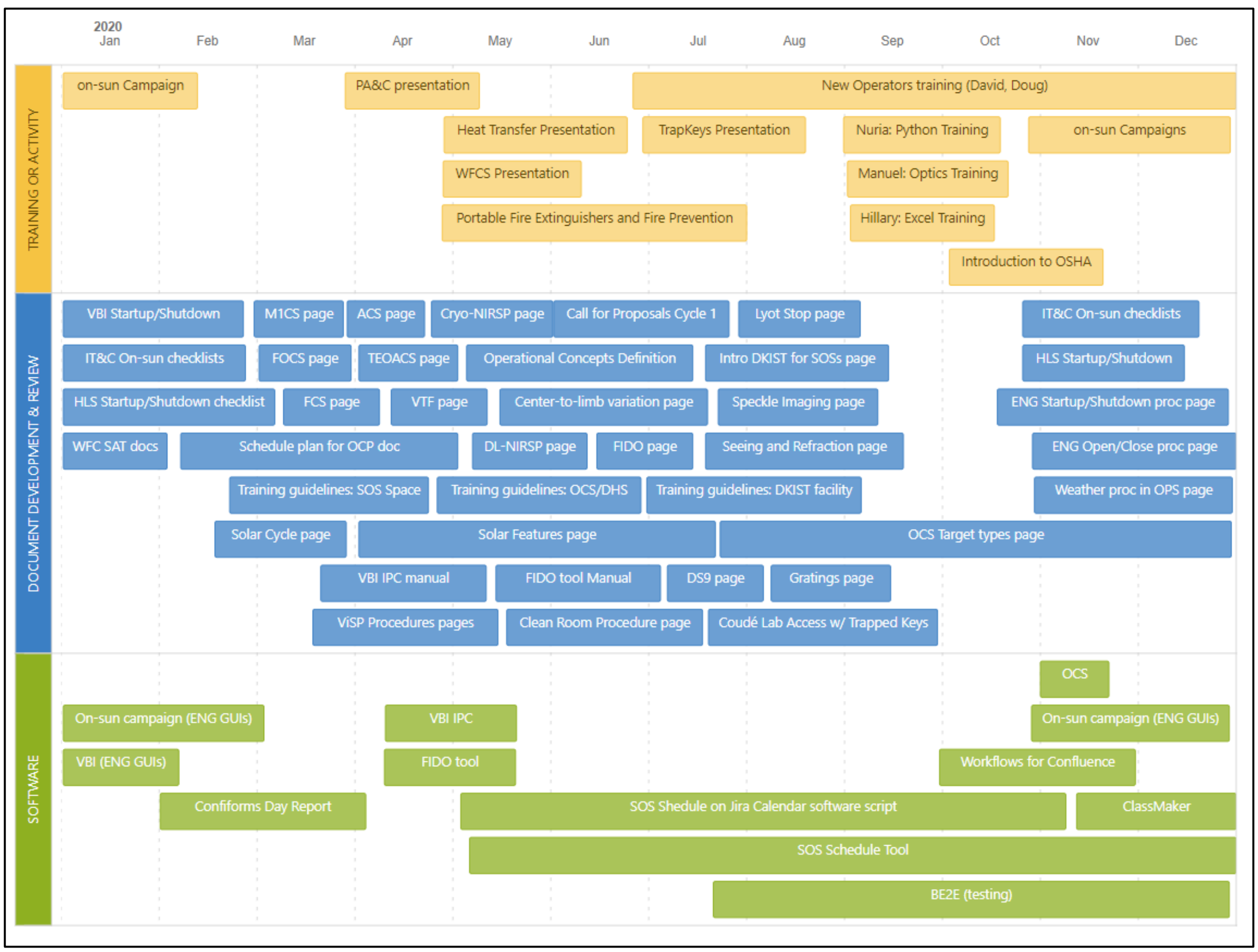


Figure 3-18. Main 2020 SOS training activities.

At the beginning of 2020, SOSs had the opportunity to particriple in a new on-Sun campaign to test the WaveFront Control System (WFCS) as part of the Site Acceptance Test (SAT). Detailed notes were taken in order to create SOS operational procedures based on what was learned during that campaign. There were no further SOS staff visits to the DKIST summit due to the COVID-19 situation until November 2020 when the SOSs will operate the telescope to support an IT&C on-Sun campaign.

The SOS group has been and will continue to use additional software applications that will support information gathering for operations:

- Confluence – for operations procedures and troubleshooting notes;
- Jira – for the creation of reports in case of technical problems; and
- Slack – for IM and video conferencing.

Specific training pages where created for each system to make sure that each SOS has the basic knowledge to understand, utilize and manage these tools.

With the experience acquired during the on-Sun campaigns and the study of the documentation available from IT&C, the SOS group began creating informational content in their Confluence wiki. All new pages included in the website passed through an internal review process by the SOS group members to get constructive feedback, correct errors, and to improve the overall information and content. This internal review process indirectly created a training activity for all the SOSs with the new content within those pages.

The experience showed that the SOS should have a good idea of the subsystems that are part of the Observatory Control System (OCS). The Group started to create the OCS overview page as well as all the pages that describe each subsystem: Data Handling System (DHS), Telescope Control System (TCS), Enclosure Control System (ECS), Gregorian Optical System (GOS), and others. In the same wiki area, the SOS group created the DKIST Instrument pages to describe in general terms the features and important information with respect to operations. All of this technical information will be included in specialized knowledge training for operators.

In addition, the SOS Group started to develop pages that describe details about the Sun and the fundamentals for solar observations. Some examples of pages for training created in these areas are: Coordinate System for Solar Observations, Solar Rotation, Solar Structure, Solar Cycles, Solar Features, and OCS solar targets types.

Other training material under development is related to Basic Astronomical concepts: Astronomical "Seeing" in telescope operations, Diffraction Gratings, and Atmospheric Refraction. Procedures pages for operations that describe the access to the Coudé room according to the clean environment requirements and safety conditions were created after online training with IT&C.

3.5.8.3 SOS Training 2021: Looking Forward

The main goal for next year is the development of the SOS group training process. At the end of FY 2020 the group is working on the definition and implementation for the basis of training. Two areas of development were identified: Knowledge Training and Skills Training.

Knowledge training is based on the information that the SOS needs to know for operations within the solar observations field. The knowledge training will not include any description of activities, procedures, or actions in general during operations. Knowledge training will include material and activities as follows:

Material

- Training pages in the SOS wiki space (Confluence).
- Training overview and goals.
- Training definitions: estimated training time, methodology, and requirements.
- Training topics and content (pages, presentations, videos, etc.).

Activities

- Training Checklist: list of topics and descriptions that are priorities as part of the training process. The checklist must be completed by the SOS in training to demonstrate the conclusion of the training.
- Quiz: Depending on the training content, the SOS group will have a quiz to certify that the SOS learned crucial training information.

If the SOS in training learns all the material available and completes all the training activities, the SOS will be certified in that specific area of the training.

There are four areas to develop as part of the knowledge training:

1. Safety: all basic safety training that is considered a requirement for future operations. Some of these trainings are provided by external entities (e.g., First Aid, CPR, & AED).

2. Software: training to learn how to use the tools/applications that will be used for operations (Confluence/Jira, Dropbox, Slack, etc.)

3. Group documentation: training to better understand of how to use the SOS space, the document formatting/templating, and the use of the SOS Group Scheduling tool along with the Calendar for operations.

4. General information: all information needed to understand the operations model, the observation strategies, the facility, and the software systems. An essential part of the section is the fundamental concepts for solar observations that include descriptions of solar features and the main characteristics of the Sun.

Skills training will include all the activities, actions, procedures that the SOSs will need to perform during operations. Some of the skills training activities will have knowledge training completed as a requirement.

The skills training will include material and activities as follows:

Material

- Training page in the SOS wiki space (Confluence).
- Training overview and goals.
- Training definitions: estimated training time, methodology, and requirements.

- Training topics and contents.
- Procedure and checklist pages that include detailed steps for the execution of each activity.

Activities

- Training Checklist: list of topics and descriptions that are priorities as part of the training process. The checklist must be completed by the SOS in training to demonstrate the conclusion of the training.
- Quiz: Depending on the training content, the SOS group will have a quiz to certify that the SOS learned crucial training information.
- Execute the procedure a number of times or for a period of time in operations (to be defined case by case).

If the SOS in training learns all the material available and completes all the training activities, the SOS will be certified in the specific area of the training.

There are four areas to develop as part of the skills training:

1. Safety Procedures: How to proceed in case of eathquakes, fire emergency or how to execute safety inspections.
2. Weather Procedures: How to proceed with lousy weather situations to shut down and close the facility, or set the observatory in a standby state in temporal bad weather conditions for eventual observing.
3. Daily Operations Procedures: How to execute operational procedures in a typical day of operations -- How to startup/shutdown/open/close the observatory, create reports and execute standard science observations.
4. Calibration Procedures: How to execute calibrations for the different systems of the telescope, instruments, and the wavefront system.

The following figure describes and summarizes the Knowledge and Skills Training definitions:

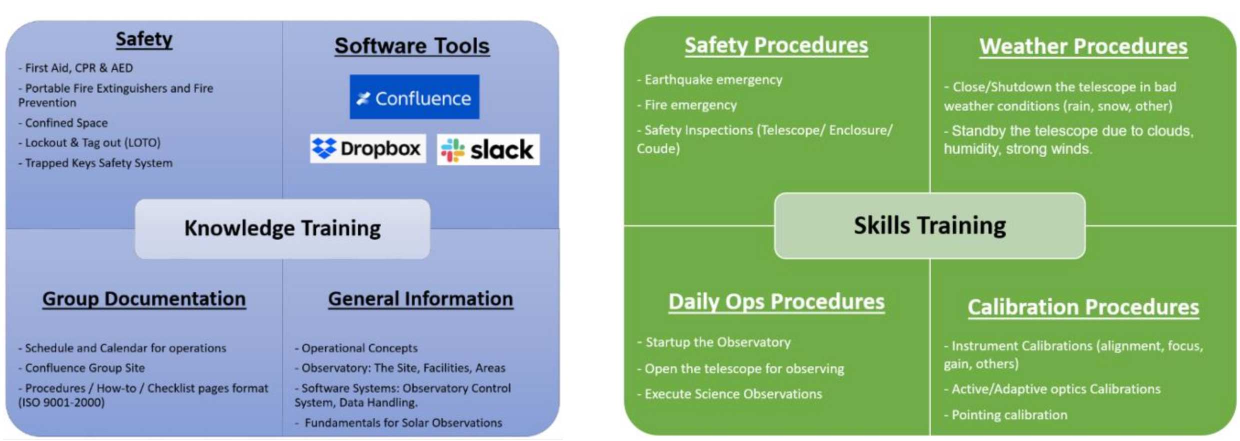


Figure 3-19. SOS knowledge and skills training definitions.

The experience that will be gained in the upcoming on-Sun campaigns during FY 2021, along with the new documentation from IT&C, as well as the first months in operations during OCP will provide the SOS group with the information needed to create the Skills training contents.

The SOS group must participate in training sessions for all DKIST Instruments as (or after) they are installed on the DKIST summit during FY21–FY22. Some of the topics to review during these sessions are as follows:

- Instrument GUIs, basic functions and procedures.
- Calibration plan and reference images for Quality Assurance (QA).
- Science image products and references images for QA.

Facility Instrument Distribution Optics (FIDO) is one important system for the SOSs to be trained on in FY21. The FIDO setup and changes will mostly be a task for engineers and technicians; the SOS group must be able to perform tests of the new FIDO configuration to make sure that science observations can be executed.

3.5.9 Operations Commissioning

Following DKIST IT&C and the end of construction, the DKIST will go through an Operations Commissioning Phase (OCP). This phase will allow science operations and the data center to ramp up and transition into steady-state operations. One major goal of the OCP is to build up complexity from simple instrument configurations to full capabilities (i.e., multi-instrument operations). At the end of construction, each instrument will be essentially "science ready" for only a very few select modes of operations. It is outside the scope of the construction project to fully develop, test and verify all key use cases for each instrument or instrument combinations (e.g., the ViSP alone can observe more than 300 unique combinations of different spectral lines). During the OCP, DKIST will thus continue to optimize performance of the instruments and exercise key operational modes and obtain data in these modes. The Critical Science Plan use cases will provide the guidance to define "key operational modes". Another major goal of the OCP is the implementation and verification of calibration pipelines for the various instruments. Although the Data Center has proceeded to implement and test with simulated data prototype calibration pipelines, it is only when a sufficient set of real data from the actual instruments is available that calibration pipelines can be fully developed and finalized.

The Operations Commissioning Phase will also be used to complete documentation, procedures, and general workflow processes. It is anticipated that hardware and software systems will get debugged and fixed on a fast cadence, utilizing good communication between technical staff, development staff and operations staff. PIs are also being asked for feedback so that documentation and tools can be improved upon after each proposal cycle. The internal and external Help Desk will be utilized for booking of bug/issues/problems and their resolution.

An important operational requirement for the DKIST is to regularly co-observe with other observatories and missions (aka coordinated observations). Hence, part of the OCP plans to allow for a limited amount of coordinated observations to test current baseline practices adopted by the DKIST. Proposal PIs will request a specific coordination and provide relevant details like requested time window, dates, and individual co-observing partners using the Proposal Architect. During the actual coordination, the PI will be responsible for the information exchange with the DKIST (i.e., Resident Scientists) about targets and pointing positions on a daily basis or as adequate. Emails and email aliases will be used to share and communicate this information although other channels can be used amongst individuals (e.g., Skype, Zoom). Resident Scientists will incorporate those details (i.e., pointing information and execution window of the Observing Program script) into the planning of observatory operations and instruct SOS staff accordingly. Lessons learned from these coordinated observations will be folded into DKIST Science Operations procedures in order to improve on future strategies for coordinated science with the DKIST.

Commissioning all of these aspects requires considerable effort and time. Facilitated through OCP Proposal Calls, we plan to invite community members who are willing to contribute to the effort to participate, as shared-risk users, in many of the OCP aspects. These “shared risk users” are expected to work closely with DKIST staff to commission DKIST Operations aspects starting with proposal submission and the proposal review process. For PIs of approved proposals, this collaboration will continue during Experiment generation and simulation using the Boulder End-to-End facility, and testing on the actual hardware. The verified Experiments are then run in service mode including necessary calibrations for the participating instruments and the facility. For each Experiment, the

respective raw data is transferred to the data center. The PI (and other team members), ideally spending significant time at the Boulder offices, will work closely with the Data Center and other DKIST staff on implementing the data calibration pipeline. PIs are also being asked for feedback so that documentation and procedures can be improved.

The OCP is expected to take on the order of 12 months. A balance between achieving high-priority OCP objectives and user pressure for regular operations to begin will have to be struck through regular discussions with the community.

In order to efficiently organize the OCP effort, we use an approach similar to the System Integration Module (SIM) approach that is being used during the IT&C phase of construction. Although, during the OCP we are not integrating testing and commissioning hardware components but rather functions and procedures, software tools, and data pipelines most of the general SIM approach, with well-defined flow charts, procedures, plans, and milestones for each module is still applicable. In analogy to IT&C’s SIM’s the OCP defines four Operations Commissioning Modules (OCMs) closely coupled to the DKIST’s Science Operations Lifecycle and its four Proposal Cycle windows (see Section 3.5.4. Proposal Process): Proposal Preparation and Submission (OCM1); Proposal Review (OCM2); Experiment Generation and Quality Assurance (OCM3); and Experiment Planning; Execution and Completion (OCM4). The OCP OCMs together define and plan the work/labor (i.e., functions and procedures) and the tools in support of that work/labor (i.e., the software tools, data pipelines, etc.) that need to be integrated, tested and commissioned. The OCP effort distinguishes between a development phase (OCP-DEV) and an execution phase (OCP-EXE) for each of its OCMs. During the development phase, procedures, plans, and flowcharts are developed and during the execution phase, those developed procedures and plans are implemented and executed. A major difference to the construction project’s IT&Cs SIM approach is that the OCP is planned and organized in a cyclic manner coupled to mini Proposal Cycles of a planned length of eight months each (compared to the planned steady-state Proposal Cycle length of 12 months). In this way, we can iterate and exercise three times through each individual OCM (i.e., OCMx-A/B/C) and gradually ramp up and implement lessons learned and improvements from one iteration to the next at least two times until steady-state operations. The start of a new iteration (or cycle) is triggered through an Operations Commissioning Call (OCC). The OCP schedule and current timeline is shown in Table 3-4.

5.5.9.1 Operations Commissioning Activities in 2020

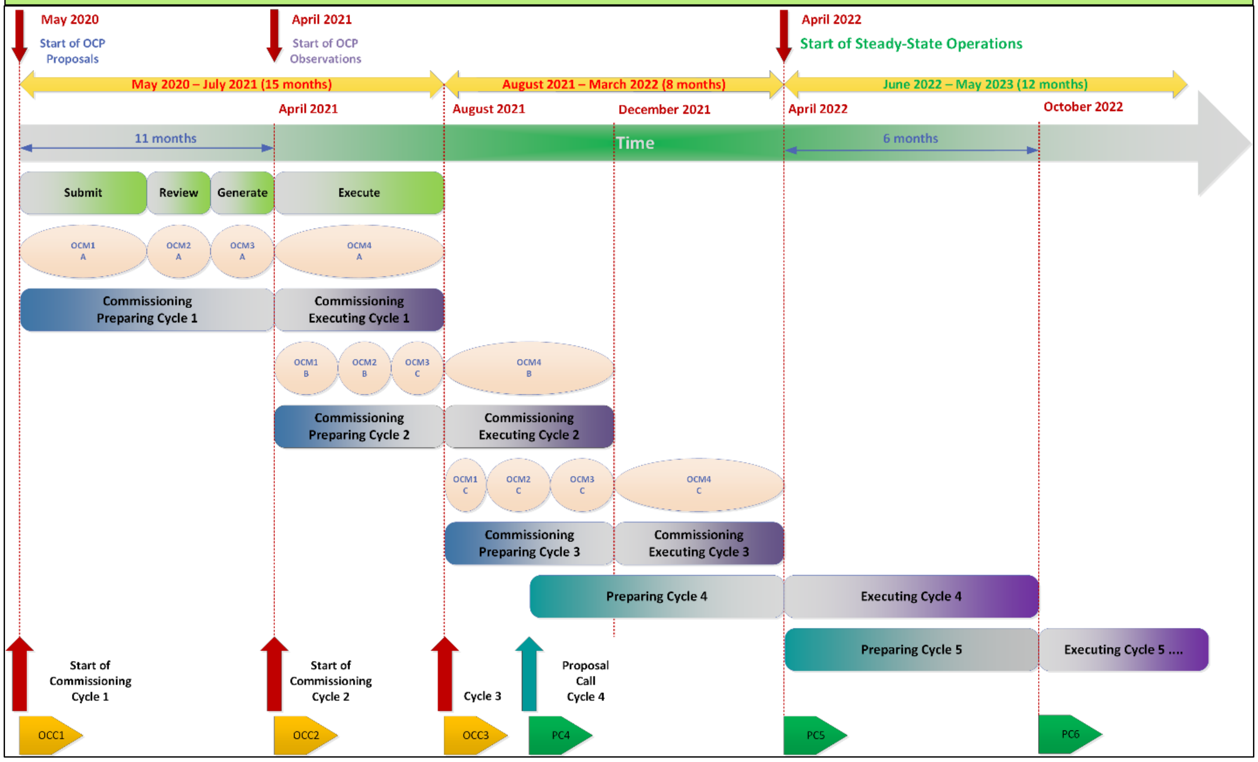
We evaluated and purchased supporting management software tools (not to be confused with the DKIST Operations Tools, mentioned above and described in Section 3.5.3.1) for documentation of processes and procedures. The Atlassian Cloud products Confluence and Jira are used for content management and ticket management, respectively. The Jira Service Desk product is used for the DKIST internal and external Help Desk. Operations staff has been trained in using both tools.

All procedures, flowcharts and plans for the OCM1 and OCM2 packages were developed and the corresponding first iteration was successfully executed (OCM1-A; OCM2-A: with some activities reaching into FY 2021). Following the OCM1 procedures and plans, the OCM1-A execution specifically included the preparation of the Cycle 1 OCP Proposal Call (OCC1); the preparation of the Proposal Architect for the limitations of the Call and subsequent testing of its functionality; the preparation and release of Science Operations webpages and documentation; the announcement and posting of the Call; the release of the Proposal Architect to the community as the proposal preparation tool; the preparation, testing and release of the DKIST Help Desk and its Knowledgebase (see also Section 3.5.3.3); management of the Help Desk and its services including the work shifts of the Help Desk agents (see also Section 3.5.3.3); and the gathering of feedback from the Proposers and the Help Desk agents. Following the OCM2 procedures and plans, the OCM2-A execution included the implementation of an OCP or prototype proposal review process. This prototype process is based on three tiers involving a technical review by internal DKIST science staff, an anonymous science review performed with significant participation of external community members, and a final review by a Time Allocation Committee (TAC) formed by NSO/DKIST leadership. As the Proposal Review Tool is the last of the Operations Tools to complete development, it is not available during this stage of the OCP. Hence, many aspects of the proposal review process were and will be facilitated through manual procedures making extensive use of JIRA and Google Drive/Sheets. The development phase of OCM3 was initiated, a flowchart was developed, and some procedures were drafted. The development phase of OCM4 has not started.

3.5.9.1.1 Cycle 1 DKIST Proposal Call for Observations

This first DKIST Proposal Call for Cycle 1 observations during the OCP was announced on May 15, 2020. For this first out of three Proposal Calls during the OCP, the submission window was extended to three months, providing proposers with ample time to familiarize themselves with the Call's offered capabilities, the general proposing process, and the tools and services supporting proposers during the proposal preparation phase. The response of the community to this first opportunity was tremendous despite the limitations of the Call. At the time of the closure of the submission window on August 14 at 23:00 GMT, a total of 101 proposals were submitted by 91 unique proposers with the largest contributions from the US (46%) and European DKIST partners (UK with 17%, Germany with 12%). The remaining international contributions came from Japan, Spain, Sweden, China, Norway, Switzerland, Italy and Austria. Almost 13% of the submitted proposals intend to use the requested observations in the context of a PhD thesis. The vast majority of proposals (80%) requested the combination of the Visible Broadband Imager (VBI) and the Visible Spectro-Polarimeter (ViSP) which could be a very early endorsement that multi-instrument operations will play a major role in the

Table 3-4. Operations Commissioning Phase Schedule Timeline



scientific success of the DKIST. The Cryogenic Near-Infrared Spectro-Polarimeter (Cryo-NIRSP) was requested by 10% of the proposals, while the residual 10% requested either the VBI or the ViSP individually.

On August 19, an anonymous survey was sent out to the proposers, requesting feedback on the general experience, clarity of the Proposal Call, ease of use of software tools, quality of documentation and webpages, and the Help Desk and its knowledgebase. More than half of the unique proposers, covering all career stages and levels of expertise in solar physics, responded to the survey and provided invaluable feedback. The results of the survey are evidence of a very positive experience, which is particularly encouraging for the Proposal Architect and the DKIST Help Desk. Both services were perceived very well and rated highly. We received a lot of suggestions and very good guidance on how the documentation, tools, and the transparency of the proposing process could be improved. The proposals are currently under review with the technical review completed and the science review well underway. After the science review, the proposals will be prioritized by a Time Allocation Committee (TAC) based on science merit, OCP objectives and policy guidance. It is expected that Proposers will be notified of the results of the review by the beginning of December 2020.

3.5.9.2 Operations Commissioning Milestones for FY 2021

The FY 2021 foresees major activities and milestones. First, the development phase of OCM3 (Experiment Generation and Quality Assurance) will be completed and following its procedures and plans, OCM3-A will be executed. This execution essentially entails that all Cycle 1 Experiments will be generated, then simulated, and tested at the summit. While the former two activities will heavily involve internal scientists relying on the Experiment Architect, the Operations Planning and Monitoring Tool and the Boulder End-To-End facility, the latter activity also involves SOSs using the OCS proper at the summit and the real hardware connected to it. Prior execution of OCM3-A, training of staff on the Experiment Architect and the Operations Monitoring and Planning Tool is planned. Ideally, OCM3-A is executed prior the start of the Cycle 1 observing window which is coincident and timed with the end of the IT&C construction effort and the start of operations. Depending on the proposal pressure (i.e., the number of approved proposals) and availability of time at the summit, the testing of experiments at the summit will have to be folded into the time available during the Cycle 1 observing window.

Second, the development phase for OCM4 (Experiment Planning, Execution and Completion) will start in early 2021 and be completed in April 2021, and following its procedures and plans, OCM4-A will be executed during the Cycle 1 observing window. This execution will include the medium and short-term planning of summit science operations, conducting and monitoring of the observations, the assessment of the completion status of observations, and the association of calibration with science measurements for the Data Center to be able to start the data reduction pipeline. All activities involve internal scientists and the SOSs using the Operations Monitoring and Planning tool and the OCS proper, respectively.

Third, the second OCP Call (OCC2) will be prepared and announced (i.e., OCM1-B will be executed) and subsequently all submitted proposals will undergo the proposal review (i.e., OCM2-B will be executed). It is planned to implement some of the lessons learned during the first execution of those modules.

3.6 DKIST Technical Summit Operations

3.6.1 Scope Summary

The DKIST Technical Operations Team will comprise of Maui-based Technical Operations management along with a staff of engineers and technicians to maintain, repair, and upgrade the DKIST Observatory according to NSO overall priorities. In FY 2020, key construction staff have received and accepted offers to, at the end of construction, transition into operations positions. The Maui-based Technical Team will require remote support from Boulder-based colleagues, for example, specialists in camera or instrument software, and for deployments when appropriate to collaborate on major upgrade and repair efforts. The delay of the construction completion due to COVID-19 has in turn delayed the transition of some construction staff into operations positions.

3.6.2 Maintenance Plan

3.6.2.1 Technical Operations and Maintenance Support

From an engineering perspective, there are three functions in operations. The first is support of day-to-day observing to proactively minimize the loss of observing time. The second is maintenance, which can be subdivided into planned and unplanned maintenance, with further division of planned maintenance into activities which may be conducted concurrently with observing and activities incompatible with concurrent observing activities. The third category is observatory and instrument upgrades. Over time, as observatory uptime is optimized, provision of technical resources sufficient to cover the first two objectives will result in underutilization of technical staff. Therefore, the technical operations team is also envisioned to actively drive ongoing major observatory upgrades, and substantially participate in overall NSO development activities, such as new instrumentation and the MCAO project. For major efforts, additional staff would be deployed from NSO Boulder to work collaboratively with NSO Maui-based staff at the DKIST Observatory.

Daily Startup

A key technical operations support function is ensuring the morning start-up is not delayed by minor problems or glitches. Such problems, with the right support, can be quickly resolved but significant prime observing time could be lost without immediate attention. To minimize this risk, a core support team of a duty engineer, electrical technician, and mechanical technician are planned to accompany the startup Science Operations Specialist(s) each day.

Daytime Operations Support

The Facility Thermal System requires attention to both weather conditions and system performance throughout the observing period to optimize facility performance to the type of observing being performed. This is not a continuous activity but does require specialist knowledge or substantial training. In addition, monitoring performance of other subsystems will allow assessment of maintenance following daily shutdown and help in longer-term preventive maintenance. A combination of onsite and on-call support will be scheduled encompassing the remainder of the technical operations staff, with daily assignments dependent upon the observing conditions and maintenance or repair needs and priorities.

Maintenance Support Categories at DKIST

Observatory maintenance can be separated into three categories:

1. Planned Concurrent Maintenance: Activities which may be scheduled within the regular observing day, which can be conducted with no or minimal interference with observing, for example routine inspections in unhazardous areas.
2. Planned Downtime Maintenance: Activities that are incompatible with observing activities, and take a longer period of time but must be performed in order to maintain observatory functionality and scientific output, for example mirror re-coating, and in-situ optics cleaning.
3. Unplanned Downtime: Urgent repairs required in response to unexpected faults during observing or other operations.

Planned Concurrent Maintenance

Planned Concurrent Maintenance activities are those required daily or weekly which can occur in the periphery of the daytime observing, for example as part of the routine startup and shutdown procedures, or in parallel with observing. An example of the latter is inspection and maintenance on equipment located in non-hazardous areas such as the Utility Building, machine shop, and instrument preparation laboratory.

Planned Downtime Maintenance

Planned Downtime Maintenance will require immobilization of all or part of the facility by means of equipment shutdown or lockout-tagout procedures. Planned Downtime (or non-concurrent)

Maintenance will, as far as possible, be performed during non-observing time, for example during periods of poor weather or very poor seeing. However, cost constraints on overall staff size is likely to result in planned downtime during potential observing periods in order to ensure reliability of different observatory systems and overall lifetime of the observatory.

There are several particular activities that will require daytime observing hours to conduct:

- Carbon Dioxide (CO_2) "snow" cleaning the optics must be conducted during times of low-humidity and with active cooling of optics disabled to avoid condensation of moisture and adherence of contaminants on optical surfaces. Optics cleaning will be conducted according to science requirements and impact; it is estimated to be required on a weekly or biweekly basis. Snow cleaning of the primary mirror requires approximately six hours of unrestricted access to the telescope, which is locked in horizon-pointing position. Other planned maintenance will be paralleled with this activity.
- Primary Mirror in-situ wet-washing is estimated to require three days of downtime on a quarterly period, with actual frequency once again driven by science requirements and impact. Other planned maintenance can also be conducted in parallel with this activity.
- Primary Mirror re-coating will require four to five weeks of downtime to perform; the duration is significantly increased over other facilities due to the need to transport the primary mirror to and from the neighboring Air Force facility. For the best possible coating outcome, this activity should be performed during the dryer, warmer summer months. The strip and recoat process requires a large technical team, but some maintenance may be performed in parallel such as facility cleaning, Coudé Environmental System filter changes, and software updates.

Note that any maintenance on major optics, in particular the primary mirror, will also require the technical team to perform system verifications prior to re-commencing observing. These verifications may include co-alignment of the Target Acquisition Telescope/Acquisition Control System to telescope pointing and Polarization Calibration routines.

Unplanned Downtime

Even with the best maintenance programs, unforeseen failure can occur. In the event that a failure impacts observing, the technical team will be immediately tasked with returning the DKIST Observatory to functionality. Follow-up engineering work will then be scheduled to fit within the Planned maintenance program. To ensure personnel and equipment safety and proper re-start of the facility, comprehensive inspections of work areas will be required prior recommencing observing following either unplanned or planned repairs.

Milestones FY 2020

- Key positions were filled, including the Technical Operations Manager, Deputy Technical Operations Manager and several Engineering Leads.
- Staffing plans and Summit Engineering budgets were revised.
- Regular planning sessions were held.
- Streamline startup procedures and shift schedules developed.
- Long-lead spares list and recommendations developed.
- Recruitments made.

Milestones FY 2021

- Start of operations.
- Full implementation of staffing.
- Support of OCP.
- Optimization of optical and thermal systems.
- Improvements and upgrades, including integration of VTF.
- Implement process for technical proposals and prioritization.
- Determine regular maintenaince cycles (e.g., CO_2 cleaning frequency).

3.7 DKIST Data Center

3.7.1 Introduction and Scope

The DKIST Data Center will provide storage, computational resources and services supporting DKIST science goals, while broadening community engagement, data use, and inquiry in solar physics. The DC will be the primary long-term repository of DKIST scientific data and will produce calibrated data sets while maintaining association to its measurement context. In addition, the DC will manage the full lifecycle of petabytes of raw and processed data and will enable advancement of solar science through search and discovery tools and the publication of open-source implementations of published algorithms.

A number of national and international high-resolution ground-based facilities have heretofore operated in PI mode. Historically, the raw data collected during an observing run, including all calibration data, have been simply provided to the PI on hard disk or tape. It has been the PI's responsibility to perform all necessary data processing, including calibrating the data. In some cases, the NSO and its partners have provided calibration and reduction software to aid in the data processing, but due to the limited assistance that could be provided, every user had to become an expert user of the facility's complex instrumentation.

When multiple imaging and spectro-polarimetric instruments are observing simultaneously, as is often the case at the DST and elsewhere, users had to master the many intrinsic details of instrument and facility calibrations in order to have a reasonable chance of achieving their scientific goals. Consequently, it often took many years of experience for a user to arrive at the necessary proficiency and, with limited support, build an individually owned tool box for performing calibrations. Furthermore, the carefully calibrated data have usually remained with the PI and are not generally available to the community for other scientific investigations. It follows then that science productivity has been limited due to the lack of any data handling support or any broader scheme to provide a unified collection of the high-resolution data.

The DKIST Operations model is designed to significantly increase science productivity by providing both support for service mode operations and a Data Center that facilitates access to the raw and processed data. The Data Center component of DKIST that is being developed during this Cooperative Agreement period encompasses several essential functional elements that address the needs of science to ingest, process, curate, and make available petabytes of high-resolution data to the entire heliophysics community.

The DC must be properly developed and integrated in order to have an operational capability that meets the needs of the community. The DKIST DC development efforts have and will continue to draw from previous experiences by other large-scale scientific projects, as well as new technologies developed for commercial big data projects.

The data produced by DKIST will be of much higher volume and significantly more complex in terms of product types, reduction steps, and dimensionality than synoptic data. In order to understand the magnitude of the task to develop operate the DKIST Data Center, it is useful to break the task into a set of goals that the DKIST DC should meet.

3.7.2 DKIST Data Center Goals

The DKIST DC goals, as distilled from the DKIST DC science requirements, can be broadly categorized as follows:

1. Receipt and ingest of summit data.
2. Receipt and ingest of ancillary data.
3. Storage and curation of scientifically relevant data.
   a. Roughly 6 PB of new science data every year.
4. Science data processing.
5. Search and discovery of DKIST produced data.
6. Data distribution.
7. Operations support.

In addition to these general goals, the design for the DKIST Data Center had to be within the following constraints:

1. The DKIST DC is being designed and built under operational funds, which are not as set as MREFC funds, and may fluctuate on a yearly basis.
2. The DKIST DC is being designed and built without the benefit of being integrated into the telescope system from the beginning. This manifests as possible changes to DKIST systems as they interface with the DC, or as contractual or programmatic changes with partners as the DC requests data that had not been envisioned previously.

3.7.3 Design Overview

3.7.3.1 Design Process

In order to meet the goals of the DKIST DC, the DC staff created and used a design process—called and documented as the Metahow Process—that combined science and system requirements with process flows to gain an understanding of the requirements in the context within which they would apply. This design process, as shown in Figure 3-20 and described in more detail in Table 3-5, has been followed throughout the DC development and will continue to be used during operations whenever new capabilities are to be developed.

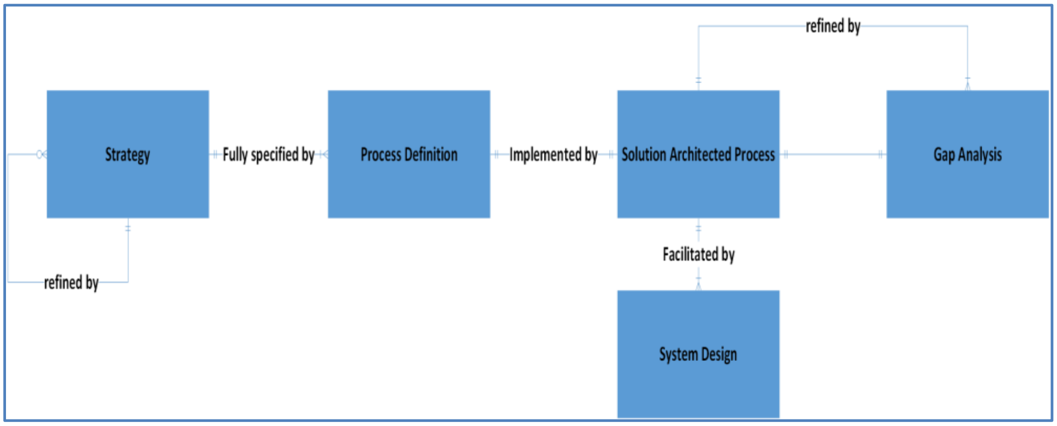


Figure 3-20. Metahow Process.

Table 3-5. Metahow Process Phases		
Phase	**Activities**	**Produced Artifacts**
Strategy	• Set Goals • Set Scope • Define Operational Approach	• Goals • Scope Diagram • Process Approaches • Key Performance Indicators • Key Concepts • Sticky Subjects
Process Definition	• Define Processes in Strategy Context • Define Necessary Support Processes • Identify Roles & Responsibilities • Identify Necessary Rules • Identify Necessary Data to Collect	• Processes • Roles & Responsibilities • Rules • Data Dictionary
Solution Architecture + Gap Analysis	• Integrate System Design to Process Definition to Create Solution Architected Processes • Define Necessary Solution Architected Support Processes • Augment Roles & Responsibilities Where Solution Architecture Requires • Augment Rules Where Solution Architecture Requires	• Solution Architected Processes • Augmented Roles & Responsibilities • Augmented Rules
System Design	• Define System Architecture to Support Process Definitions • Define Logical Data Models to Support System Design and Data Dictionary Needs	• System Architecture • Logical Data Models

3.7.3.2 Data Center Infrastructure Design

The Data Center is designed as a Service Oriented Architecture (SOA), also known as an Event Driven Architecture. This is an architecture wherein services are provided to the application components, through a publish-subscribe communications protocol. The basic principles of SOA make it an excellent design choice for the DKIST DC, given that it is a very long running project that is expected to change over its lifetime. SOA hallmarks are that it provides:

- Independence
  - from technologies.
  - between components and services.
- Maintainability.
- Testability.
- Extensibility.

- Scalability.
- Flexibility.

The services within the architecture are organized into Composite Applications (see Figure 3-21).

Some services may provide a service to only one Composite Application while another may provide a service to many. The services have been categorized into three classes of service:

- **System Management Services:** These services are depended upon by all others and serve to provision, configure and monitor the running system.
- **Shared Services:** These services are utilized by multiple Application Services and are primarily data stores and commercial off-the-shelf (COTS) products.
- **Application Services:** These services are designed as microservices which generally do just one thing. When grouped together, these services can fulfill the needs of a particular process.

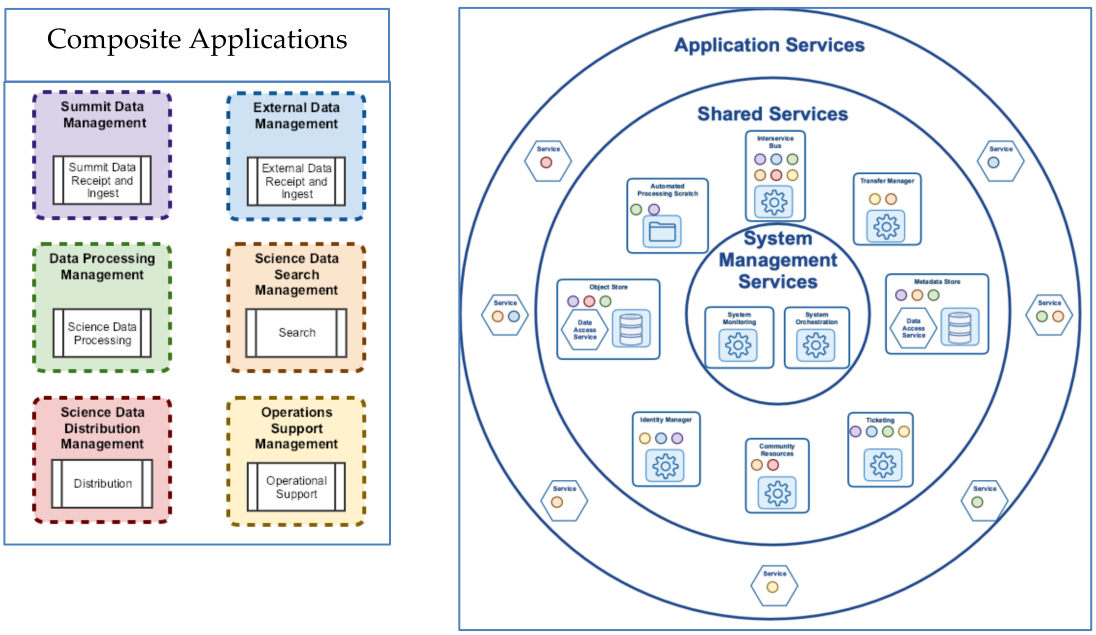


Figure 3-21. DKIST Data Center Architecture.

Grouping different services into Composite Applications, the software structure supporting the solution architected processes (defined above) takes form.

The SOA will allow DKIST personnel to evolve the capabilities of the DC over the coming years as the DKIST observatory ramps up to operational status, new requirements emerge, capabilities require modification, and new algorithms are developed and introduced.

3.7.3.3 Data Center Data Processing Pipelines

Given the expected daily volume and variety of data the DKIST observatory is expected to produce and transfer to the DC, one of the key exigencies of the DC design is that it be capable of automating the processing (calibration) of the raw data. This requires that the DC incorporate a capability to determine the completeness of a set of received data, assembling that set of data into a processing candidate, determining the set of implemented algorithms that will act upon that processing candidate, and set into motion the act of processing the data.

While the infrastructural aspects of the DC design were relatively straightforward, the automated processing of scientific data is fraught with risk that is rooted in:

- The multiplicity of modes, combinations, and wavelengths that the instrument package is capable of.
- The unknown amount of human intervention that will have to be performed in order to accomplish data processing.

The first of these will drive a multiplicity of calibration algorithms, dependent on the modes and regimes within which the instruments collected the data, while the second could conceivably overwhelm the small scientific staff planned for the DC.

In order to mitigate one of these risks, the DC is using the Airflow platform to author, schedule, and monitor data calibration workflows. These workflows are and will be built as Directed Acyclic Graphs (DAG) of tasks (see Figure 3-22). The tasks that make up a DAG are essentially discrete processing modules that can be rearranged and/or mixed and matched to create new processing pipelines. It is expected that this will reduce the amount of work required to "tweak" implemented algorithms to account for new instrument usage modes.

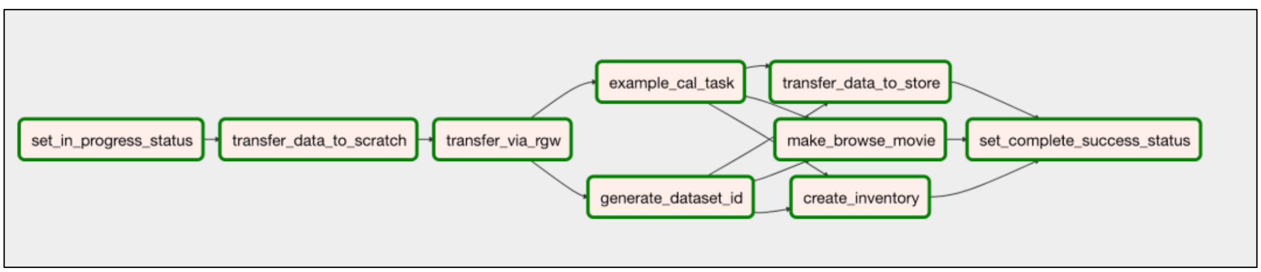


Figure 3-22. Example Direct Acyclic Graph (DAG).

3.7.4 Data Center Schedule and Current Status

Given that the DKIST Data Center is being developed with an operations funding stream that extends to FY 2024, the DKIST DC schedule is broken up into a development phase and an operations phase. It should be noted that the passage from the development phase to the operations phase won't be abrupt but instead will start when the infrastructure is complete and will ramp up into full operations as instruments come online and calibration algorithms are implemented and operationalized.

As of FY 2019, the Data Center had passed its Critical Design Review, which led to some design augmentation and implementation based on the review committee report. The Data Center has completed all the requirements at this time and is currently undergoing performance tests and tuning. There is still technical debt to be handled and there is a plan to address it in the upcoming year, after performance tests and acceptance test are completed. The Data Center has also developed and is ready to implement its Commissioning Plan with the rest of the Operations planning and scheduling.

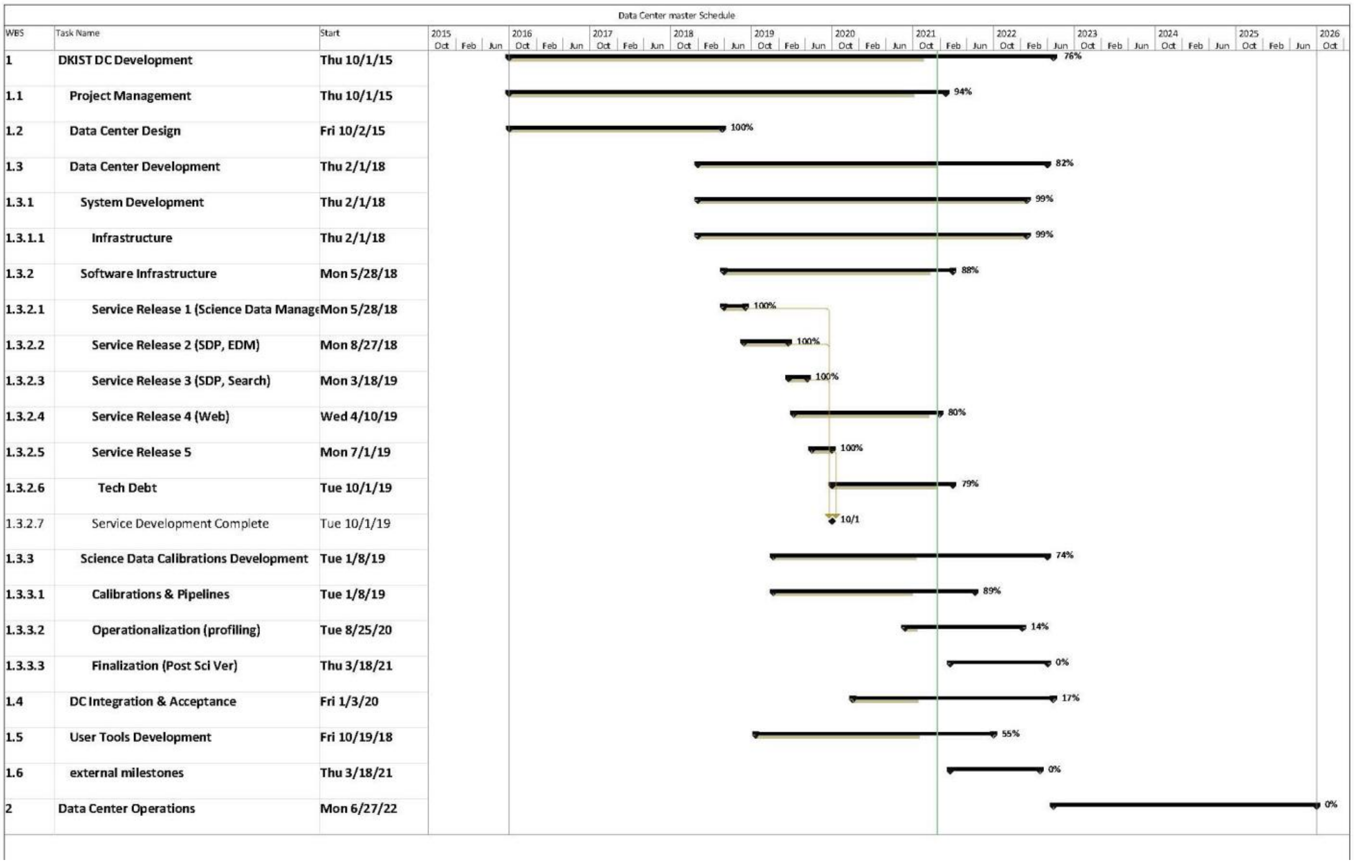


Figure 3-23. DKIST Data Center development schedule.

3.7.4.1 Development Schedule

The development phase of the DKIST DC project is shown in Figure 3-23.

Development of the Data Center infrastructure, which includes all of the hardware and software required to ingest, process, and disseminate data, is expected to be completed by the end of January 2021. The current schedule for the infrastructure has at least three months of total float to the expected time when DKIST will begin streaming data from at least some instruments. Initial calibration code for three instruments (VPI, ViSP, Cryo-NIRSP) is expected to be completed by September of 2021. Calibration code for the DL-NIRSP is expected to be started prior to the end of FY 2021. During this operational ramp-up time, defined as OCP, it is expected that issues will manifest themselves, software bugs will be discovered, and unthought of use cases will become apparent, requiring some undetermined mix of new rework and new work. This work and its attendant testing may extend the calibration development phase into FY 2022.

In addition to the development of the Data Center infrastructure, the DKIST DC project has also undertaken a separate but related effort to develop user tools that aim to facilitate the usage of the data that will be made available by the Data Center. The tools will be downloadable from the DKIST web site and will allow users to search data sets in multiple ways, slice data sets down to only those frames the users are interested in, and provide analysis tools to manipulate, stitch together mosaics, and otherwise visualize the data.

3.7.5 Development Status

Table 3-6 lists the tasks and milestones that have been completed as well as those that remain to be completed.

Table 3-6. DKIST Data Center Development Status

Activity	Time Interval	Status
Early Definition	2013 - 2014	Complete
PM Arrives; First Staff	2014	Complete
CA Budget Reprofiling	Late 2014 - Early 2015	Complete
Science & System Concept Definition	Late 2014 - Mid 2015	Complete
Operational Concept, Science Requirements	Mid 2015 - Mid 2016	Complete
Prototyping	2015 - 2018	Complete
System Concept, System Requirements	2016 – 2017	Complete
Conceptual Design, System Sizing	2016 - 2017	Complete
Conceptual Design Review	March 2017	Complete
Final Design & System Decomposition	2017 - 2018	Complete
Critical Design Review	Feb 2019	Complete
Infrastructure Implementation	2018 - 2020	Ongoing
Staff Augmentation	2018 – 2020	Complete
Data Portal Development	2019 -2021	In Process
Integration, performance and acceptance Tests	Sept 2020 -Feb 2021	In Process
Ramp to Full Operations (OCP)/Commissioning	Apr 2021 – May 2022	Not started
Begin Steady State Operations	June 22	Not started

The remaining development tasking for the DKIST DC is as follows:

- Software Development.
    - Complete Web Portal development.
    - Bug fixes and enhancements resulting from performance and acceptance tests.

- System Development.
    - Performance testing and tuning.
    - Acceptance testing.
    - Further yearly purchases of production hardware.

- Calibrations Development.
    - Implement, optimize construction (verification) codes.
    - Enhance calibration codes based on L1 data quality.
    - Integrate and automate pipelines within science data processing system.

3.7.6 Data Center Operations

As the DKIST Data Center transitions into operations—which under the current Cooperative Agreement with NSF extends through FY 2024—the focus will shift from development of the DKIST DC towards maintenance of the infrastructure and software developed during the previous few years. In general, DKIST Operations can be broken into several functions as defined and described in the following paragraphs.

3.7.6.1 DKIST DC Science Processing Operations

Science Processing Operations, which is described in this section, relates to all the tasking that the DC calibration engineers will undertake in order to generate calibrated data sets for public consumption.

3.7.6.1.1 Raw Data Calibration

The DKIST DC calibration engineers will be responsible for implementing new, and modifications to, algorithms generated by either science staff or internally by DC staff. New and/or modified algorithms are expected to be generated on a routine basis as instruments come online and are used in different modes.

In addition, it is expected that DC calibration engineers will be performing manual calibrations of raw data until enough is learned about the calibration steps and resulting data quality to fully automate the calibration runs. These manual runs will likely result in algorithm and/or code modifications meant to either make automation easier or improve quality of the resulting data sets.

3.7.6.1.2 Science Data Quality

The DKIST DC calibration engineers will be responsible for conceiving metrics that may be used to assess the quality of both raw as well as calibrated data sets with the goal of removing human intervention from the data calibration process to the maximum possible extent. The idea is that numerical quality metrics could be applied and tested starting with the raw data and continuing through the processing steps to assure that the calibration codes are generating the best possible calibrated data given the state of the art.

Data that do not meet specified quality metrics will be flagged for human quality checking in order to discern the reasons for the possible low quality of the data. The metrics as well as human intervention in the quality assessment, while geared to producing the highest possible quality of data, will over time also be instrumental in detecting algorithm anomalies, code bugs, instrument anomalies, and data trends that will be useful in maintaining the DKIST as a whole.

3.7.6.1.3 Implementation of User Feedback and New Features

The DKIST project will take advantage of opportunities to collect user feedback and provide information and training to the community. We envision organizing special DKIST information and training sessions at SPD, AAS and AGU meetings and various international astronomical conferences. A regular DKIST science workshop will be conducted during the CSP phase and likely beyond, which will provide an excellent opportunity for user feedback and information exchange with the Data Center. Furthermore, Data Center personnel will participate in ongoing data training workshops in the context of the Level-2 effort, reaching users early on. We will also encourage DKIST users to spend time in Boulder to work on their data in collaboration with DKIST staff. It is expected that the DKIST

DC scientists and calibration engineers will be heavily involved in the planning and production of these activities since they share responsibility for implementing new algorithms and/or features that have been proposed by community scientists. The SWG (during CSP phase) and the NSO Users' Committee will be consulted on the implementation of improvements and new features or products.

3.7.6.2 Technical Operations

Technical Operations, which is described in this section, relates to all the tasking that the DC systems and software personnel will undertake in order to maintain and augment the infrastructure necessary to facilitate the generation of calibrated data sets for public consumption.

3.7.6.2.1 System Maintenance

The DKIST DC systems engineers will be responsible for maintaining the physical infrastructure as well as the virtualized computing infrastructure that all DC software depends on to accomplish its mission. The maintenance activities include monitoring the storage and computing appliances for errors or degraded performance and acting to resolve these errors before they impact the overall function of the Data Center.

The systems engineers will also be responsible for monitoring the state of the services running on the servers and assuring that these services are working at peak capacity by either allocating/deallocation resources or throttling incoming/outgoing data and message streams to relive burdens on services that may be overwhelmed.

The systems engineers will be responsible for monitoring and maintaining the interface infrastructure that allows the DC to ingest raw and disseminate calibrated data. The engineers will monitor incoming and outgoing traffic to assure that data are being and received and delivered without loss, as well as to monitor the web servers to assure that no security related events are occurring on the web portals that would adversely affect the DC capability to serve data. In the event that such an occurrence is detected, the system engineers will inform the DKIST cybersecurity officer and take appropriate remedial actions in accordance with DKIST security policies.

Lastly, the systems engineers will be responsible for scheduling maintenance down times whereby infrastructure software updates may take place without disruption to the normal activities of the DC as they relate to data ingest and egest. These maintenance downtimes will be coordinated with DKIST telescope engineering maintenance downtimes so as to minimize impact to DKIST Operations as a whole.

3.7.6.2.2 Hardware Replacement and Capacity Augmentation

The DKIST DC systems engineer will be responsible for the hardware refresh evolutions of the DC Hardware. Currently, all production hardware is scheduled for replacement on a three-year cycle. The

systems engineers will be responsible for physically replacing the hardware and running the necessary scripts and/or software to make the new appliances ready for inclusion into the DKIST DC environment as processing or storage nodes. The systems engineers will also be responsible for repurposing the replaced appliances to either the development infrastructure or to a science sandbox environment where DKIST scientists may test out new algorithms for calibration or analysis.

Lastly, systems engineers will be responsible for detecting and replacing failed or failing hardware, either through the manufacturers warrantee process or by purchasing replacement parts as necessary to maintain the functioning of the DC infrastructure.

3.7.6.2.3 Software Maintenance

The DKIST DC software engineers will be responsible for maintaining the software infrastructure the DC depends on to accomplish its mission. The maintenance activities include prioritizing and acting upon technical debt generated by previous development activities, prioritizing and fixing bugs that were identified either through the continuous testing process, through Help Desk activities, whereby a user of the DKIST DC infrastructure submitted a ticket for a perceived issue, or through DC personnel assessment of logged errors or issues identified through system monitoring dashboards.

The software engineers will be responsible for vetting application logs to assure that services developed by the software team are behaving in a manner consistent with their design. Software engineers will submit work tickets for any perceived issue and run those tickets to ground to keep the system functioning at the level necessary to discharge the DKIST mission.

3.7.6.2.4 Software Improvement/Upgrade

The DKIST DC software engineers will be responsible for monitoring technology advances relative to the technologies in use by the DC, and for keeping those technologies up to date within the DC. These software evolutions may be implemented within the DC software stack as a simple update as part of a normal release or, if significant enough, during a scheduled maintenance period (downtime) mentioned above.

3.7.6.3 System Help Desk Support

The DKIST DC staff will be responsible for assisting in the triage, prioritizing, allocation, and resolution of tickets generated though the Operation Help Desk function.

3.7.6.4 Exploratory Development

The DKIST DC staff will be responsible for maintaining currencies in the technologies relevant to their fields, whether they be science, system, or software. Maintaining currency in this context requires that DC staff attend conference trade shows and attend training sessions in order to keep abreast of current trends. It is expected that maintaining currency will enable the DKIST DC operations staff to propose new technologies, algorithms, and/or systems that will elevate the productivity of the DC as well as improve quality of the services the DC provides, both in terms of data quality as well as responsiveness to community needs.

3.8 DKIST Instrument Program

3.8.1 Multi-Conjugate Adaptive Optics (MCAO) and DKIST

3.8.1.1 Upgrade of Classical Adaptive Optics to MCAO

The initial High-Order Adaptive Optics (HOAO) system of DKIST, which is scheduled to be integrated in spring of 2019, is a *classical adaptive optics* system and is based upon well-established techniques and scaled-up technologies, such as the first and pioneering high-order system in solar adaptive optics developed at the DST. Being a single conjugate or *classical* system, the DKIST HOAO deploys one deformable mirror (conjugate to the telescope aperture) to correct the light path and one unidirectional wavefront sensor to measure the adjustments needed. In such a system, the corrected field of view is typically limited to a patch on the of order 10 arcseconds in diameter around the viewing direction of the wavefront sensor. Scientifically interesting regions, however, can span dozens of arcseconds. Deployment of multiple deformable mirrors that are conjugate to different atmospheric altitudes in which strong turbulence occurs—a concept that became known as *Multi-Conjugate Adaptive Optics (MCAO)*—can widen the corrected field. While drafting the science requirements for the DKIST the science working group early on recognized the importance of pursuing this promising technology, which at the time (early 2000s) was not demonstrated to work for the solar application.

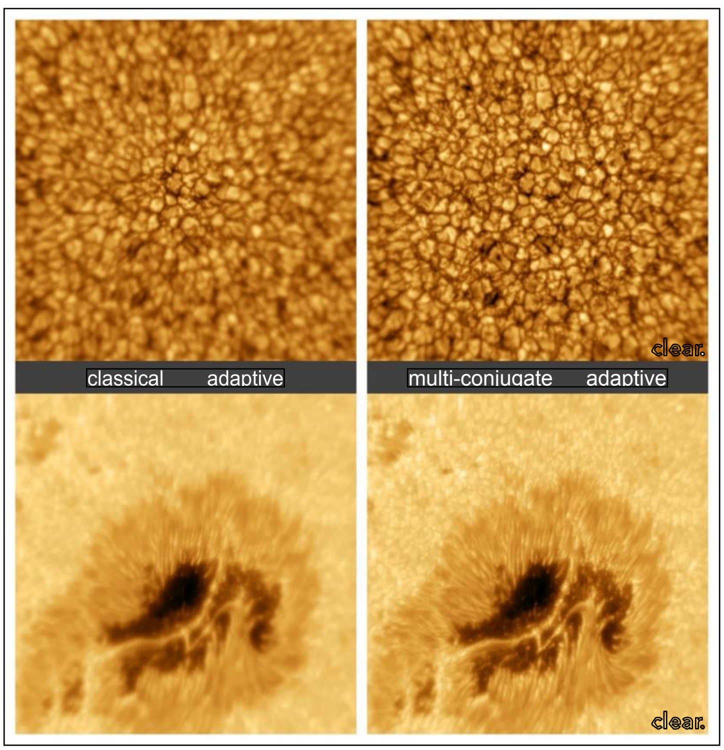


Figure 3-24. Solar granulation and a sunspot corrected for atmospheric turbulence by the adaptive optics system "Clear" (left) on the Goode Solar Telescope.

The ATST (DKIST) Science Requirements Document (SRD) states: "The ATST shall be designed in a way so that Multi-Conjugate Adaptive Optics (MCAO) can be implemented as soon as this technology has been successfully demonstrated on the Sun. A future ATST MCAO system shall achieve diffraction-limited resolution over a field of views of >1.5 arcmin."

In parallel to the ongoing construction of DKIST, NSO has pushed the development of multi-conjugate adaptive optics for solar observations with the goal of demonstrating the technology on smaller telescopes and to MCAO-upgrade DKIST as soon as possible. For over a decade, NSO has been collaborating with the German Kiepenheuer-Institute (KIS, now Leibniz-Institute for Solar Physics) and the New Jersey Institute of Technology (NJIT) in the development of MCAO. Under the leadership of NSO and funded by NSF grants, the experimental solar MCAO pathfinder, called *Clear*, was developed for NJIT's 1.6-meter Goode Solar Telescope (GST) located at the Big Bear Solar Observatory in Southern California (Figure 3-24).

Clear features three deformable mirrors and it was designed to be ultra flexible in order to enable experimental testing of various theoretical concepts. Simultaneously, DKIST developed the MCAO computer simulation tool, called *Blur*, which accounts for solar adaptive optics peculiarities, to predict the performance of MCAO for DKIST. In 2016, the *Clear* team was able, for the first time, to demonstrate under realistic observational conditions that multi-conjugate correction can indeed outperform classical correction in solar observations. The area of the corrected field of view that *Clear* provides with multi-conjugate correction is about nine times as large when compared to classical single-conjugate correction. *Clear* was also the first astronomical MCAO system to successfully use three deformable mirrors on the sky to accomplish corrections and to our best knowledge is still the only instrument of its kind. Following up on this success, the team has been continuously improving *Clear* to enhance its usage and to stabilize MCAO operations in preparation of this new technology for DKIST. In light of the excellent progress made with *Clear*, DKIST is now pursuing design and development of a much larger MCAO system for DKIST.

DKIST will be upgraded with a three deformable mirror MCAO system that will provide a corrected field of view of 60 arcsec in diameter, corresponding to the field of view of DKIST's Fabry-Perot spectropolarimeter "Visible Tunable Filter" (VTF). The fundamental principles for DKIST's MCAO follow closely the most successful configuration of *Clear*. Due to the sheer aperture size of DKIST, however, *Clear* cannot simply be scaled up for DKIST with currently available technology. In *Clear*, using a single CMOS detector for wavefront sensing and one high-performance computer is sufficient. For a similar system on DKIST, a much greater number of pixels is needed than there is currently available in fast and applicable image sensors. Furthermore, no current single computer is able to process the wavefront sensor data and to timely compute the control commands for the deformable mirrors in a DKIST-size MCAO system. Our concept therefore is to split up both the wavefront sensor and the computer system into a number of identical parallel subsystems. Some of the basic specifications are listed in Table 3-7 and compared against the *Clear* configuration.

3.8.1.2 Deformable Mirrors

DKIST's MCAO shall have three deformable mirrors, conjugate to 0, 4, and 11 km on the optical axis. The "M10" ("DM0") mirror is the conjugate to the purple deformable mirror in DKIST's initial HOAO and will be reused for MCAO. The additional two deformable mirrors shall replace the existing folding-flat mirrors "M9" and "M7". The original flat "M9" is about 400 mm in diameter while the footprint of 60 arcsec on this mirror is only about 300 mm. The deformable mirror "DM4" replacing "M9" will also be 400 mm in diameter with the central 300 mm actively controlled. The fabrication of "DM4km" is under contract with Northrop Grumman AOX Xinetics. A fabrication review is scheduled for December 2020. Its technology will be similar to the existing "DM0" made by the same company.

For the second deformable mirror "DM11km" that will replace "M7", a design and feasibility study was performed by Northrop Grumman AOX Xinetics and concluded in FY 2020. We are preparing the PDR design phase contract, which we expect to conduct within the first half of FY 2021. A final design and fabrication contract is expected to be led in the second half of FY 2021.

Table 3-7. Basic Specifications of 'Clear' and of DKIST's MCAO

	GST/Clear	DKIST (Preliminary)
Full telescope aperture diameter Wavefront sensing diameter	1.6 m 1.42 m	4.0 m 3.81 m
Number of deformable mirrors Conjugate heights Number of active actuators	3 0, 4, 8 km 241, 137, 177	Same 0, 4.34, 11.2 km 1600, ≈1600, ≈400
Wavefront sensor type	High-order, wide-field, Multi-directional, Correlating Shack-Hartmann	high-order, narrow-field, uni-directional correlating Shack-Hartmann
Number of wavefront sensor units	1	9
Subaperture diameter	8.8 cm	9.3 cm
Number of subapertures across	16	41
Number of subapertures per sensor	208	1313
Number of guide regions total	9 (3×3)	same
Number of guide regions per sensor Optical field of view per sensor	9 35×35 arcsec	1 12×12 arcsec
Field of view spanned by all sensors	35×35 arcsec	≈60 arcsec
Guide region field of view	12×12 arcsec	same
Pixel scale Correlation size	ca. 0.6 arcsec/px 20×20 px	same same
Number of correlation fields total Number of correlation fields per sensor	1872 1872	11817 1313
Wavelength range	512 – 537 nm	similar
Image sensor read-out size Number of image sensors Frame Rate	992×992 px 1 1568 fps	1000–1200 px square 9 2000 fps
Control matrix size CPUs Number of computers Cluster network	4 MB 2× Intel Xeon Gold 6154 1 n/a	≈380 MB 20 CPUs of same type 10 Infiniband EDR (100 Gbps)

The wavefront sensor system in DKIST's MCAO will be made of nine separate sensors and will replace the sensor of the HOAO. Each sensor will be similar to the existing HOAO wavefront sensor but points at different directions in the 60 arcsec field of view (Figure 3-25). Each sensor shall carry its own CMOS camera. We plan to contract the camera manufacturer in order to upgrade to one of their latest-generation commercial camera models with a fast streaming interface.

Each of the nine wavefront sensor cameras will be connected to a dedicated computer. The full computer system will be comprised of nine identical camera computers and one central master in a cluster network. One CPU in each camera computer will process the camera image and compute the image shifts in the Shack-Hartmann subapertures.

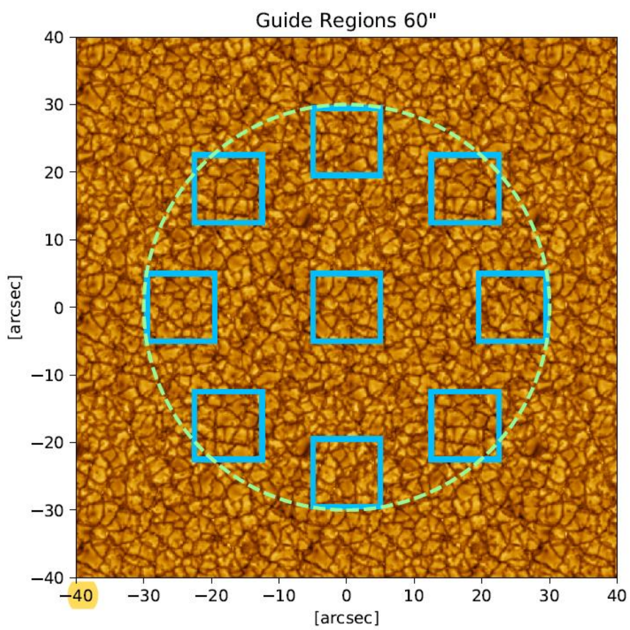


Figure 3-25. DKIST MCAO samples the 60" FOV with nine wavefront sensors .

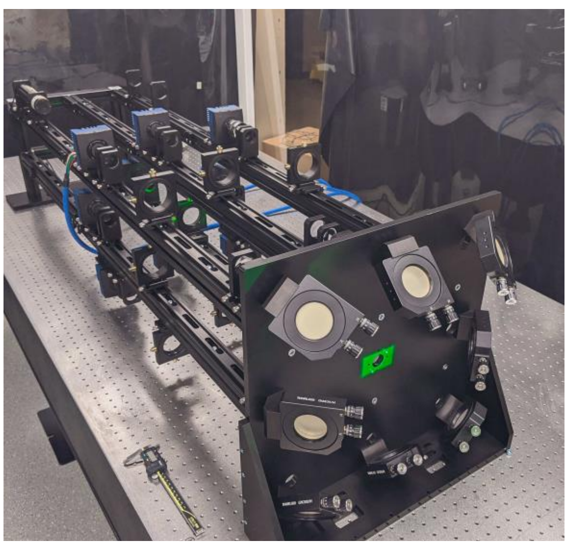


Figure 3-26. MCAO prototype assembled in the Boulder optics lab. Nine separate wavefront sensor units in a 3×3 grid.

The other CPU in each camera computer shall compute part of the control commands for the deformable mirrors from the wavefront slopes via vector-matrix multiplication. The control software will be based upon the software "KAOS Evo 2" used in *Clear*. Benchmarks performed on *Clear*'s existing computer indicate that current off-the-shelf computer hardware is capable of processing the wavefront slopes as well as the matrix-vector multiplication at the required speed.

For the modeling of the DKIST MCAO system and to predict and to optimize its performance, DKIST uses the solar simulation tool "*Blur*". *Blur* models the combined physical effects in the imaging of the solar surface through the turbulent atmosphere and all the components of the MCAO system, and then presents KAOS Evo 2 with a simulated wavefront sensor camera image. KAOS Evo 2 then analyzes this image, and computes the necessary corrections that need to be applied by the deformable mirrors—just as it would do in a real system—and sends the actuator commands out to *Blur,* that in turn updates the simulated wavefront sensor image starting the next control loop cycle. *Blur* realistically models the image distortion along with the image displacement and the image blur. This is a critical peculiarity in solar AO and is not included in most other AO simulation tools.

Figure 3-25 compares an example of a simulated observation with the DKIST HOAO and a preliminary version of the MCAO system.

Blur takes advantage of multi-core CPUs for parallel computations (task parallelism) and requires high performance computer hardware and continued software development and maintenance effort.

The DKIST MCAO system will be made of three major systems: the wavefront sensor system; the real-time control system; and the deformable mirror systems. Each system is multiple times more complex than the existing HOAO system in DKIST.

In FY 2020, we set up a prototype of the wavefront sensor system in the Boulder lab (Figure 3-26). This system comprises nine separate wavefront sensors, involving nine cameras, optics and a mechanical structure.

The structure was designed in-house using off-the-shelf components and parts that were fabricated by contractors. The optics and nine prototyping cameras were procured as well. This prototype has been assembled and has been used to evaluate the concept of this novel approach, in particular to verify vignetting effects that arise in this concept and to test the aligning strategy. A device to synchronize all nine cameras has been designed and fabricated. The control system shall be comprised of a cluster of 10 servers. We procured a server with the latest generation of AMD processors. After benchmarking and testing of this platform, we concluded with using those processors in the real-time controller. Options for the specific server models are being analyzed. The servers in the cluster shall be interconnected with 200 Gb/s Infiniband. The respective hardware was procured and benchmarking performed to verify the feasibility. The fabrication of the 4-km deformable mirror by Adaptive Optics Associates-Xinetics (AOA Xinetics) is progressing but delayed by the COVID-19 situation. A design study by AOA Xinetics for the 11-km deformable mirror was concluded showing that they potentially can fabricate this mirror to our specifications. The fabrication of nine high-speed cameras for the wavefront sensor system has been awarded to PCO.

The digital interface for the deformable mirror system has been specified and quotes of two potential suppliers are being reviewed.

Milestones FY 2021

- Develop detailed design requirements for the MCAO subsystems.
- Procure hardware for the real-time controller cluster and the digital interface.
- Delivery of the 4-km mirror in spring 2021.
- Design the mount for this mirror in DKIST.
- Set up contract for a preliminary design and fabrication of the 11-km mirror.
- Develop real-time control software for cluster hardware.
- Complete the evaluation of the wavefront sensor system.
- Finalize the design definition for the DKIST wavefront sensor system.

3.8.1.3 Numerical Simulations of DKIST MCAO Performance

In FY 2020, we performed numerical simulations of the DKIST multi-conjugate adaptive optics (MCAO) system's performance as part of the design process currently underway. The simulations are performed using *Blur*, our in-house adaptive optics simulation package, and KAOS, a state-of-the-art adaptive optics controller software. *Blur* performs a physical simulation of the MCAO system and atmosphere. While KAOS operates the MCAO loop by performing wavefront sensing and reconstruction, *Blur* interfaces with KAOS to provide a realistic simulated environment while KAOS operates as if it was controlling a real MCAO system.

The performance of the DKIST MCAO system was measured with numerical simulations to explore a range of design parameters:

- Different seeing strengths and atmospheric configurations.
- Two FOV correction sizes: 36" and 60"

- Dfferent degrees of correction, i.e., number of modes corrected, in each of the system's DMs.
- Different reconstruction techniques: plain least-squares and minimum-mean-square error reconstruction.

The MCAO performance results obtained have been used to determine technical requirements for the MCAO system, in particular to optimize the sky direction of the nine wavefront sensors and the design characteristics of the deformable mirrors.

We have also used MCAO numerical simulations to evaluate a new technology of deformable mirror proposed by AOA Xinetics: a Silicon Carbide mirror with actuators mounted parallel to the surface of the mirror, a surface parallel actuator (SPA) mirror. This SPA mirror would be used as the highest conjugated deformable mirror of the DKIST MCAO system, conjugated to a height of 11.2 km above the telescope. Due to the large physical size requirement of this mirror, a more traditional deformable mirror design with actuators mounted perpendicular to the mirror surface, a surface normal actuator (SNA) mirror, was deemed technically unfeasible. Numerical MCAO simulations with *Blur* and KAOS are an indispensable tool to evaluate the feasibility of using an SPA mirror in a solar MCAO system. Through numerical simulations, we have tested all of the SPA mirror designs proposed by AOA Xinetics to date and determined which designs are acceptable and meet our correction requirements. Additionally, we have discovered a potential problem with actuator saturation that may occur while operating an SPA mirror under normal conditions. We used numerical MCAO simulations to evaluate actuator saturation mitigation strategies: to measure efficacy and their effects on correction performance.

Milestones FY 2021

- Fine tune DKIST MCAO design parameters as the project progresses and the specifications of the components become better defined.
- Optimize correction strategies for the MCAO system.
- NSO is in talks with AOA Xinetics to start a preliminary design review phase for a SPA mirror. We will use MCAO simulations, among other tools, to evaluate the possible SPA designs proposed by AOA Xinetics.
- Explore the effects of a narrow FOV MCAO system configuration of around 30". The corrected footprint on the deformable mirrors shrinks with the FOV size, which means less actuators will be in play. We expect a possible reduction in correction, in particular for SPA mirrors.
- We will use numerical MCAO simulations to test a customized servo loop control that is necessary to mitigate possible excitation of resonant modes of an SPA mirror. The resonant frequencies of an SPA mirror are likely to be well within the bandwidth of the MCAO system.

3.9 Instrument Upgrades

The Daniel K. Inouye Solar Telescope incorporates five state-of-the-art instruments for observations of the solar atmosphere. In addition to replacement of technology lifecycle items, such as detectors and replacement of failing components (e.g., motors) there are opportunities for enhancing the capabilities of these instruments. The first-light set of DKIST instruments constitutes a considerable investment.

Upgrades and enhancements of capability of instruments, including software upgrades, are therefore a cost-effective way to extend the scientific viability and lifetime of instrumentation. Furthermore, due to budget constraints of the construction project, de-scopes had to be implemented for some first-light instruments. For example, the slit-jaw imager was removed from the VISP and the CRYO-NIRSP "cold" context viewer was de-scoped to a "warm" context imager with reduced IR performance. Re-gaining these capabilities during operations is a long-term objective.

Infrared detectors for DL-NIRSP and CRYO-NIRSP continue to be a big concern. There are currently no spares for these custom-built detector systems. To meet requirements of solar observations, the H2RG detectors have to be controlled in non-standard ways (e.g., fast frame rates). Many issues with the analog technology used to control these devices have been revealed during the development phase. Through vendor interactions throughout FY 202, we have determined that new IR detector technology that is now available and utilizes digital focal planes meets the challenging requirements, provides additional capability and is robust. Off-the-shelf controllers (frame grabbers) are available for this technology. However, lead times are long (~two years) and these devices are relatively expensive. In FY 2021, we plan to release an RFP for the fabrication of four-to-six infrared detector devices that would replace the current detectors used by DL-NIRSP and CRYO-NIRSP over the next two-and-a-half to three years.

We note that at this point pursuing the development and implementation of an entire second-generation instrument is not considered viable within the scope of this CSA within the boundaries of the CSA budget. One of the community's top priorities for a second-generation instrument is an infrared version of the VTF—an Infrared Tunable Filter (ITF). Using the VTF as a basis of estimate for the cost of an ITF is in the order of $15M. We continue to pursue partner-funding opportunities.

In the following, we describe upgrade and enhancement opportunities for each of the DKIST instruments, which will be prioritized with input from the community and pursued contingent on funding.

The **Visible Spectro-Polarimeter (ViSP)** is a triple-camera slit-based spectrograph with the capability to analyze the polarimetric properties of the light in the range of 380–900 nm. Its wavelength versatility is limited only by the number of order selecting filters in each arm and the ability to insert them into the beam.

Upgrade paths for the ViSP:

1. Near term: the instrument can be upgraded to include, for each camera arm, a motorized and automated order selection filter cassette. In addition to this, a mechanism has been preliminarily designed to hold additional filters, which can be procured to greatly increase the efficiency with which wavelengths can be selected and set up in each arm without having to enter the DKIST Coudé floor.
2. Mid/long term: the instrument can be upgraded with the existing spare Andor Balor 16 Megapixel cameras. These cameras will allow the ViSP to achieve the design field-of-view in the spatial direction and potentially allow access to a wider spectral bandpass. A redesign in particular of the camera arms and arm rail would be required to support the Andor Balor cameras.

3. Mid/long term: the instrument can be upgraded with an image slicer, allowing access to two-dimensional spatial information simultaneously to the spectral information. This will require a redesign of a large portion of the spectrograph part of the instrument.

The **Visible Broadband Imager (VBI)** is an interference filter-based imaging instrument with two cameras for high spatial and temporal resolution observations of photosphere, chromosphere and corona at fixed wavelengths in the range of 393–789 nm. It currently does not have polarimetric capabilities.

Upgrade paths for the VBI:

1. Near term: Each filter wheel in each arm of the VBI provides space for one additional interference filter. These filter wheel positions could be equipped with one additional interference filter in the blue arm, and one additional interference filter in the red arm. The choice of central wavelength and bandpass can be arbitrary as long as they are within the wavelength ranges of the blue and red arms (380-550 nm and 550-850 nm, respectively).
2. Mid term: One, or both arms of the VBI could be upgraded to obtain polarimetric capabilities. In particular such an upgrade in the blue arm would enhance DKIST scientific capabilities, as the DKIST VTF Instrument, also an imaging spectro-polarimeter, currently does not have the capability to observe between 390-525 nm.

The **Visible Tunable Filter (VTF)** is a Fabry-Perot-based imaging spectro-polarimeter capable of densely scanning a spectrum line sequentially while analyzing its polarimetric properties at the current wavelength step. It will observe the photosphere and chromosphere within a wavelength range of 525–850 nm at fixed wavelength diagnostics. At first light, the VTF will be delivered as a single etalon system with fixed wavelength interference filters as pre-filters, which will provide a narrow spectral window.

Upgrade paths for the VTF:

1. Near term: the VTF will be upgraded with a second Fabry-Perot etalon. This will allow a larger spectral window that the VTF will be able to scan and provide improved throughput performance, increasing the instrument's efficiency. The SWG requested this upgrade option with high priority. NSO/DKIST is pursuing the upgrade in partnership with the German instrument partner (KIS) developing the VTF. Development of the second etalon is in progress. The fabrication of the etalon plates has progressed well in FY20 and is expected to be completed in the first quarter of FY21. The VTF is expected to be upgraded to a dual etalon system in 2022.
2. Near term: the VTF can be upgraded to include additional interference filters as pre-filters to include more diagnostics for the solar atmosphere. Any spectral line within the range of 525–850 nm can be accessed with the VTF, and would only require the corresponding pre-filter.

The **Diffraction-Limited Near-Infrared Spectro-Polarimeter (DL-NIRSP)** is a three-camera fiber-fed IFU spectro-polarimeter capable of analyzing the spectral and polarimetric properties of the incoming light simultaneously within a two-dimensional field of view. Each camera arm corresponds to a particular wavelength range (500–900 nm, 900–1350 nm, 1350–1800 nm) and contains Dense Wavelength Division and Multiplexing (DWDM) filters that constrain both the diffraction order observed and the spectral bandwidth. These DWDM filter-central wavelengths and band-passes are centered on diagnostics that pertain to the solar photosphere, chromosphere and corona.

Upgrade paths for DL-NIRSP:

1. Near/mid term: the DL-NIRSP can be upgraded with additional DWDM filters pertaining to additional diagnostics of the solar atmosphere, enhancing the scientific versatility of the instrument.
2. Mid/long term: the DL-NIRSP can be upgraded by replacing the fiber-fed IFU with an image-slicer unit to improve throughput and performance above 1800 nm (Figure 3-27).

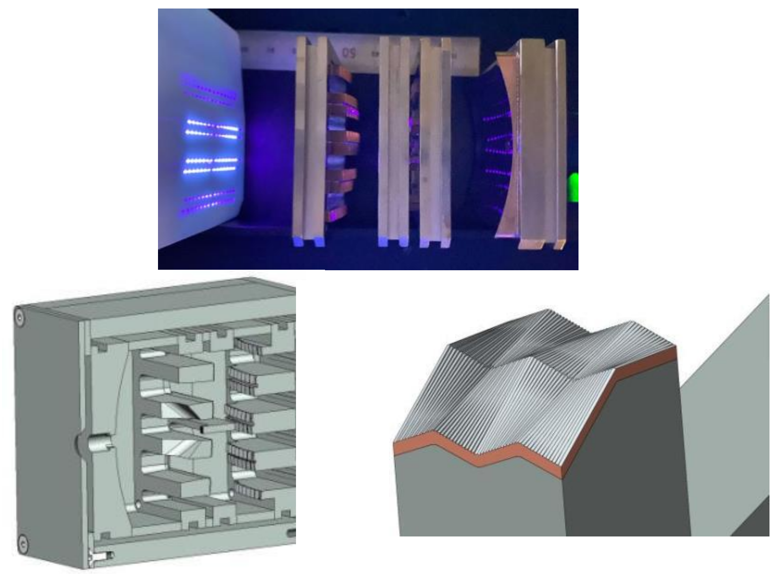


Figure 3-27. CAD models (top left, bottom) of image slicer upgrade option for DL-NIRSP. Image slicer design and evaluation unit produced by Canon. The unit has been tested and evaluated by H. Lin. A test report is available and demonstrated the viability of the design and implementation.

The **Cryogenic Near-Infrared Spectro-Polarimeter (Cryo-NIRSP)** consists of a cryogenic spectro-polarimeter and a cryogenic context imager capable of observations at near infrared wavelengths between 1000 – 5000 nm, primarily for chosen coronal diagnostics. Its science wavelengths are limited only by the number of available order-sorting filters. The instrument is located upstream of the adaptive optics system; light is fed into the instrument using a mirror that can be placed into the science beam.

Upgrade paths for the Cryo-NIRSP:

1. Near term: the Cryo-NIRSP can be upgraded by including more order-sorting filters in both the spectrograph and context imager dewars. This will enhance the instruments' scientific versatility. Several additional pre-filters were obtained in FY20.

   For the spectrograph:

   - 854 nm (Ca II polarization calibration of all DKIST instruments at a common wavelength).
   - 1077 nm (replacement of He I, Fe XIII that had one of the Fe XIII lines in the wings of the filter bandpass).
   - 1252 nm (S IX FIP effect, coordinated observations with Parker Solar Probe and Solar Orbiter).

- 1282 nm (H Paschen Beta, Stark effect to determine electric field strength and observation in hydrogen line).
- 2218 nm (Fe XII coronal temperature and density diagnostic, predicted coronal lines and several photospheric lines in the bandpass).
- 3028 nm (Mg VIII FIP effect and temperature diagnostic).

For the context imager:

- 1049.5 nm (continuum for background subtraction of narrowband images around 1 micron).
- 1281.8 nm (H Paschen Beta, context image in hydrogen line).
- 1079.8 nm (Fe XIII, also have context image in the second Iron line around 1.08 micron).

2. Mid term: the mirror that is inserted into the science beam can be replaced by a dichroic beamsplitter, allowing the instrument to operate simultaneously with all other DKIST first light instruments. This will enhance the ability to address more complex scientific use cases.
   - A successful proposal for supplemental funding was submitted to the NSF Windows on the Universe Multi-Messenger Astrophysics (WoU-MMA) program. The funds will be used in FY 2021 to implement this beam splitter.

3. Long term: the Cryo-NIRSP can be upgraded with a low-order adaptive optics system. This would increase the average output of high spatial resolution data since the frequency of diffraction-limited observations at infrared wavelengths will therefore be increased.
   - In FY 2021 we plan to perform initial concept studies for this upgrade.

3.10 Supporting Facilities

Figure 3-28. DKIST Science Support Center at Pukalani, Maui.

Facilities supporting the DKIST Operations include the DKIST Science Support Center (DSSC) on Maui, and instrument laboratory and a machine shop facility in Boulder. The telescope facility on the Haleakalā summit also includes machine shop capabilities that currently are used to support the construction effort but once DKIST is in operations will continue to support summit operations.

The approximately 13,000-sqft DSSC provides offices and work areas for the scientists and postdoctoral researchers (permanent and guest), non-site operations and engineering personnel and administrative staff not required to work at the summit on a day-to-day basis (Figure 3-28). The DSSC provides individual and shared office spaces. On average, 25 to 30 permanent and visiting staff will use the facility daily. Limited instrument lab and workshop space is provided. In addition to staff and visitor vehicles, facility vehicles for the DKIST facility will be staged in the parking lot of the DSSC.

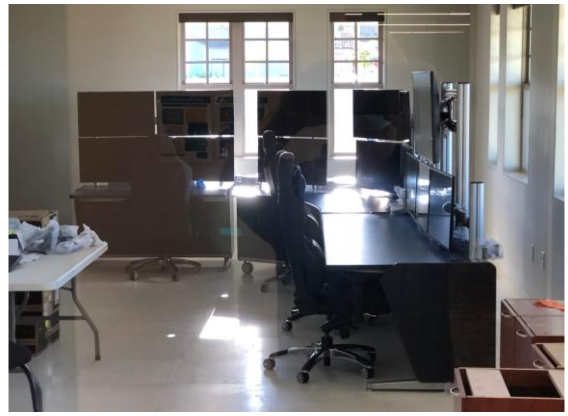


Figure 3-29. Remote control room at the Maui DSSC implemented in FY20.

In addition to office space, the DSSC supports specialized functions including hosting a remote operations control room where staff and visiting scientists can participate in and guide summit operations. A computer room supports limited initial data processing and other IT functions. The small instrument laboratory supports the maintenance and future upgrades to DKIST instrumentation. For example, the lab is currently used to host optics and polarimetry metrology equipment. In operations, the DSSC will serve as the off-summit center for day-to-day operations of DKIST. We note that remote ooperations functions from the DSSC will initially be limited to real-time monitoring of instrument performance and health, data quality assessment and resident astronomers providing guidance to the summit operations staff (Figure 3-29).

Machine Shop: In FY 2017, NSO relocated the machine shop equipment from Sunspot to a Boulder off-campus leased space. Early in the transition, NSO initiated discussions with LASP about co-locating our machines at their facilities in the LASP engineering building. Because of prevailing International Traffic in Arms Regulations (ITAR) at LASP and complex liability concerns, it was necessary to search for an off-campus machine shop location. NSO/AURA has leased 2,757 square feet of usable space at an industrial warehouse. DKIST Operations plans to utilize the machine shop to manufacture parts for new instrument developments. In the near term, the MCAO is likely to be the main development effort.

The NSO Headquarters building in Boulder houses the instrument lab facility. The lab is currently being used to develop new instruments such as the multi-conjugate adaptive optics system.

The DKIST construction project is renting warehouse space and lay-down area. During operations, suitable storage space is needed for the large mirror coating equipment. The currently leased warehouse is situated close to the Maui coastline in Wailuku and as such, with the prevailing trade winds, gets a high level of salt air mist. This leads to a higher level of corrosion for long-term storage compared to a more central or elevated location. DKIST rents a section of the commercial facility, which is not a separate area, but rather a fenced off area within a larger warehouse. Within the larger warehouse area, there is constant vehicle traffic (forklifts) and during normal daytime hours the loading bay doors to this facility are left open. Because of vehicular traffic and the open bay doors, cleanliness in the facility is poor and equipment stored in this facility for delivery to the summit generally needs significant cleaning. This would increase both the prep time for mirror coating activities and potentially reduce the lifetime for equipment that is not designed for long-term storage in such an environment. The warehouse leased by construction is predominately used for receiving containers, unloading, storing and redistribution of goods; there is constant traffic and access to the DKIST side of the facility for equipment is not always possible, so planning is required. For instance, if handling equipment is required for serving a system failure and is stored, their access to the equipment may not be same day. Furthermore, the facility is only accessible during normal hours; it may not be possible to access equipment required outside of normal hours or on the weekend.

For these reasons, the currently rented space is considered unsuitable for operation's needs. We are exploring options for leasing suitable storage space on Maui. We are also investigating options to buy or build a 6,000–7,000-sqft storage facility. An upfront investment to buy or build would result in significant cost savings over the lifetime of DKIST. In FY 2020, market studies were performed and cost estimates for a build option were developed.

3.11 Safety Program

3.11.1 Operations Plan Safety Program

Safety, health and environmental management is an integral part of our work from the initial planning and design, construction, commissioning, and finally the operation of DKIST. In the operations phase, as in all phases, management is responsible and held accountable for incorporating safety, health, and environmental policies, standards, rules, and principles into their work. We hold each other accountable for having safe designs and to work safely. We ensure adequate protection for our workers, the public, our equipment, and the environment. Safety management includes the DKIST Director, engineers, managers, and supervisors. The Safety officer reports directly to the DKIST Director and is located on Maui.

The original "DKIST Safety, Health and Environmental Program Plan" (SPEC-0086) and the other initial safety related plans were written for the project life and will be reviewed and revised as needed to ensure applicability for the operations and maintenance phases. We have developed specific safety element program plans during construction such as "Confined Space Entry Safety", "General Safety and Laboratory Policies", "General Shop Policies", "Lockout/Tagout Policy", "Expanded Work Hours Policy" et al. that are applicable to the operations phase. The Safety Committee and safety staff have been developing the detailed safety manual for the operations and maintenance phase while implementing sections incrementally as needed for the construction and IT&C phases. Also, several checklist procedures developed for IT&C, from construction task job hazard analysis, will transition to and be further evolved into the operational procedures.

These include the Coudé, mount and enclosure movement operational checklists and the night operations testing checklist. As the project structures its operations and management organization, the safety staff and management will ensure the processes and personnel continue to incorporate safety, health, and environmental policies, standards, rules, and principles into their work.

4 NSO INTEGRATED SYNOPTIC PROGRAM (NISP)

4.1 Introduction

The NSO Integrated Synoptic Program (NISP) was formed in July 2011, combining the Global Oscillation Network Group (GONG) and Synoptic Optical Long-term Investigations of the Sun (SOLIS) programs, increasing organizational efficiency, and yielding greater scientific synergy. Together, DKIST and NISP provide a complete view of solar phenomena on a range of spatial scales from tens of kilometers to the full disk, and on time scales from seconds to decades. In particular, NISP is a long-term and consistent source of synoptic solar physics that observes the Sun as a whole globe over solar-cycle time scales. While space missions, such as SOHO and SDO, also observe the entire solar disk, they cannot match the long-term coverage provided by NISP, which started in the mid-20th century with the advent of the sunspot drawings time series (1949–2004), Sac Peak flare patrol (late 1950s–early 2000s), H-alpha and Ca K line spectroheliograms (1965–2002), Kitt Peak magnetographs (the 40-channel magnetograph, 1970–1975; the 512-channel magnetograph, 1974–1993; and NASA/NSO Spectromagnetograph, 1993–2003), coronal images (since 1949), spectra, and Sun-as-star observations (1976–2015), and helioseismic observations (since 1995).

In addition to supporting solar magnetic field and helioseismology studies, NISP is a valuable source of data for national space weather, which has become increasingly important to national security and planning. The National Academy Decadal report on *Solar and Space Physics: A Science for a Technological Society (STS)* strongly supported synoptic solar physics (STS pp. S-6) as an essential component of the science needed for space weather. The White House has identified the development of improvements in forecasting space weather as a crucial activity, as shown by the October 2015 release of the National Space Weather Action Plan and the October 2016 Executive Order instructing the NSF, NASA, and other federal agencies to support space weather research. In March 2019, the US Administration updated the National Space Weather Strategy and Action Plan[1]. *The importance of ground-based observations in support of space weather forecast has been recently re-iterated by* the "Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow" (PROSWIFT) act signed into law on 21 October 2020[2].

NISP's current and future plans include active participation in these activities, in particular as it relates to the second key objective of the updated Space Weather Action Plan that states the importance of *"Developing and disseminating accurate and timely space weather characterization and forecasts."*

4.2 NISP Science

Blasts of hard radiation and energetic particles from violent solar activity can significantly affect planetary environments, including societal impacts on Earth (*NWNH*, pp. 28, 29, STS, pp. 3-1,7). Forecasting space weather and its effects is an overarching science theme of the STS Decadal Survey. NSO currently provides several synoptic solar measurements of violent eruptive activity at a cadence as fast as once per 20 seconds to understand the fundamental physics well enough to aid the development of a predictive capability and address some of the critical objectives of the Decadal Surveys.

[1] *https://www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf*
[2] *https://www.congress.gov/bill/116th-congress/senate-bill/881*

To a significant degree, NISP's scientific enterprise is intermingled with the business of acquiring and processing observations. NISP scientists use insights from their own research to monitor and improve the quality of the data and to suggest and develop new data products. Examples of such interplay include the GONG refurbishment, GONG magnetic zero-point improvements, photospheric and chromospheric full-disk vector field observations, and synoptic maps, Hα limb maps, mean polar field time series, helioseismic measurements of subsurface vorticity as a forecast of flare activity, and detection of active regions from far-side imaging.

In 2020, the GONG Network celebrated its 25th anniversary. In February 1995, the first of GONG instruments at El Teide Observatory, Canary Islands achieved its first light. Other sites followed in rapid succession, and in September 1995, after completion of the GONG instrument at Udaipur Solar Observatory in India, the full network became operational. Today, GONG continues to provide critical data to research and space weather forecasting communities.

In 2020, the Program experienced several emergencies, which required significant attention of the scientific, Data Center, and the engineering staff.

On January 1, 2020, the ephemerides that are required for processing the helioseismology data including far-side imaging had expired. The data processing pipeline stopped. The ephemerides tables were created about 15 years ago, and the information about their creation was lost. Several NISP scientists and NISP Data Center personnel formed an ad-hoc team to address the issue. A stop-gap solution was put in place within a few days, and at the end of January the team implemented a more permanent solution. The issue and the solution were tested and fully documented and by early March, it was full resolved.

Due to COVID-19 restrictions, GONG-El Teide was shut down from March 30 through April 12, 2020. Fortunately, due to the weather patterns, this shutdown did not result in a significant data loss (only about 23.9% duty cycle during this period).

On April 10, GONG-Udaipur went down because of failure of the power supply on the GPS receiver. Due to COVID-19 restrictions on travel and shipping, the failed components could not be replaced, and the instrument was shut down. On May 21, the team developed a workaround solution, and after some testing, on June 2 the instrument was turned on. In mid-September, after India reopened for shipping, the replacement GPS was shipped and installed.

On July 17, the camera at GONG-Big Bear began exhibiting intermittent image distortions. With time, the issue became more profound, and the instrument was turned off on August 25. An emergency preventive maintenance (PM) trip was made by two engineering staff during September 1–5, and the defective camera was replaced. At the end that PM trip, the only working air conditioning unit in the GONG shelter failed, and the instrument continued to be off until September 21, when the replacement AC unit was finally installed.

Despite this significant pressure on their time, the NISP scientific staff continued to work on several research projects, including the investigation of large-scale subphotospheric flows, studying the effect of uncertainties in magnetic field measurements on modeling of solar wind, investigating the effect of additional data from different viewing directions (Lagrange L* points). The work also included investigation of past extreme space weather events and solar rotation using historical data. NISP scientific staff also were involved in the development of science objectives and new instrument concepts for a future NASA over-the-pole SOLARIS mission.

The solar meridional flow is a crucial ingredient in modern dynamo theory. However, seismic estimation of the flow has been challenging, particularly in the deeper layers. Recent measurements using the time-distance technique and GONG data confirm a shallow return flow (Böning et al., 2017). Both the global and local helioseismology continue to track the evolution of large-scale flows, including the north-south meridional flow and the east-west zonal flow known as the torsional oscillation (Howe et al., 2018; Komm et al., 2018). These flows are intimately connected with the dynamo mechanism that produces the solar magnetic field and associated activity. For example, the timing of the zonal flow migration has proven to be a good indicator of the future behavior of sunspot activity. Observations from GONG (supplemented by the Michelson Doppler Imager (MDI) and Helioseismic and Magnetic Imager (HMI) data) suggested that the flow patterns of the next activity cycle, number 25, have reached 25 degrees latitude with a strength that is weaker than the current cycle but comparable to Cycle 23. Based on the position of this pattern, Howe et al. (2018) have speculated that the onset of widespread activity for Cycle 25 was most likely sometime in 2020. Indeed, the GONG magnetic field observations showed the onset of Cycle 25 in November–December 2020 (see Figure 4-1). At that time, small active regions with the magnetic orientation expected for Cycle 25 began emerging at the latitudes similar/slightly higher as compared with the previous Cycle 24. Early magnetic field observations from SOLIS/VSM indicated the strength of polar magnetic fields comparable to Cycle 24. Taken together, the strength of polar magnetic field and the latitude of early emergence of active regions suggest that solar Cycle 25 will be of equal strength or perhaps even slightly stronger than the previous Cycle 24.

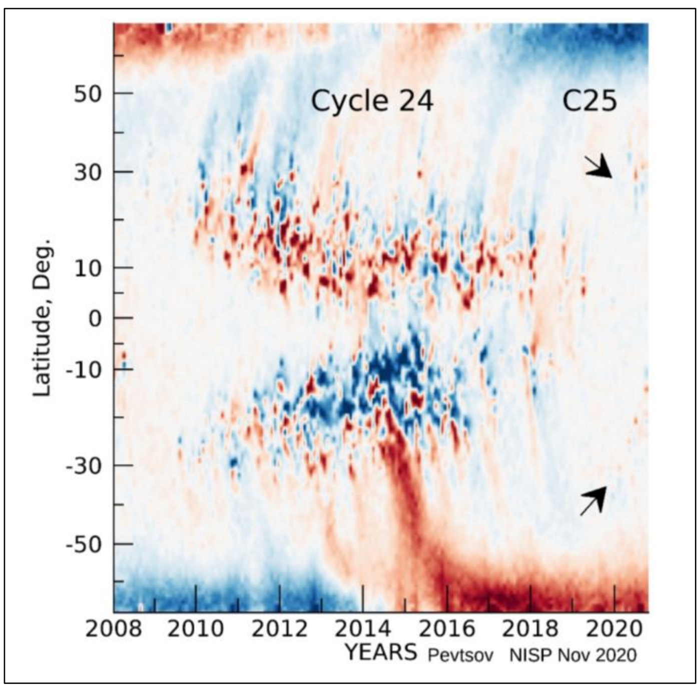


Figure 4-1. Time vs. solar latitude diagram of the radial component of the solar magnetic field (super-synoptic map or "butterfly" diagram) for Cycle 24 based on the (zero-point corrected) integer rotation synoptic maps from GONG. Blue/red show negative/positive polarity fields scaled between ±5 Gauss. Two black arrows mark approximate location of two latitudinal bands of Cycle 25. Data are acquired by GONG instruments operated by NISP/NSO/AURA/NSF. Adopted from Pevtsov et al. (2020).

During FY 2020, the Parker Solar Probe (PSP), launched by NASA on August 12, 2018, completed three closest approaches to the Sun: January 29, 2020 – Perihelion #4; June 7, 2020 – Perihelion #5; and September 27, 2020 – Perihelion #6. The PSP perihelion passages were supported by the coordinated observations organized in the framework of the Whole Heliosphere and Planetary Interactions (WHPI) initiative. GONG instruments provide regular observations of the photospheric magnetic fields (*https://whpi.hao.ucar.edu/whpi_groundbased.php#gong*), which were extensively used for modeling of magnetic connectivity between the solar surface to the PSP location in the heliosphere between Sun and Earth (Figure 4-2). The modeling community has repeatedly praised the zero-point-corrected GONG magnetograms as their preferred choice for modeling of the coronal and heliospheric magnetic fields. In addition, GONG magnetograms are used for comparison with early observations of magnetic fields from Solar Orbiter.

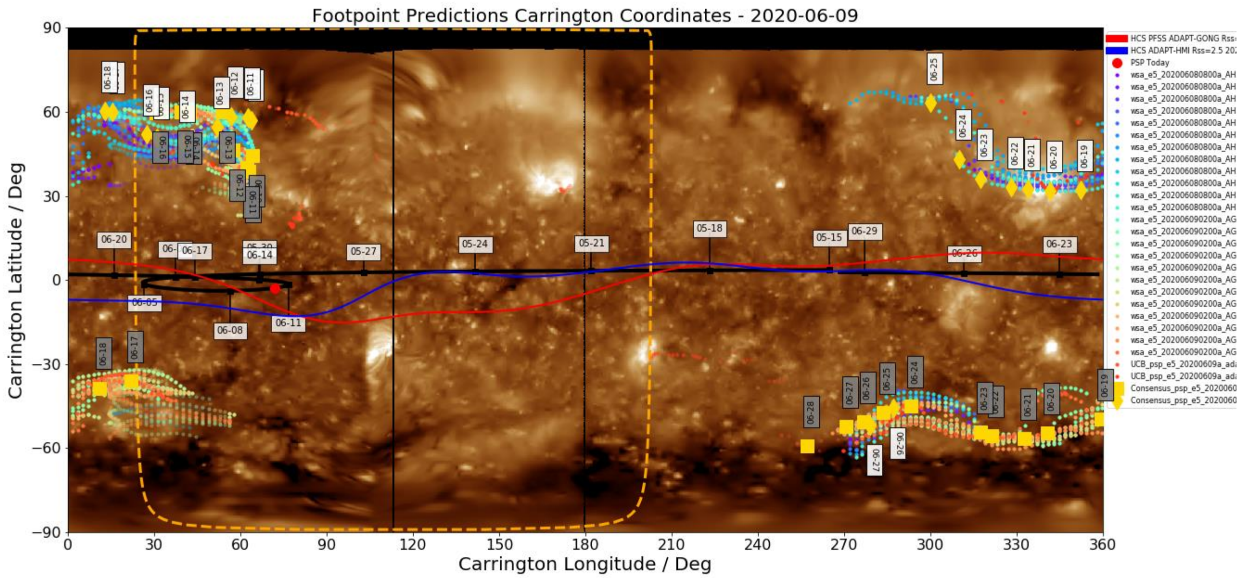


Figure 4-2. Synoptic map of coronal image with magnetic field footpoints connecting to PSP location as predicted by a different model for PSP Encounter 5. The diamonds with white date labels and squares with grey labels show ADAPT HMI and ADAPT GONG predictions, respectively. The smaller colored dots show the underlying ensemble. We observe a complete bifurcation in HMI and GONG ADAPT maps. GONG suggests PSP skirts along the underside and then crosses above the HCS on the outbound, just like Encounter 4. Both models are tracking a featureless polar coronal hole at the time they come on disk. Courtesy Robert C. Allen (APL/JHU).

A community effort to determine the internal solar rotation rate using all available helioseismic data is now underway. This effort will take advantage of GONG, the longest available helioseismology time series at just over 25 years, as well as data from other ground- and space-based experiments. This is an ongoing work, initiated by Michael Thompson, and helioseismologists from all over the world are involved in this effort. This project is now led by Joergen Christensen-Dalsgaard (Aarhus University, Denmark) with significant support from NSO. The project aims to produce a unique rotation profile that can be used without the biases present in existing ones. Solar rotation profiles were also studied by Bertello et al. (2020) using historical spectroheliogram observations in the Ca K spectral line at Mount Wilson Observatory from 1915–1985. Bertello et al. (2020) found no indication of any detectable periodicity in the temporal behavior of the orthogonalized rotation rate coefficients, suggesting that the global chromospheric dynamics have not changed during the 70 years investigated in this work. Also, no significant evidence was found of a hemispheric asymmetry in rotation rates.

Komm, Howe, and Hill (2020) studied the solar-cycle variation of subsurface zonal and meridional flows for both active and quiet solar regions for Solar Cycles 23 and 24, combining the data obtained with the MDI, GONG, and HMI programs. The subsurface flows associated with active and quiet regions were found to show the same variation with the solar cycle with alternating bands of faster- and slower-than-average zonal and meridional flows moving from mid-latitudes toward the equator during the course of a cycle. For Cycle 24, the average difference between the fast- and slow-flow amplitude is 9.5 ±0.5 ms^{-1} for the zonal flows and 7.0 ±0.4 ms^{-1} for the meridional flows of the quiet-region subset averaged over 2 to 12 Mm within ±30° latitude. For the active-region subset, the average difference is 10.4 ±0.9 ms^{-1} for the zonal flows and 9.3 ±0.7 ms^{-1} for the meridional flows. Subtracting the flows of the quiet-region subset from those of the active-region allowed the determination of active regions contribution to the long-term flow pattern. The resulting meridional flow associated with active regions has a maximum amplitude near 3.1 Mm and its amplitude decreases with depth. This implies that the converging flows attributed to active regions are a shallow-layer phenomenon. The results agree with Spruit (2003), who explained the torsional oscillations as a geostrophic flow, where the flow is driven by temperature variations near the surface due to the enhanced emission of radiation by the small-scale field. A shallow meridional flow would be a side-effect in this model.

Improving the scientific value of our data products has always been a priority for the NISP research and development group. During the past five years, several major projects were undertaken that address this goal. The Carrington rotation maps are the main drivers of coronal and heliospheric models and play a critical role in models designed for space weather prediction purposes. The widely adopted WSA-ENLIL solar wind prediction model, among other MHD models, is based on the Wang and Sheeley (1990) empirical relationship between the solar wind speed observed at 1 AU. It also employs the rate of magnetic flux tube expansion between the photosphere and the inner corona, where it is computed using coronal models (e.g., the current sheet source surface (CSSS) and the potential field source surface models). These models take the photospheric flux density synoptic maps as their inner boundary conditions to extrapolate the photospheric magnetic fields and to deduce the coronal and the heliospheric magnetic field configuration. These synoptic maps are among the most widely used of all solar magnetic data products and, therefore, the uncertainties in the model predictions that are caused by the uncertainties in the synoptic maps are worthy of study. However, an estimate of the uncertainties in the construction of these synoptic maps was not available until recently when Bertello et al. (2014) obtained the spatial standard deviation synoptic maps. Poduval, Bertello, and Petrie (2020) derived an estimate of uncertainties in the solar wind speed predicted at 1 AU by the CSSS model due to the uncertainties in the photospheric flux density synoptic maps. They also compared the coronal hole locations predicted by the models with the EUV synoptic maps obtained by the Sun Earth Connection Coronal and Heliospheric Investigation instruments on board the Solar TErrestrial RElations Observatory (STEREO). In order to quantify the extent of the uncertainties involved, the predicted speeds were compared with the OMNI solar wind data during the same period (taking the solar wind transit time into account) and obtained the root mean square error between them. The significance of the uncertainty estimate in the solar wind prediction was demonstrated for three Carrington rotations at three different phases of Solar Cycle 24: CR 2102 (3 – 30 October 2010); CR 2137 (14 May – 11 June 2013); and CR 2160 (1 – 28 February 2015), which fall within the extended minimum, the late-ascending, and the early-descending phases, respectively, of Solar Cycle 24.

NISP scientists continued investigating the possible benefits of full-disk magnetogram data observed from the Lagrange points L_1, L_5, L_4, and L_3 and combined with the Earth line-of-sight observations. Modeling the space weather conditions for a near-Earth environment depends on a proper representation of magnetic fields on the Sun. There are discussions in the community with respect to the value of observations taken at several Lagrange points (L_1-L_5) in the Sun-Earth system. Observations from a single (e.g., Earth/L_1) vantage point are insufficient to characterize rapid changes in magnetic field on the far side of the Sun. Nor can they represent well the magnetic fields near the solar poles. However, if the changes in sunspot activity were moderate, how well would our predictions of the solar wind based on a single viewing point work? How much improvement could we see by adding magnetograph observations from L_5, L_4, and even L_3? Pevtsov et al. (2020) used the results of their previous modeling (Petrie et al., 2019) to demonstrate the level of improvement in forecasting the properties of the solar wind at Earth made possible by using additional observations from different vantage points during a period of moderate evolution of sunspot activity. The approach also allows the evaluation of improvements to the solar wind forecast from adding a single observation from out-of-ecliptic spacecraft such as Solar Orbiter. These results are essential in the context of the space opportunities described in Section 4.3.2.

The connections between the use of NISP data and space weather research and forecasting are numerous. As one example, NISP personnel took part in a NASA-funded collaborative study with the University of Michigan aimed at implementing the vector field synoptic maps in state-of-the-art modeling. Early results are encouraging and demonstrate the improvements to space weather modeling when the vector field data are used instead of pseudo-radial field based on longitudinal magnetograms.

NISP has become an essential provider of solar data needed to predict space weather events, particularly to the Space Weather Prediction Center (SWPC) in Boulder. Funded by NOAA, SWPC uses GONG data as input to drive a predictive model of terrestrial geomagnetic storms. SWPC, recognizing the value of the data and the need for its availability, declared GONG data essential for national security during the 2013 and the 2019 Government shutdown episodes. A support agreement between NOAA and the NSF is now in place, with NOAA providing to SWPC for GONG operations about $800K annually for five years (ending in 2021, with additional supplement in FY 2021 of about $150K). NISP is working with SWPC to migrate GONG's space weather data-processing pipelines into SWPC's more robust infrastructural environment. NISP data are also used to drive models hosted by NASA's Community Coordinated Modeling Center (CCMC), and all NASA solar space missions use NISP data for context and supporting observations. Extending beyond space weather forecasting examples, the open software repository available in Github[3] that predicts the magnetic connectivity with the Sun of the Parker Solar Probe mission also has GONG as provider of the necessary boundary data. NISP personnel actively participate in the Committee on Space Research (COSPAR)-led International Space Weather Action Teams (ISWAT) initiative[4].

Helioseismology research is also helping space weather modeling. NISP produces estimates of the new active regions that emerge on the far side of the Sun that is turned away from the Earth (González Hernández, 2007). These far-side maps provide a signal of new active regions that will appear on the Earth-facing side up to two weeks in advance, as demonstrated in the appearance of the first naked eye sunspot of Cycle 25.[5] This tool has become a key ingredient in space weather forecasts, and its importance is increasing as the Solar TErrestrial RElations Observatory (STEREO) mission ages. Research at the US Air Force Research Laboratory (AFRL) has shown (Arge et al., 2013) that the assimilation of far-side data into the construction of synoptic magnetic field maps greatly improves the

[3] *https://github.com/dstansby/publication-code/tree/master/2019-psp-connection*.
[4] *https://www.iswat-cospar.org/*
[5] *https://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=301716*

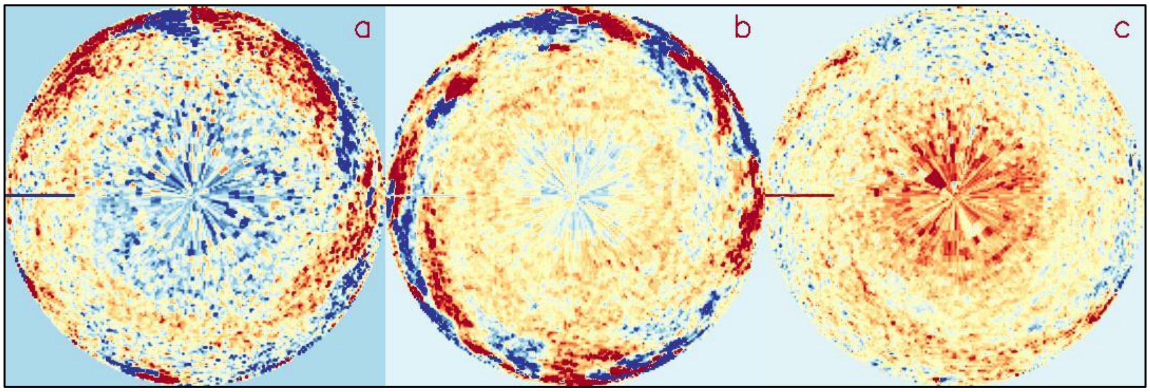


Figure 4-3. Polar view of the southern pole during (a) Jan.-Feb. 2004, CR2012; (b) Jan.-Feb 2013, CR2133; and (c) Jan. 2017, CR2186 using the synoptic maps of pseudo-radial magnetic field from VSM/SOLIS. Positive/negative polarities are shown as reddish/bluish halftones. The magnetograms are scaled between ±15 Gauss. The horizontal line in panels (a) and (c) corresponds to the beginning and end of the Carrington rotation. In this projection, the solar (Carrington) longitudes start at the horizontal line at 360 degrees and decrease in the clockwise direction to 0 degrees back at the horizontal line. The solar rotation as viewed from southern pole is in the counterclockwise direction. Since these images are constructed from the Carrington rotation maps with the mean solar rotation removed, only the component related to the differential rotation is present in these images. Adopted from Pevtsov et al (2020).

quality of the maps as it reduces errors at the edge of the map that would otherwise contain older data from 28 days earlier. A more recent investigation by Virtanen et al. (2021) has shown that including the magnetic flux of short-lived regions, which live long enough to be observed on the Earth-side hemisphere, improves the representation of polar magnetic field over a longer period of time. Over the last part of the current Cooperative Agreement, NISP plans to reinvigorate research on far-side techniques to improve the reliability and understanding of far-side imaging so that it can be used operationally.

Finally, an area where NISP data and research has marked community relevance is in the context of solar polar magnetism modeling. Although the visibility of solar poles from Earth is limited, synoptic observations such as SOLIS and GONG do allow investigation of the evolution of polar fields during their reversal (Figure 4-3). Virtanen et al. (2019) used the photospheric magnetic field measured by the NASA/NSO Spectromagnetograph, VSM/SOLIS, and HMI/SDO to determine the axial dipole moments of active regions and their contribution to solar polar fields. It was found that, typically, about 30% of active regions have opposite-sign axial moments in every cycle, often making more than
20% of the total axial dipole moment. It was shown that Cycle 24 differs from Cycles 21–23 in many ways. Cycle 24 is the only cycle where the northern butterfly wing includes more active regions than the southern wing, and where axial dipole moment of normal sign emerges on average later than opposite-signed axial dipole moment. The total axial dipole moment and even the average axial moment of active regions is smaller in Cycle 24 than in previous cycles.

The Sun's polar fields are globally influential. Polar coronal holes dominate the large-scale structure of the corona and channel most of the fast solar wind over most of the solar cycle. However, full-disk synoptic magnetographs lack the spatial resolution and sensitivity to resolve the facular-scale magnetic structure that dominates the high-latitude photospheric vector field. With a view to future applications with high-resolution DKIST data, high-resolution polar vector magnetic field measurements from *Hinode*/SOT-SP were combined with NISP synoptic magnetograms, and their effect on global coronal and modeling was studied (Petrie, 2017). When the polar fields were strongest, the representation of the polar fields was much improved. However, there remained a lack of sensitivity to smaller-scale structure, mainly when the polar field was weak overall, close to its polarity reversal. We anticipate much-improved sensitivity with DKIST. Better regular mapping of the polar fields is one of the main scientific drivers of the new network described in Section 4.3.2.

4.3 The NISP GONG Component

This year (2020) was the 25th anniversary of GONG operations. GONG is a six-site network, located in California, Hawaiʻi, Australia, India, Spain, and Chile, of automated telescopes circling the world to provide continuous observations of the Sun (Hill, 2018). Originally established purely to study the internal structure and dynamics of the Sun via helioseismology (i.e., the measurement of resonating acoustic waves that penetrate throughout the solar interior), GONG has since been upgraded to support critical space weather monitoring and modeling needs. Every minute, 1K × 1K 2.5-arcsec pixel velocity, intensity, and magnetic flux images are obtained in the photospheric Ni I 676.7 nm line. The network's duty cycle of approximately 90% enables continuous measurement of local and global helioseismic probes from just below the visible surface to nearly the center of the Sun. Highly sensitive magnetograms averaged over ten minutes, seismic images of the far side of the Sun, and 20-second cadence (when combined from network sites, 60-second cadence from each site) 2K × 2K Hα intensity images are produced in near real-time. GONG's magnetograms (Figure 4-4, right) are currently the highest cadence measurements of their type available and provide data for studies of rapid changes in the Sun's magnetic field. The Hα images (Figure 4-4, left) are an increasingly popular data product and have been used to study filaments, flares, and the oscillations of the chromosphere.

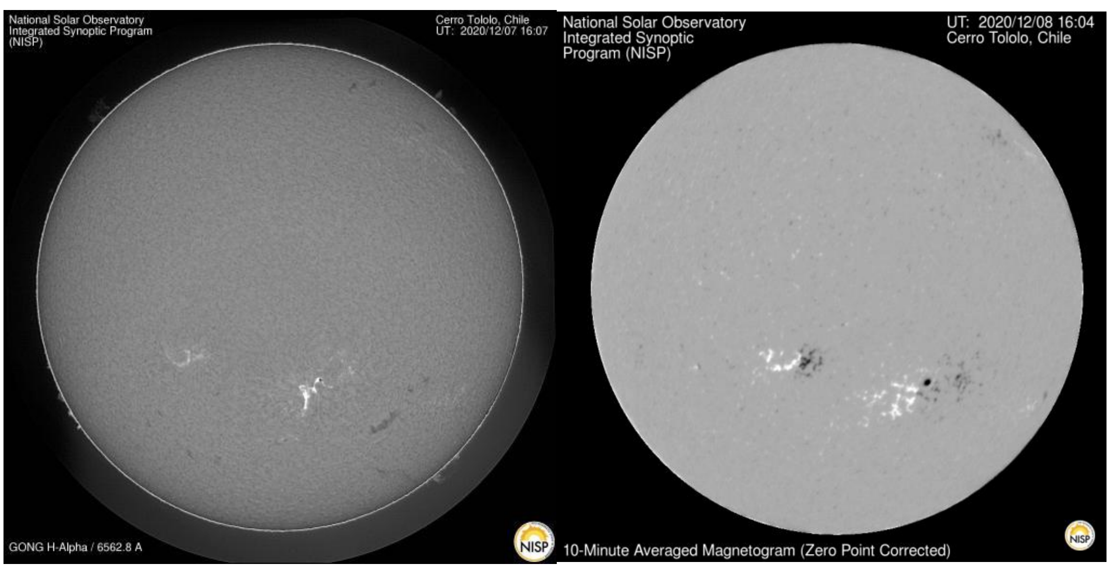


Figure 4-4. (left) Sample Hα image and (right) 10-minute average longitudinal magnetogram from Cerro Tololo at 16:07 UT on 8 December 2020, catching Hα two-ribbon flare (X-ray class C7.4) in new Cycle 25 active region AR 12790.

The effectiveness of a network is measured by its duty cycle, or fraction of clear-sky observing time achieved during some time period such as a day or month with a duty cycle of one indicating no missing data in that time period. The GONG sites were selected in 1990 after a world-wide survey of 15 locations using a simple instrument that measured the cloud cover at each site. GONG selected the six sites that produced the best network in terms of duty cycle. Note that a good duty cycle for a single site is 0.3, given the daily setting of the Sun and the weather. However, at any given time, two or three GONG sites are observing the Sun simultaneously, increasing the overall network coverage. This improved coverage is critical for the continuity in the measurements required by both helioseismology and space weather monitoring. Figure 4-5 shows a histogram and a cumulative histogram of the daily duty cycle of GONG from its deployment in 1995 through August 2020.

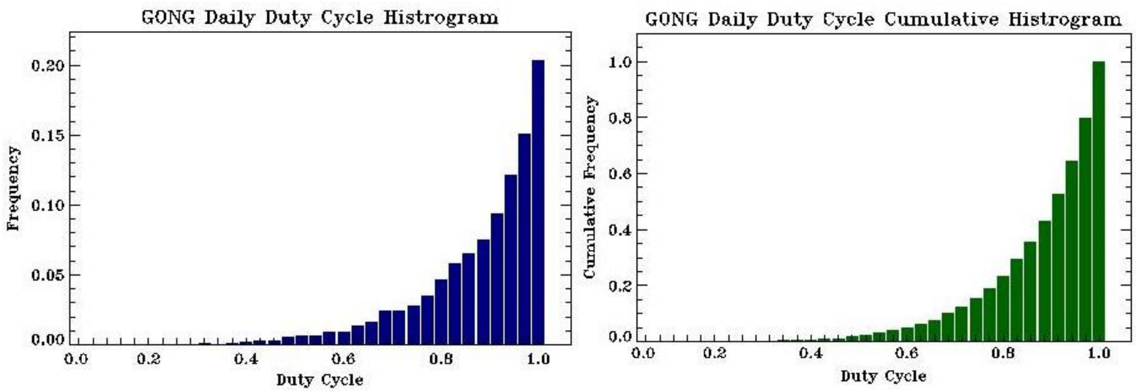


Figure 4-5. (left) Histogram and (right) cumulative histogram of the daily duty cycle of GONG from May 1995 through August 2020. The median daily duty cycle is 0.91. Courtesy K. Jain (NSO/NISP).

The mean daily duty cycle of GONG is 0.86 and the median is 0.91, which is less than what can be achieved by observations from L_1, but compares well with near-Earth orbit observatories impacted by eclipses.

The relocation of NISP from Tucson to Boulder included the GONG engineering site. The engineering site is now being used regularly for supporting remote site operations, new initiatives, and the GONG refurbishment project. At the end of FY 2020, the engineering site was used for testing the Compact Doppler Magnetograph (CDM), a compact and lightweight helioseismic and magnetic instrument developed in collaboration with the Southwest Research Institute (SwRI) for a future over-the-pole SOLARIS mission selected by NASA for Phase A.

In 2016, the NSF allocated $2.5M to NSO for a multi-year refurbishment of GONG so it can continue to operate for another 10 to 15 years while its replacement (see Section 4.6) is developed. In FY 2020, progress was made on the following GONG refurbishment tasks:

- Replacement of 1K × 1K cameras. Following the exhaustive testing of the candidate camera (Emergent HB-1800-S), the selection was made and 11 cameras have been ordered. The cameras are staged in the optical lab for acceptance testing (Figure 4-6). One "test" camera is undergoing a protective window replacement to mitigate camera fringes. Depending on the results, the plan is to send the remaining cameras for window replacement. Work is underway for a mechanical adaptation of the new camera to the rotating mount.
- Improved polarization modulators. Replacement modulators were respectively deployed at five sites prior to FY 2020. Deployment to the Cierra Tololo site was

delayed due to COVID-19 travel restrictions. Deployment will resume once the travel restrictions are lifted.

- Tunable Hα filters. Due to staff limitations, only limited progress on the tunable Hα filters was made in FY 2020. Tuning the existing Hα mica etalons by tilting is currently the most promising option.
- Data Center upgrades. Replacement data processing servers were acquired and are now in use.
- Refreshed workstations. Consolidated replacements for aging workstations that currently handle Hα and 676.7 nm observations separately have been acquired and are being configured and tested.
- Magnetic zero-point improvements. Analysis of the software responsible for zero-point correction in post-processing is underway. Mechanical design is 80% completed.
- Additional improvements. After brief shipping restrictions due to COVID-19, replacement site-maintenance kits and restocked spare components have been shipped to the remote sites.

Figure 4-6. Ten CCD cameras with logbooks for GONG refurbishment staged for acceptance tests in the optical lab at NSO in Boulder. Courtesy G. Card (NSO/NISP).

4.3.1 End-to-End GONG Calibration

Space weather and operations projects such as the AFRL's Air Force Data Assimilative Photospheric Flux Transport (ADAPT) and Wang-Sheeley-Arge (WSA) models rely heavily on accurate, consistent magnetic field measurements from the solar surface. These projects are hindered by well-known but poorly understood discrepancies between magnetograms from different solar telescopes (Riley et al., 2014). So far, efforts to characterize these discrepancies have been limited to direct comparisons between final data products and have not reached firm conclusions regarding what the correct measurement should be.

To solve this problem, NSO is making a concerted effort to model every step of a magnetogram observation. We begin with a known solar surface field from a magnetohydrodynamic (MHD) simulation. We first synthesize spectral line profiles using an in-house radiative transfer code, then we model every significant process undergone by the solar signal (thus the name end-to-end) during a magnetogram observation, including atmospheric seeing, the degradation of the signal by the instrumental limitations such as, for example, finite spatial and spectral resolution, and finally the effects of the data processing software pipelines that transform the solar polarization signal to magnetogram data via calibration, Stokes inversion, etc. The result is then compared to the original MHD data. The calibration resulting from the model will not merely consist of a single number but a function of the viewing angle of the pixel and of the nature of the region being observed (sunspot, plage, quiet Sun), as determined by the intensity of the pixel and the amount of polarization observed. The results of this modeling approach were published in a series of three papers by Plowman and Berger (2020) describing the theory of calibration and end-to-end simulation.

So far, we have a working model of a GONG magnetogram observation and are refining an example calibrated synoptic magnetogram and coronal field model. It is based on a software simulator developed for the magnetograph on-board Solar Orbiter (Blanco Rodriguez et al., 2018) that has been adapted to the GONG measurement concept. The final result of the project will be a unique model encapsulating a full understanding of the causes of disagreement between the magnetograms from GONG and other instruments. This approach will also facilitate the merge of GONG data and the magnetograms produced by the Solar Orbiter mission. Significantly improved performance of near real-time solar coronal and heliospheric models and space weather forecasting tools is anticipated. We will test the effect of the improvements to the data using the AFRL's ADAPT photospheric flux transport model and WSA solar wind prediction model as part of a NASA-funded grant led by the CU Boulder *Space Weather* Technology, Research and Education Center (SWx-TREC). At the second half of FY 2020, lessons learned from application of the GONG software simulator were extended to include the Helioseismic and Magnetic Imager (HMI) aboard the Solar Dynamics Observatory (SDO). NISP scientist Gordon Petrie is applying the simulator to address the 12- and 24-hour variations in HMI magnetic and Doppler measurements. This work continues into FY 2021.

4.3.2 Adapting the GONG Concept for Space Use: The Compact Doppler Magnetograph (CDM)

The Sun is a global and interconnected system whereby events happening at one location can create changes at another place separated by more than half of the solar circumference. Also, coronal mass ejections can be ejected from any solar longitude, which is frequently on the side of the Sun oriented away from the Earth and thus impossible to observe. For these reasons, there is currently considerable interest in providing solar observations from multiple viewpoints in interplanetary space. Three classes of viewpoints are typically considered: out-of-the-ecliptic heliocentric solar polar orbits (e.g., Ulysses, Solar Orbiter); heliocentric drifting orbits close to that of the Earth (e.g., STEREO); or at one of the Lagrange points where the gravitational fields of the Sun, Earth, and Moon create stable points in space around which spacecraft can orbit. One of these points, L_5, is located 60° eastward of the Earth's subsolar position, which makes it particularly attractive for space weather observations as it increases the warning time of activity by three days.

To help meet the need for light-weight solar instrumentation required for these multi-viewpoint missions, NSO/NISP has started a program to develop a compact and light-weight magnetograph for space applications, based on the GONG measurement principle. By replacing the Lyot prefilter and rotating half-wave plate with modern narrow-band filters and liquid-crystal variable retarders (LCVRs), and eliminating the camera rotator, in 2018, Sanjay Gosain and Jack Harvey have produced a design and a prototype with a mass of around 10 kg, compared to the range of 30 to 70 kg for currently flying space-borne magnetographs. This early development led to a close collaboration with the Southwest Research Institute (SwRI) to create a prototype Compact Doppler Magnetogram (CDM) for NASA's over-the-pole SOLARIS mission. The SOLARIS mission was selected by NASA for Phase A, and the instrument prototype is undergoing extensive testing, including solar observations at one of the GONG engineering sites in Boulder.

4.4 The NISP SOLIS Component

SOLIS has three main instruments: a Vector SpectroMagnetograph (VSM) capable of observing full-disk vector and line-of-sight magnetograms in the photosphere and chromosphere; a Full-Disk Patrol (FDP) imager; and an Integrated Sunlight Spectrometer (ISS) for observing high-resolution spectra of the Sun-as-a-star. The VSM produces 2K × 2K longitudinal and vector magnetograms constructed from full Stokes polarization spectra at a resolution of 200,000 in the Ca II 854.2 nm line and the Fe I 630.15/630.25 nm line pair. The FDP can take observations with a temporal cadence as short as 10 seconds in several spectral lines including Hα, Ca II K, He I 1083.0 nm, continuum (white light), and photospheric lines. The ISS observations are taken in nine spectral bands centered at the CN band 388.4 nm, Ca II H (396.8 nm), Ca II K (393.4 nm), C I 538.0 nm, Mn I 539.4 nm, Hα 656.3 nm, Ca II 854.2 nm, He I 1083.0 nm, and Na I 589.6 nm (D line) with a resolution of 300,000.

Until its relocation to Big Bear Solar Observatory (BBSO), the FDP operated with a temporary tunable filter. A new Visible Tunable Filter (VTF) was built and tested in May 2014; however, the installation was delayed by the relocation of SOLIS from Kitt Peak to Tucson, the repairs of resulting damage to the FDP, and the addition of the 854.2 nm vector modulator to the VSM. The VTF is slated for installation as part of bringing up SOLIS to full operations at BBSO in the second half of CY 2021 (see Figure 4-6, left). BBSO is an excellent site for the type of synoptic observations acquired by SOLIS; the daytime seeing is excellent and, perhaps more importantly, it is generally stable over the course of the day. BBSO also enjoys a clear daytime fraction of 71%, already hosts a GONG site, and has sufficient internet bandwidth to transfer SOLIS data to the NISP Data Center. BBSO is three hours east of the DKIST site, so SOLIS will be able to supply solar context observations to DKIST in advance of daily operations.

Figure 4-6. A satellite view (left) of Big Bear Solar Observatory in July 2019 showing the final location of SOLIS relative to the existing GONG site and BBSO's Goode Solar Telescope (GST). The NISP engineering team (right) starting the VSM instrument inspection at BBSO in May 2019.

The relocation of SOLIS to the Big Bear Solar Observatory was hampered by a tedious permitting process, which was not well understood at the beginning of the relocation process. Only by early 2019 were all structural, civil and architectural details for the new SOLIS site finally coordinated, and the project filed for land disturbance (grading) permit in late April 2019. In May 2019, NISP sent a technical and scientific team to BBSO to start instrument inspection and preparation (Figure 4-6, right). At that time, the SOLIS/VSM was made operational under an ambient-controlled tent after almost two years of no activity.

Construction activities have started in November 2019 with clearing the site of vegetation and foundation excavation (see Figure 4-7). Shortly after that, however, the construction activities were put on hold due to unexpected increase in costs resulting from miscalculations by the structural engineer of the soil properties and the volume of required excavation depth. The contractor was asked to provide a realistic (not to exceed) cost estimate. This estimate was provided in early February 2020, but the amount was significantly larger than the amount of allocated funding for SOLIS relocation. In late June 2020, NISP initiated a cost-benefit analysis for possible relocation of SOLIS to Sac Peak as an alternative site. Both NSF and NJIT were informed about this cost-benefit analysis. The overall situation was further complicated by newly imposed restrictions by the COVID-19 pandemic. The solution was found in late August, when NJIT offered to offset some of the construction costs by not charging the site fees for the construction year (FY 2021) and the first year of operations (FY 2022). The budget analysis of NISP FY 2021 funding, including carry forward, confirmed the availability of funds in the FY 2021 budget; however, funds need to be re-profiled from several existing budget lines including NISP Data Center hardware replacement. To formalize the NJIT in-kind contribution, an amendment to the AURA-NJIT SOLIS MOU was signed on November 16, 2020. Restarting the construction requires NSF approval, and the documents for securing that approval have been prepared. Once NSF approval is received, NISP will proceed with obtaining a construction contractor and the building permit. If the NSF approval and the building permitting are successful, the construction is scheduled to begin in Q1 FY 2021 and completed at the end of Q2 FY 2021. The entire SOLIS instrument suite will be fully operational by late Q3 FY 2021.

The original AURA-NJIT MOU, signed in June 2018, describes the long-term operations of SOLIS and GONG at BBSO. The agreement includes NISP funding a total of 1.5 FTEs at BBSO for the combined operation of the two facilities. Figure 4.8 shows the current construction schedule of SOLIS.

Figure 4-7. Left: Construction site preparation, vegetation removal (13 Nov. 2019) and Right: Foundation excavation at the future site of SOLIS. Courtesy G. Card (NSO/NISP).

ID	Task Name	Duration	Start	Finish	Predecessors
1	**SOLIS RELOCATION CONSTRUCTION & COMMISIONING**	**455 days**	**Mon 1/4/21**	**Fri 9/30/22**	
2	**Building Permits - Structural, Civil & Electrical**	**63 days**	**Mon 1/4/21**	**Wed 3/31/21**	
8	San Bernardino County - Contractor's Declaration Form Submission	1 day	Fri 3/12/21	Fri 3/12/21	7
10	**Phase 2 Construction - Foundations & CMU Walls**	**66 days**	**Thu 4/1/21**	**Thu 7/1/21**	
11	START SOLIS CONSTRUCTION	1 day	Thu 4/1/21	Thu 4/1/21	9
24	SOLIS FOUNDATION - END CONCRETE 14 DAY CURE	1 day	Mon 5/24/21	Mon 5/24/21	22
27	SOLIS FOUNDATION - END OF CMU WALL 14 DAY CURE	1 day	Fri 6/11/21	Fri 6/11/21	25
28	**Phase 2 Construction - Instrument Mounts & Steelwork**	**72 days**	**Thu 4/1/21**	**Fri 7/9/21**	
30	Fixator Core Drilling	2 days	Thu 6/17/21	Fri 6/18/21	29
38	**Phase 2 Construction - ISS Shelter Installation**	**79 days**	**Thu 4/1/21**	**Tue 7/20/21**	
46	ISS SHELTER INSTALLATION COMPLETE	1 day	Tue 7/20/21	Tue 7/20/21	45
47	**Phase 2 Construction - Roll-Off Canopy**	**97 days**	**Thu 4/1/21**	**Fri 8/13/21**	
53	STRUCTURAL CONSTRUCTION COMPLETE	1 day	Fri 8/13/21	Fri 8/13/21	52
54	**Phase 2 Construction - SOLIS Mount Installation**	**5 days**	**Mon 8/16/21**	**Fri 8/20/21**	
57	SOLIS MOUNT INSTALLATION COMPLETE	1 day	Fri 8/20/21	Fri 8/20/21	56
58	**Phase 2 Construction - Driveway & Parking Area**	**50 days**	**Thu 4/1/21**	**Wed 6/9/21**	
61	**Road Encroachment Permit Expires**	**1 day**	**Wed 6/9/21**	**Wed 6/9/21**	
62	**Phase 2 Construction - Support Equipment Shed**	**49 days**	**Tue 5/18/21**	**Fri 7/23/21**	
67	SUPPORT EQUIPMENT SHED COMPLETE	1 day	Fri 7/23/21	Fri 7/23/21	66
68	**Phase 2 Construction - Electrical**	**55 days**	**Mon 6/7/21**	**Fri 8/20/21**	
72	ELECTRICAL INSTALLATION COMPLETE	1 day	Fri 8/20/21	Fri 8/20/21	69,70,71
76	**NSO/AURA Site Inspection & Punch List Walk**	**5 days**	**Mon 8/30/21**	**Fri 9/3/21**	
78	Construction Punch List Closure	4 days	Tue 8/31/21	Fri 9/3/21	77
79	**OBTAIN OCCUPANCY PERMITS FROM SBC**	**15 days**	**Mon 9/6/21**	**Fri 9/24/21**	
81	OCCUPANCY PERMITS GRANTED	1 day	Fri 9/24/21	Fri 9/24/21	80
82	**SOLIS Utility Connections & Mounting of Instruments**	**66 days**	**Mon 8/2/21**	**Sat 10/30/21**	
94	Move VSM & Install on Mount - Crane Ops	1 day	Mon 10/18/21	Mon 10/18/21	
96	Move FDP & Install on Mount - Crane Ops	1 day	Tue 10/19/21	Tue 10/19/21	
99	**Instrument Startup & Recommissioning**	**240 days**	**Mon 11/1/21**	**Fri 9/30/22**	
105	**SOLIS FULLY OPERATIONAL**	**1 day**	**Fri 9/30/22**	**Fri 9/30/22**	

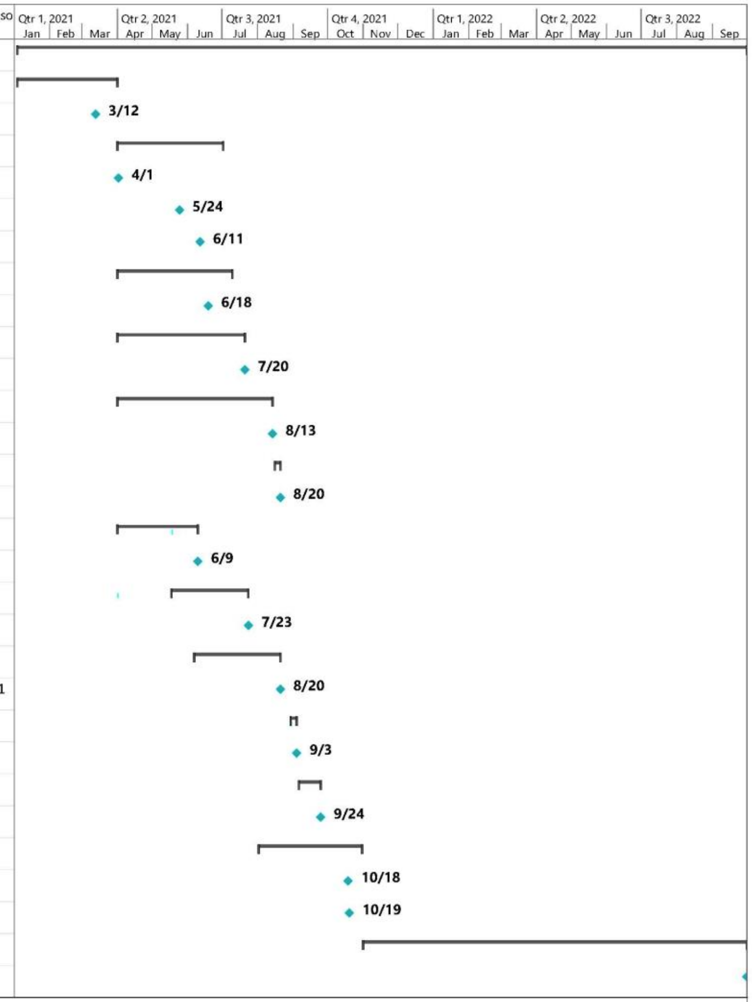


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Figure 4-8. SOLIS construction and recommissioning schedule.

4.5 NISP Data Center

Between SOLIS and GONG (post-refurbishment), NISP acquires (depending on the observing cadence of the SOLIS/FDP) approximately 370-470K of full-disk observations in an average month. That corresponds to 900-990K of raw data files that are transferred from the remote sites to the NISP Data Center (see Figure 4-9) located on the first floor of the SPSC Building. Those observations are processed, for both scientific research and space weather applications, through various pipelines resulting in more than a hundred derived data products (including intermediate ones that are primarily for internal purposes), or 5.5–7.4 TB of total data per month. About 50% of those files are publicly available within a minute of the observation being acquired, another 10% within 15 minutes, and 10% more within an hour. The remaining 30% are based on one to several months of observations and are provided accordingly. The NISP Data Center currently uses 4 FTEs, with two data center personnel working remotely from Tucson.

Figure 4-9. Photos of the NISP Data Center in Boulder showing the data processing server rack (left), the POD in the SPSC Data Center that houses all four NISP racks (middle), and the Isilon data storage cluster rack (right).

In addition to the direct observations already discussed, NISP provides the community with a wide variety of derived data products, including global helioseismic frequencies, localized subsurface velocity fields derived from helioseismic inversions, synoptic maps of the solar magnetic field, potential field-source surface extrapolations of the magnetic field in the corona, full-disk vector magnetic field maps produced from inversions of the Stokes profiles, and time series for spectral parameters as well as global and polar mean magnetic fluxes. Full Stokes profiles are also provided for each pixel of SOLIS/VSM full disk observations. These data products are essential for understanding the Sun, its activity cycle and related space weather, and even the impact of stellar activity on habitable planets.

Significant effort was invested over the past years towards improving the SOLIS/VSM 6302v vector data products. In addition to identifying and addressing a multi-faceted weak-field calibration problem, a more sophisticated scattered light correction was implemented, the inversion algorithm was modified to fit the filling factor simultaneously, and the disambiguation was adjusted to eliminate weak-field artifacts. The reprocessing of SOLIS/VSM 6302v vector observations, which includes two-line inversion based on both the 630.15 nm and 630.25 nm spectral lines, has been completed. Prior to June 2017, only the 630.25 nm line was used in the spectral line inversion. Synoptic maps of the photospheric vector magnetic field were re-created using two-line inversion results. Early analysis of SOLIS/VSM vector data shows that the photospheric magnetic field is in general non-radial. In the meridional plane, the field is inclined toward the equator, reflecting the dipolar structure of the solar magnetic field (Virtanen et al., 2019). SOLIS/VSM vector observations are noisy at high latitudes and suffer from the vantage point effect more than LOS observations. This is due to different noise properties in the LOS and transverse components of the magnetic field which need to be addressed in future (ngGONG) observations.

Supporting the migration of GONG's near real-time space weather data processing to NOAA/SWPC continues to be a significant emphasis. Many of the original deadlines were affected by the COVID-19 pandemic and are now extending to FY 2021. Currently, the planned switch-over period to NOAA/SWPC is March of 2021. The zero-point pipeline has been made more accessible to maintenance efforts with a development environment, and a couple pieces of its operations have been reconfigured for better stability. Work to be able to retroactively correct the zero-point bias of the past active period remains a future project.

GONG Hα data products originally were only intended for near real-time space weather monitoring purposes. As these data have become increasingly used for research purposes, corresponding emphasis is being placed on them as a curated archival data set. In previous years, Hα images were used to create a new data product—synoptic limb maps of prominences including their height. Initially, such maps were created for a limited number of years. Recently, the research community expressed interest in continuing this data product. This work will continue subject to priorities and the availability of resources.

NSO has a rich history of synoptic magnetic field measurements. In response to community feedback, ongoing efforts are underway to improve the calibration and data quality of early magnetograms acquired with legacy instrumentation on Kitt Peak. Once completed, these will be cross-calibrated with SOLIS/VSM observations and processed into synoptic maps using the same pipelines currently in use for GONG and SOLIS. Other recent and near-future data products include composite synoptic maps of the photospheric magnetic field, which combine radial field from vector and pseudo-radial from line-of-sight magnetograms; the synoptic maps of pseudo-radial magnetic field using observations of longitudinal magnetic field in Ca II 854.2 nm.

4.5.1 Access to NISP and Legacy NSO Data: The NSO Data Archives and the Virtual Solar Observatory

In addition to its dedicated telescopes, the NISP Data Center operates the NSO data archives that provide historical synoptic data sets to the research community. The archive includes the Kitt Peak Vacuum Telescope (KPVT) magnetograms and spectroheliograms, the Fourier Transform Spectrometer (FTS) interferograms and transformed spectra, the Sacramento Peak Evans Solar Facility (ESF) spectroheliograms and coronal scans, solar activity indices, and the NSO/Sac Peak Flare Patrol Hα data. Additional NISP archives comprise GONG and SOLIS instrument data sets. GONG data include full-disk magnetograms, Doppler velocity and intensity observations, local and global helioseismology products, and near-real-time Hα, far-side, and magnetic-field products.

The near-real-time products are automatically disseminated to various agencies, including the US Air Force 557th Weather Wing, AFRL, NOAA/SWPC, the United Kingdom Meterological Bureau, and NorthWest Research Associates (NWRA) for space weather prediction applications. The SOLIS data archive includes the VSM, ISS and FDP. On average, about 60 TB of combined NISP and NSO historical data are exported to over 1,300 users annually. We also host some non-NSO data sets such as the Mt. Wilson CaK synoptic maps, the AFRL Air Force Data Assimilative Photospheric flux Transport (ADAPT) magnetic field forecasts and forecasts of the F10.7-cm and EUV flux, the Improved Solar

Optical Observing Network (ISOON) products, and the CaK Kodaikanal observations. Other historical data are also available. The NISP Data Center also hosts the data sets from the Dunn Solar Telescope Service Mode observing runs. To improve the discoverability of NSO historical data, NISP adopted assigning DOI numbers to specific datasets. This is done in collaboration with the University Libraries of the University of Colorado Boulder. In FY 2020, a complete dataset of sunspot drawings recorded at NSO Sacramento Peak Observatory from late 1947 till mid-2004 has been digitized (Carrasco et al., 2020). The digitization also enabled identifying many early Sac Peak observers, and acknowledging their critical role in creating this important dataset. The dataset is available via DOI: 0.25668/9x5p-6d86, and accessible via the Historical Archive of Sunspot Observations (*http://haso.unex.es*).

Since May 1998, more than 5120 TB of science data files have been distributed to the user community. These figures exclude any NSO or NOIRLab staff members. The holdings of the NISP Data Center hosted a storage system that currently has over 1000 TB of on-line storage, and are currently accessible via custom-tailored Web-based search interfaces to relational databases, FTP and Web browsing, and through the Virtual Solar Observatory.

In order to further leverage the substantial national investment in solar physics, NSO has been participating in the development of the Virtual Solar Observatory since its inception. The VSO funds 0.5 FTE of the NISP Data Center personnel. The VSO comprises a collaborative, distributed solar-data archive and analysis system with access through the Web. The system has been accessed approximately 2.4 million times since Version 1.0 was released in December 2004. The current version provides access to more than 80 major solar instruments and 200 data sets along with a shopping cart mechanism for users to store and retrieve their search results. In addition to the graphical user interface (GUI), there is an interactive data language (IDL) and a Web service description language (WSDL) interface (e.g., for Python programmers). These two interfaces are now the major routes to data search and access through the VSO.

The overarching scientific goal of the VSO is to facilitate correlative solar physics studies using disparate and distributed data sets. Necessary related objectives are to improve the state of data archiving in the solar physics community; to develop systems, both technical and managerial; to adaptively include existing data sets, thereby providing a simple and easy path for the addition of new sets; and eventually to provide analysis tools to facilitate data mining and content-based data searches. None of this is possible without community support and participation. Thus, the solar physics community is actively involved in the planning and management of the Virtual Solar Observatory. None of the VSO funding comes from either NSO or the NSF; it is fully supported by NASA. For further information, see *http://vso.nso.edu/*. The VSO maintains a number of remote mirror nodes for the data set produced by NASA's Solar Dynamics Observatory mission with one of these nodes located at NSO. SDO downloads via the VSO are currently close to a 1 TB/day.

The VSO is developing a spatial search capability. Currently, almost all of the data accessible through the VSO are in the form of full-disk solar images. A spatial search capability will allow the user to locate data in a specific area on the Sun delineated by heliographic coordinates. The returned data could be either observations of a restricted area on the Sun, or full-disk data covering the required Carrington longitudes. The spatial search capability requires information on the location of the observational instruments, since current NASA missions such as STEREO are not located near the Earth. In addition to the spatial search capability, the VSO plans to provide access to another 6-12 data sets that have been requested to be included. Another active VSO development is an improved usage reporting system. This is challenging, given the distributed nature of the data sets and the access methods available to users.

4.6 Towards a Multi-Purpose Next-Generation Global Observatory Network Group (ngGONG)

NSO is promoting the definition and design of a new global network that replaces GONG and SOLIS as both facilities are more than 20 years old and as new requirements for synoptic solar observations arise. There is a strong interest for a new solar synoptic network within the space weather research and forecasting agencies in the US, but also within the broader international solar community. In the US, the NSO and the High Altitude Observatory (HAO) are jointly preparing a proposal to the NSF. This joint proposal describes a network that primarily aims at the research-driven scientific objectives common to SPRING. The NSO and HAO pre-proposal will be submitted to the NSF in January 2021. This new network, currently named ngGONG, will enable new research opportunities that build on decades-long observations from the NSO of the global Sun and its magnetic environment.

ngGONG builds on existing operational networks: GONG (the Global Oscillations Network Group); single-site observatories such as the HAO-operated Mauna-Loa coronagraph; and the NSF's Synoptic Optical Long-term Investigations of the Sun (SOLIS) instrument suite (also operated by NSO/NISP). While all these instruments are still capable of providing the critical observations for the research and space weather operations communities, they are aging rapidly. The science objectives now call for a new type of routine observations, which are not currently available from the existing facilities. Moreover, ngGONG will not only deliver proposed instruments, but also provide a long-term platform for future instruments upgrades, as new technology becomes available. There is a strong emergent interest from the international community (e.g., EU, Japan) in developing a new ground-based network of solar synoptic observations, which raises an opportunity for future international partnership in both construction and operation of ngGONG.

ngGONG will also enable the national research priority identified in Objective II of the National Space Weather Strategy and Action Plan and in the PROSWIFT (Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow) act signed into law on October 21, 2020.[6] That priority specifically directs NSF and other US Government Agencies to "*maintain and improve ground-based observations of the Sun*" and "*continue to provide space weather data through ground-based facilities*" by supporting basic research in solar and heliospheric physics. ngGONG fulfills that directive.

The proposed network consists of a set of six observing stations distributed around the world with an additional engineering site in Boulder, Colorado. The geographically-distributed stations are located at international sites with longitudes, weather patterns, and technical expertise specifically selected to provide nearly continuous observations of the Sun for many years. Each ngGONG station will have several solar instruments: infrared spectrograph-based spectropolarimeter; visible-infrared tunable filter spectropolarimeter; helioseismic doppler imager; and two coronagraphs: internally-occulted and

[6] *https://www.congress.gov/bill/116th-congress/senate-bill/881*

the emission-line coronagraph. This approach has been adequately demonstrated to succeed with existing solar networks, both research and operational.

Once operational, ngGONG will:

- Provide key (infrastructure for) measurements of the solar atmosphere and that drive the heliosphere (and space weather) as a single system and its evolution in time;
- Provide quantitative context for high-resolution and in-situ measurements of the heliosphere;
- Bridge solar and stellar research in the area of stellar activity and its consequences for habitability on planets around other stars; and
- Enable discoveries by providing data to future generations of scientists.

The science case for a new synoptic network is described in a white paper submitted to the ASTRO2020 Decadal survey.[7]

The proposed ngGONG has to provide as a novel prime target the boundary data needed to forecast the direction of the magnetic field of a CME when it interacts with the Earth's magnetosphere. This direction is a key determinant of the effectiveness of the CME in creating geomagnetic storms. But we lack routine forecast of the magnetic field of a propagating CME at 1 AU. GONG radial magnetic field measurements are used as boundary conditions to feed heliospheric models (such as the Wang–Sheeley–Arge/Enlil model) that produce a prediction of the relatively smooth solar wind conditions, including the magnetic field, at 1 AU. However, existing models that forecast CME properties, such as arrival time, do not predict magnetic field orientations partly because there are currently no suitable measurements of magnetic fields in the filaments that comprise the cores of CMEs. By regularly observing the He I 1083 nm spectral region, ngGONG will fill this gap and provide synoptic observations of the vector magnetic field observed in the central regions of coronal mass ejections. Such boundary data allow for data-driven propagation of magnetized CMEs in heliospheric models and predict the magnetic configuration at 1 AU and the potential geo-effectiveness of the solar storms. We note that models containing the physics of the propagation of flux ropes in the heliosphere already exist (Jin et al., 2017; Singh, 2018; Torok et al., 2018), but their boundary conditions are not based on observed properties of the pre-erupted filaments themselves. Currently, the CME field direction can only be determined by observations from satellites located at the L1 Lagrange point that indicates the field direction only 10-60 minutes before the CME arrival. ngGONG will provide significantly improved data-driven boundary conditions for models of the CME magnetic field and eventually increase early warnings from tens of minutes to tens of hours, the typical arrival time for a CME from the moment of ejection.

There are a number of additional scientific research directions in solar physics that motivate the desire for a new ground-based network. For example, there is a growing need for multi-wavelength measurements to provide observations of wave propagation and the vector magnetic field as a function of height in the solar atmosphere. We now know that inclined magnetic fields in the solar atmosphere convert the acoustic waves into various types of MHD modes and change the apparent phase of the waves, which produces incorrect inferences of the sub-surface structure below active regions (Gizon et al., 2009). Simultaneous helioseismic and magnetic observations would also improve understanding of

[7] https://arxiv.org/ftp/arxiv/papers/1903/1903.06944.pdf

acoustic wave propagation in the presence of magnetic fields, thus bringing us closer to forecasting the sub-photospheric properties of magnetic fields. Other topics that would benefit from multi-height observations of the vector magnetic field include the acceleration of the solar wind close to the Sun; the eruption mechanism of coronal mass ejections, the heating of the corona, magnetic reconnection processes, and the energy balance in the Sun's atmosphere. Our understanding of the generation, transport, and evolution of the solar magnetic fields would progress significantly with the availability of continuous long-term multi-wavelength observations.

These observations may also be used to improve the seismic mapping of the far-side surface of the Suns. The power of far-side imaging, first developed by NSO scientists (Lindsey and Braun, 2000), was recently demonstrated by NSO (Figure 4-10), predicting the emergence of a large active region about ten days before it rotated to the Earth-side view.[8] This powerful technique enables an early forecast of space weather—an invaluable feature for the space weather forecasters. ngGONG heliosesmic instruments will not only replace aging GONG facilities, but by employing a smaller pixel size and higher cadence would enable the derivation of subphotospheric flows at high (near polar) latitudes on the Sun. Such observations are critical for understanding the behavior of meridional circulation at high latitudes. Smaller pixel size and better signal to noise will significantly improve the detectability of active regions on far-side images, and enable better characterization of their flaring potential.

Figure 4-10. Naked eye sunspot (low-left, near the limb) predicted by NSO using far-side imaging technique rotates to visible hemisphere 10 days after its prediction. Right: Helioseismic mapping of the Sun's far-side hemisphere using uninterrupted observations from the NSF's GONG facility operated by NISP/NSO/AURA with additional support from NOAA. Dark red spot near the center depicts the presence of an active region.

4.6.1 ngGONG: Technical Aspects

The instrumentation in ngGONG cannot be a single device providing all observations but should instead comprise individual specialized instruments on a common pointing platform. This approach has several advantages:

- Fewer compromises for scientific requirements within a single instrument.
- More flexibility in funding and schedules.
- Ability to have different instrument suites at various sites to exploit specific observing conditions (e.g., coronal, radio observations).
- Lower initial costs – need pointing platform, infrastructure, and one instrument.

[8] https://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=301716

A phase for requirements consolidation and project definition (reaching Final Design status) of three years is envisioned before a construction proposal can be produced. In broad terms, Year 1 is devoted to carrying out delta conceptual design activities for the research requirements, starting the site characterization, carrying out trade studies, and researching vendor options. Year 2 will culminate in the PDR, and Year 3 will produce the FDR and a detailed construction proposal.

Instruments planned for the network include a Full-disk Telescope for Visible/IR, a Vector Spectropolarimeter IR, a Helioseismic Doppler Imager, a Full-Disk Imager, an Internally Occulted Coronagraph, an Emission-line Coronagraph, and a Sun as a star instrument. Of those, only the helioseismic doppler imager requires a duty cycle of better than 90%. Thus, all sites will be equipped with this instrument. The distribution of the other instruments between all six sites or only three sites will be determined based on science requirements and the trade-off studies produced during the design stage. Based on science requirements, additional/alternative sites may be considered, e.g. for coronal observations.

To provide the required increased magnetic field sensitivity, it is estimated that a telescope with a 50-cm aperture is required. The telescope will feed a stable optical bench that carries the infrared slit spectropolarimeter and the helioseismic Doppler imager. In addition to this telescope, the two coronagraphs each require direct sunlight. The visible-infrared tunable filter spectropolarimeter also needs a dedicated light feed because it overlaps in spectral range with the infrared slit spectropolarimeter. Those instruments will be mounted on the solar-pointed platform. We expect that the 50-cm telescope will be mounted on a pier at a height of 5 to 15 meters above the ground (Figure 4-11) in order to avoid as much as possible ground turbulence boundary layer; this height will be determined in a trade study with a ground-layer adaptive optics system.

Figure 4-11. A potential concept of an ngGONG site with the telescopes in a fully retractable dome (shown open here), a structural element containing the transfer optics, and the base building.

One aspect that remains to be developed is a high level of observatory automation. The philosophy of GONG was to make the hardware as robust as possible and implement only simple automation for acquiring the solar image, tracking, and then shutting down on a daily basis. Changes in weather conditions are simply ignored, unless severe conditions are expected. In that case, GONG relies on the staff of the remote sites to shut down and protect the instrument. Automation was also implemented at SOLIS during its last years of operations at Kitt Peak Observatory and in Tucson. The telescope operations and observations had the option of remote operations (which was used regularly), but for safety reasons, the opening of the telescope at the beginning of its observations and closure at the end of the day had to be supervised. However, for a robust and reliable operation of a large suite of sophisticated instruments, automation of the observatory is highly desirable.

The total volume of raw data produced at a single ngGONG site is currently estimated to be about 600 GB per day, dominated by the filter spectropolarimeter (300 GB/day), the helioseismic Doppler imager (120 GB/day) and the IR grating magnetograph (160 GB/day). Returning this data volume in real time (i.e., within the same observing window and at the same observing cadence) from a single site requires a sustained transfer rate of at least 150 Mbit/s, which may be challenging from some remote locations. We will thus have substantial computing power at each site, where the raw data will be processed to meet real time provision requirements. The larger data set will be ingested into a shared data center at NSO and HAO for subsequent processing and archiving. Careful consideration of trade-offs between latency, bandwidth, and distributed processing will be necessary for establishing a successful data management plan. These trade-off studies for a global distributed data-processing facility attached to an observing site with evolving conditions will contribute to the NSF Big Data idea.

While in FY 2020 the NISP Program made some very good progress on several projects, one needs to remember that it is currently stretched to its limits. External users may be mistaken in thinking that NSO base funding supports 8 scientific personnel. In fact, given the budget constraints, the program now only supports (less than) 3 science FTEs, and the Data Center personnel is down to less than 4 FTEs. Currently, all scientific personnel are partially or fully supported by the external grants. A heavy reliance on grants may have a positive outcome by bringing supplemental funding to the Program, but it also has a major drawback of diverting the scientific, programming, and engineering expertise to other, non-NISP projects.

5 NSO COMMUNITY SCIENCE PROGRAM (NCSP)

Traditionally, the NSO program has been conducted in two almost separate branches, with the synoptic part centered around GONG and SOLIS in NISP, and the high-resolution efforts centered initially around the DST, and now DKIST. With the move of NSO Headquarters to Boulder, the opportunity arose to foster a closer cooperation between the two traditional branches. With this goal in mind, the NSO has created a new branch: the NSO Community Science Program (NCSP). It leverages so-called Strategic Initiatives (SIs) to develop solutions to scientific problems that are of interest to the solar community. These strategic initiatives ideally integrate scientists from both NISP and DKIST sides, enhance the value of data produced by NSO facilities, and have a well-defined scope and time frame. The initiatives support NSO's overall mission in facilitating community understanding of the increasingly complex data produced by NSO facilities.

Creation of the first NCSP Strategic Initiative, for the development of DKIST Level-2 tools, production pipelines and community building, was made possible with the provision of a $3.5M Supplemental Funding Request to the Cooperative Agreement, which was extended with a second year in FY 2019 for the same amount. This Strategic Initiative is described in more detail below (Section 5.1).

5.1 DKIST Level-2 Data Efforts

While the DKIST Data Center is committed to producing Level-1, i.e., science ready telescope- and instrument-calibrated data from the telescope's instruments, our understanding of solar phenomena depends on accurate knowledge of physical quantities, such as the stratification of the magnetic fields, temperature, line-of-sight velocity, etc., that are not directly observable. Instead, these quantities can be derived from (Level-1 calibrated) observations of the solar spectrum and its state of polarization with so-called spectro-polarimetric inversions.

The first NCSP Strategic Initiative lays out a plan to help DKIST reach its full potential of innovative solar research. It does so, by adopting spectral inversion techniques for a wide variety of solar spectral features, stemming from the relatively cool and dense photosphere, the hotter and more rarified chromosphere, as well as the very hot and tenuous outermost layer of the solar corona. In the initiative, we describe a three-tiered approach, each including close collaborations with the US Community, from universities to research centers. Included in this approach are:

- Data Products Initiative: Identify a limited, but generally relevant, set of Level-2 data products that NSO will generate and distribute through the DKIST Data Center. These Level-2 data products will correspond to specific, well-defined observing modes of selected DKIST instruments. The NSO will strive to make these tools efficient in dealing with large volumes of data, and intuitive enough for a large fraction of the community to take part in. However, the effort will concentrate first at NSO. This initiative will also establish the hardware capabilities at the NSO to provide support for the inversions described here.
- University Focused Initiative: Establish a graduate student support program for US universities with existing solar research faculty. The series of Critical Science Plan (CSP) Workshops has demonstrated a clear desire of the US university solar community to receive training and guidance in the generation of various Level-2 data products. This program will combine both the interest of the local faculty members and of existing DKIST Science Use Cases (SUCs) contained in the CSP. This effort will grow the workforce able to run the

inversions in scientifically competitive ways. It will also provide—to the extent possible—hardware capabilities for the inversions required by the graduate students' research.

- Community Oriented Initiative: Establish a series of visiting programs and data-training workshops that help guide the DKIST solar community—as defined by their participation in the CSP—in the effective use of the spectral inversion tools and providing them with the knowledge and skills to handle ground-based data (as opposed to space-based data, to which the majority of the US community is currently accustomed). This initiative should include fostering an understanding of the capabilities and limitations of the inversion tools so that the community can confidently apply them to a broader number of data sets than what we are targeting in the first initiative.

Sections 5.1.1 through 5.1.3 describe each of these initiatives in more detail.

5.1.1 Routine Inversion Pipeline Development

Given the large volume and great variety of spectro-polarimetric data the DKIST and its instruments will produce, it is impossible to invert each and every data set. Instead, an analysis of the existing Science Use Case in the JIRA CSP database indicates that a large fraction of these programs will benefit if the DKIST Data Center delivers the following limited set of standardized Level-2 data products:

1. NLTE inversions produced by the code DeSIRe of the Fe I 6301/6302 Å line pair and the Ca II 8542 and 8498 Å lines observed simultaneously in three separate channels of the ViSP instrument with full Stokes polarimetry. These inversions will provide the temperature, electronic pressure, LOS velocity and vector magnetic field over a height range that includes both the photosphere and the chromosphere. The Level-2 data will only provide the physical parameters at the node heights used in the inversion algorithm. We will also distribute, auxiliary code to provide the appropriate interpolation for intermediate heights.

2. He 10830 Å full Stokes polarimetry observed with any of the configurations of DL-NIRSP inverted with the publicly available Hazel2 inversion code. These inversions provide access to the physical conditions prevailing in the layers where the neutral Helium atoms reside, mostly in the chromosphere, but often reaching out to coronal heights. We are considering inverting both on-disk and off-limb data.

3. Vector magnetograms and Dopplergrams from the VTF Ca II 8542 Å images. This Level-2 data product is not based on inversions but uses the simple weak-field approximation for the magnetic field (Landi Degl'Innocenti, 1994) and a gaussian fit to the core of Stokes I profile for the LOS velocity. The prevailing weak magnetic fields in the chromosphere and the large Doppler width of this spectral line make this approximation perfectly suitable to apply to the VTF data with a relatively low computational effort.

4. Basic coronal parameters from single-line full Stokes spectro-polarimetry. Spectral lines candidates for this type of analysis are Fe XIII 1074.7 nm, Si X 1430 nm, Si IX 3925 nm, and perhaps He I 1083 nm. Except for the Si IX line, which can only be observed with Cryo-NIRSP, all of these lines are accessible with both the Cryo-NIRSP and the DL-NIRSP. The proposed analysis consists of three main products: 1) Gaussian fit to the Stokes I profiles providing peak intensities, thermal and non-thermal doppler broadenings, and LOS velocities; 2) the azimuth of the magnetic field vector projected on the plane of the sky

using the standard derivation from the ratio of Stokes Q and U; and 3) the LOS magnetic field strength from the weak field approximation and/or Eq (14) of Plowman (2014) that includes the effect of atomic alignment. The DKIST Level-2 initiative will consider other, more elaborated, coronal data products (such as the permitted/forbidden line pair technique of Dima et al., 2016) but their feasibility can only be ascertained after some example data have been acquired with the Cryo-NIRSP instrument.

The supplemental funding request for Level-2 data products included funds to purchase two 1296 core class compute clusters, one in each budgeted year, to implement the pipelines for the standard products outlined above and execute the necessary inversions. Both of these have been purchased. In agreement with the CU Boulder High-Performance Computing Facility (HPCF), they will be managed by HPCF at no cost to NSO. Figure 5-1 shows the first cluster that was installed in April 2019 in the CU HPCF condo.

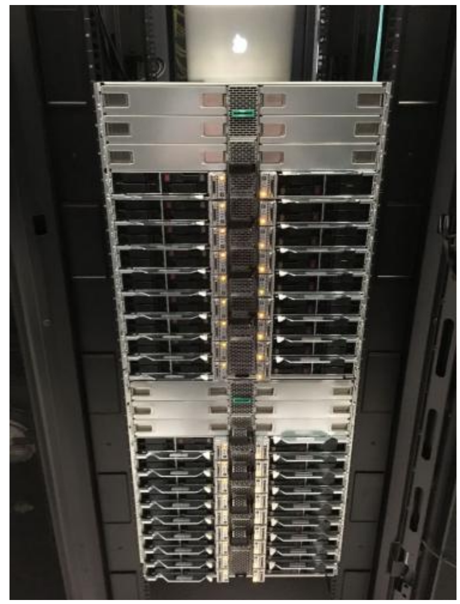


Figure 5-1. One rack of the first DKIST Level-2 1296 Core Cluster (36 nodes of 18 x 2 cores with Xeon 6150 2.7 Ghz processors, 192 Gb/node, interconnected with Infiniband).

A first draft of a specifications document, DKIST SPEC_0230, has been written, detailing the requirements for the Level-2 data analysis effort. The document has two main goals, first to inform potential users of Level-2 data products of the employed methodology for the standard data products outlined above and the required instrument configuration for automatic inversion from Level 1 to Level 2 data. In addition, the required steps in the software pipelines are outlined. Secondly, the requirement document spells out what the expected data rates are for each of the four standard products and what FITS header keywords will be polled to determine if data sets are amenable to inversion and what keywords will be required to guide the inversion process. Finally, the document lists the keywords that will describe the inverted data to enable ingestion into the DKIST Data Center, help potential users understand the inverted data and document the employed versions of the inversion software. Figure 5-2 shows an example of the data flow from DKIST proposal to Level-2 data.

5.1.2 DKIST Ambassador Program

In the late 1970s, the US solar community led pioneering work in the field of spectro-polarimetric inversions (Auer, Heasley and House, 1977; Skumanich and Lites, 1987). Subsequent developments, however, took place mostly in the European solar community, including the creation of several robust codes for general spectro-polarimetric inversions. Today, knowledge as well as experience in performing inversions is lacking in the US community, which, moreover, has also traditionally been more concentrated on employing data from space-based instruments.

To prepare the US community for the intricacies of using data obtained with ground-based instruments like those that are part of DKIST, and train the community in the use of spectral inversions, the NSO

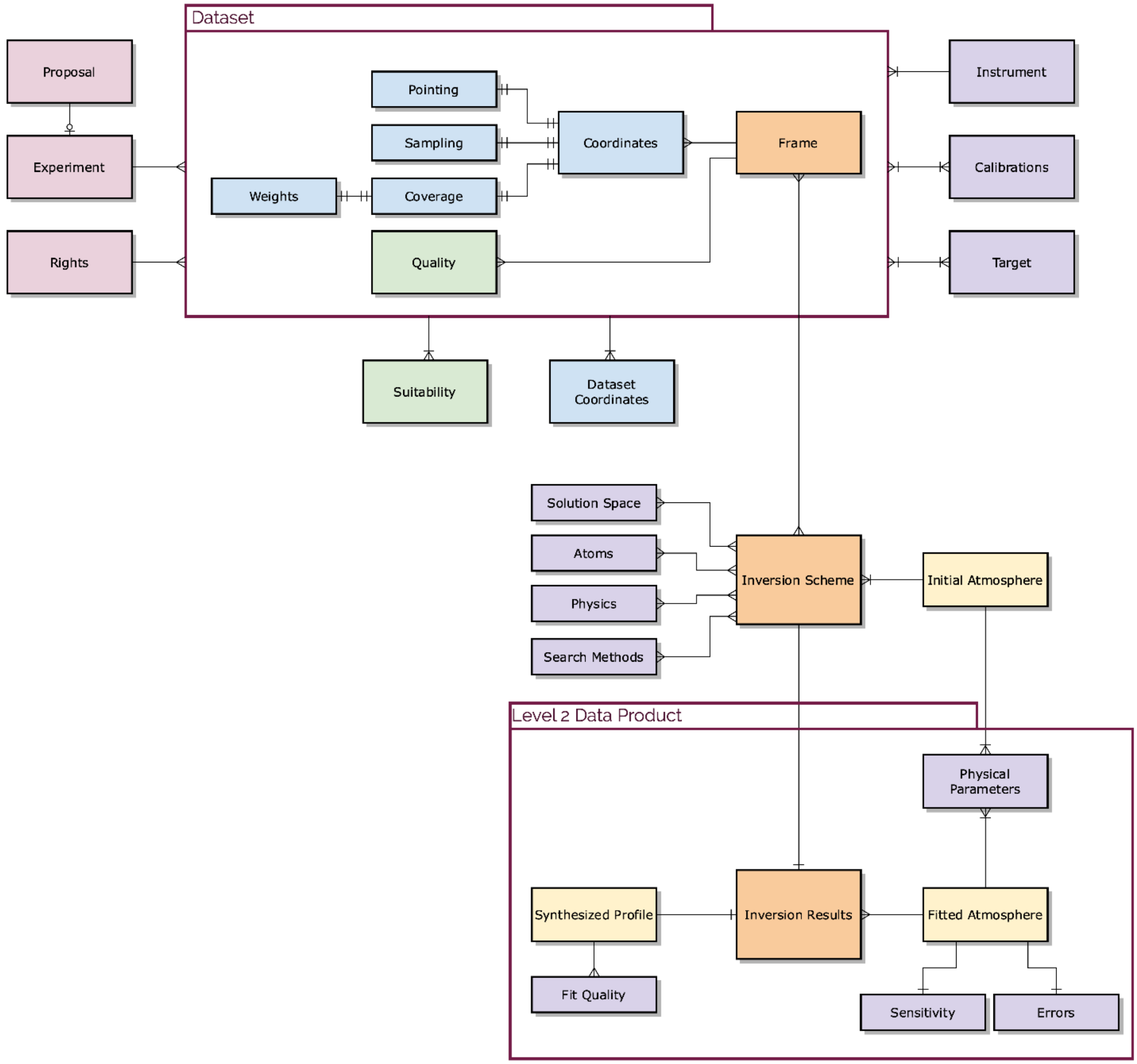


Figure 5-2. Example of the data flow from DKIST proposal to Level-2 data, including meta-data, as outlined in the requirement document SPEC_0230.

has laid out a two-pronged approach in the Level-2 data product Strategic Initiative (University Focused Initiative). First a request for proposals was sent out to US-based institutions that have participated in the Critical Science Plan workshops to create shared-funding positions for graduate students and postdocs. In the matching-fund program, the NSO seeks partners in US universities to financially support these young researchers in doing solar physics research, with the requirement that their research leads to the development of a Science Use Case (SUC) to be contributed to the DKIST Critical Science Plan (CSP), and creates DKIST Level-2 data sets. NSO's contribution to the matching-fund positions will consist of two years of graduate student/postdoc salary, overhead, some travel expenses and a scientific workstation. Additionally, the program will provide mentoring opportunities for the students at national and international centers with the expertise for developing their SUC.

Table 5-1. DKIST Ambassadors with Home Institution and Supervisors		
Name	**Home Institution**	**Supervisor**
Momchil Molnar	University of Colorado	Kevin Reardon
Ryan Hofmann	University of Colorado	Kevin Reardon
Shah Bahauddin	University of Colorado	Mark Rast
Andrei Afanasev	University of Colorado	Maria Kazachenko
Shuo Wang	New Mexico State University	James McAteer
Aparna V.	Georgia State University	Piet Martens
Eleni Nikou	George Mason University	Jie Zhang
Suman Dhakal	George Mason University	Jie Zhang
Bryan Yamashiro	University of Hawaiʻi	Xudong Sun
Wen He	University of Alabama Huntsville	Qiang Hu
Willow Reid	Montana State University	Dana Loncope
Yingjie Zhu	University of Michigan	Enrico Landi

The recipients of the matching-fund subcontracts will be called "DKIST Ambassadors", with the understanding that they will help to bring the expertise they acquire in their programs to their host institutions to broaden the base of US solar scientists skilled in using the unprecedented volume and quality of DKIST data to its full potential. The twelve students/postdocs that have been selected to become Ambassadors, together with their home institutions and supervisors, are listed in Table 5-1. All DKIST Ambassadors are strongly encouraged to attend the DKIST data-training workshops mentioned below in Section 5.1.3 and accounting for their availability they have done so for all three workshops that have been organized so far.

Prior to the deadline of the first DKIST Operations Commissioning Phase (OCP) observing proposal opportunity, we have organized a Zoom telecon with all twelve Ambassadors to familiarize them with the DKIST instrumentation and configurations that would be available in the first call and provided suggestions on how to write a strong and convincing proposal with proper scientific justification and observing strategies. In testament to the enthusiasm this has generated, we saw eleven of the Ambassadors involved in submitted proposals (for the 12th, none of the offered instrument configurations was appropriate to their research), six were involved as Principal Investigator, and several were involved in two or more proposals.

5.1.3 DKIST Data-Use Workshops

A second prong in the effort to prepare the US solar community for the DKIST era is the organization of a number of data-training workshops. These provide the necessary training to familiarize the solar community in general, and graduate students in the field of solar physics in particular, with the particularities of ground-based data, and train them in the use of existing complex inversion codes that will allow full exploitation of the DKIST potential. As the activity is mostly preparatory, we have been taking advantage of data from existing facilities such as the Dunn Solar Telescope ((DST), Sunspot, NM), the Goode Solar Telescope (GST), Big Bear Solar Observatory, CA) and others during the various training activities. The effort is guided by the existing SUCs in the CSP database and will ensure preparedness by the community to receive and utilize DKIST data.

The first data-training workshop (*https://www.nso.edu/ncsp/ncsp-workshop/intro-to-dkist/*) took place on June 4 – 9, 2019 in Boulder. We registered more than 40 participants, mostly from the US, in addition to a few from DKIST partners in the UK and Germany, as well as from potential partners in Japan. A second workshop, titled "Preparing for DKIST: Image Processing and Time Series" was held at California State University, Northridge, CA, January 13 – 15, 2020, with participation of 29 US students or early career scientists.

A third data-training workshop was planned to be held at George Mason University, Fairfax VA, in April 2020, but was cancelled because of the COVID-19 pandemic. Instead, we re-organized the workshop to be completely virtual including hands-on exercises employing Python Notebooks (*https://nso.edu/blog/virtual-dkist-data-workshop; Fig. 7.2*). Interest for the workshop was so high that participation had to be split among two sessions, July 20 – 24 and August 3 – 5, 2020 with 59 participants in total, including all twelve DKIST Ambassadors.

A fourth Data Training workshop, on Non-LTE spectro-polarimetric inversions, will be organized in early 2021, again virtually.

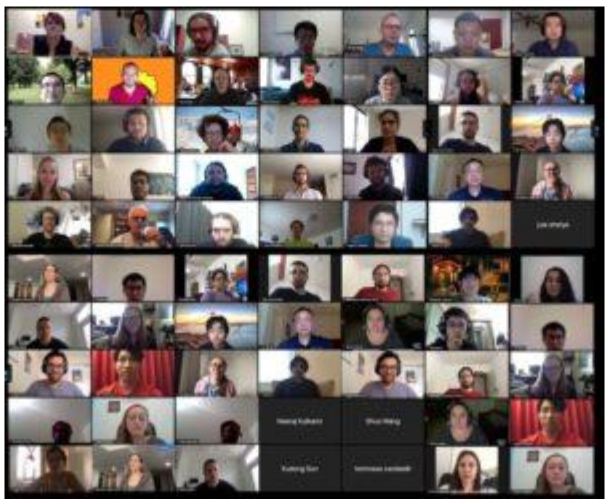


Figure 5.2. Screenshot of participants in the third (virtual) DKIST Data-Training Workshop.

5.2 Future Opportunities

The Supplemental Funding Request (SFR) for Level-2 data products provides funding for two years. The plans laid out above provide a three-pronged effort to provide the solar community with the means to optimally exploit the quality and volume of data that will be produced by DKIST in its initial years of operation. Substantial effort will go into training the US community in utilizing ground-based data and employing spectral inversions, as well as in providing the community with the pipelines and computational infrastructure to produce a select set of standard Level-2 products.

Judging from the variety of spectral lines that are requested for observations in the submitted SUCs, it is clear that the community would strongly benefit from a more expansive set of routinely inverted maps. Moreover, the quality and expected veracity of DKIST data is best used by comparing them with the best available models, namely state-of-the-art simulations of radiation magneto-hydrodynamics, that stretch from the photosphere up into the corona. Below we outline two related opportunities to enhance our capabilities to provide a wider variety of Level-2 products and produce forward modeling of sets of requested observables. After a presentation and discussion with the NSO Users' Committee, both of these would fulfill the criteria for NCSP Strategic Initiative and would provide the opportunity to further the NCSP's mission to engage NSO scientists from both DKIST and NISP in a quest to enhance the value of data obtained with NSO facilities.

5.2.1 Applying Machine Learning to Level-2 Production

Modern computing equipment has evolved enough to make a spectral-polarimetric inversion of a small set of spectral lines, even if some of them form under Non-LTE conditions, fast of the order of a minute per spatial position. DKIST instruments, however, will produce sub-arcsec resolution maps over fields-of-view of typically an arcmin, resulting in maps of several megapixels. Even on the two 1296 clusters that were specified in the initial Level-2 program, an inversion of a complete spectral map will take of the order of half a day, limiting severely the amount of inversions that can be performed routinely. Fortunately, new research in computer learning shows that additional techniques are available that might significantly speed up the application of inversions (see, e.g., Asensio Ramos and Diaz Baso, 2019).

Machine learning leverages statistical techniques to associate, in a probabilistic way, certain outcomes with certain inputs, without direct knowledge of the process that transforms one into the other. In the case of spectro-polarimetric inversions, the learning algorithm can be trained by a set of actual inversions, either performed from a sufficiently realistic set of simulations or a set of observations, to associate specific physical parameters with particular spectral line profiles. Once appropriately trained, the machine learning algorithms can then take a set of observations and deduce the physical parameters that were most likely underlying the observed spectra. From (limited) experience with the application of such machine learning techniques, it appears to be possible to speed up the inversion process by four-to-five orders of magnitude, rendering it possible to invert complete megapixel maps in minutes rather than many hours.

It should be noted that extensive (in the sense of covering a wide enough variety of observed profiles) training sets have to be created for each observable profile, or combination thereof. This implies a significant effort with testing against actual inversions in each case, and thus requires well-trained personnel.

5.2.2 Forward Modeling Data Bases

Our understanding of the physical processes that govern an astrophysical body in general, and the solar atmosphere in particular, should ultimately be tested by a detailed comparison of observations with observables generated from the best available models. However, the expertise to perform the necessary forward modeling of these observables is not widely available. This would provide an opportunity for the NCSP to seek additional funding to pursue a Strategic Initiative to provide data cubes of the most requested observable calculated through a comprehensive set of simulations to the community. These forward cubes could additionally be used as training sets for computer learning guided inversions, serving a dual purpose.

6 EDUCATION AND PUBLIC OUTREACH (EPO)

6.1 Structural Changes within the NSO EPO Team

6.1.1 EPO Goals

During FY 2020, NSO's EPO team reevaluated the overall objectives of the team. This came as a result of demand on the team's time and the plethora of collaborative opportunities becoming available as the team became more established. These goals will help with prioritization of programming and ensuring we meet the needs of the observatory.

Below we list the long-term goals of the EPO team, and the ways in which they will be accomplished:

1. **Goal 1: NSO becomes a nationwide leader in science engagement and education.**
   a. Develop new and innovative ways to engage our audiences.
   b. Present EPO results at educational conferences worldwide.
   c. Use and develop research-based best practices in designing and implementing EPO programs.

2. **Goal 2: Support the growth and development of the next generation of Solar Observatory employees.**
   a. Focused, best-practice-driven K-12 engagement with students and teachers.
   b. Pipeline development focusing on providing opportunities for engagement at all levels.
   c. Internships for higher education students, in particular those who are underrepresented in STEM.
   d. Public outreach to increase awareness of opportunities for employment and growth.
   e. Increasing career awareness amongst students from middle school and up.

3. **Goal 3: Highlight and promote research conducted at NSO.**
   a. Press engagement in collaboration with NSF and AURA.
   b. Use the NSO Blog to raise awareness of day-to-day happenings at NSO.
   c. Leverage social media to push updates to a variety of audiences.
   d. Exhibit booths at conferences to reach scientific audiences.
   e. Graphics development in support of NSO's research objectives.
   f. Develop and maintain an engaging, modern website that acts as an interface for the general public and other stakeholders.

4. **Goal 4: NSO is recognized as a community-facing organization that is in support of education and community.**
   a. Local outreach in partnership with community organizations, in particular in Maui County and across the state of Hawaiʻi (e.g., Girl Scouts, Maui Economic Development Board).

b. Host an annual Open House event at the offices in Maui, in collaboration with the University of Hawaiʻi Institute for Astronomy (IfA).

c. Support outreach by NSO employees to the local community and schools by providing training, tools, resources, activities, and other materials.

d. Provide special tours of DKIST for Kamaʻāina in Maui in collaboration with the DKIST team.

6.1.2 New Employees for EPO

Over the past two years, NSO and AURA have been advocating for increased personnel for the NSO EPO team. Specifically, the need for a dedicated Communications Officer has become apparent. Currently, the team consists of approximately ¼ the number of EPO and communication employees as compared to other NSF-funded observatories.

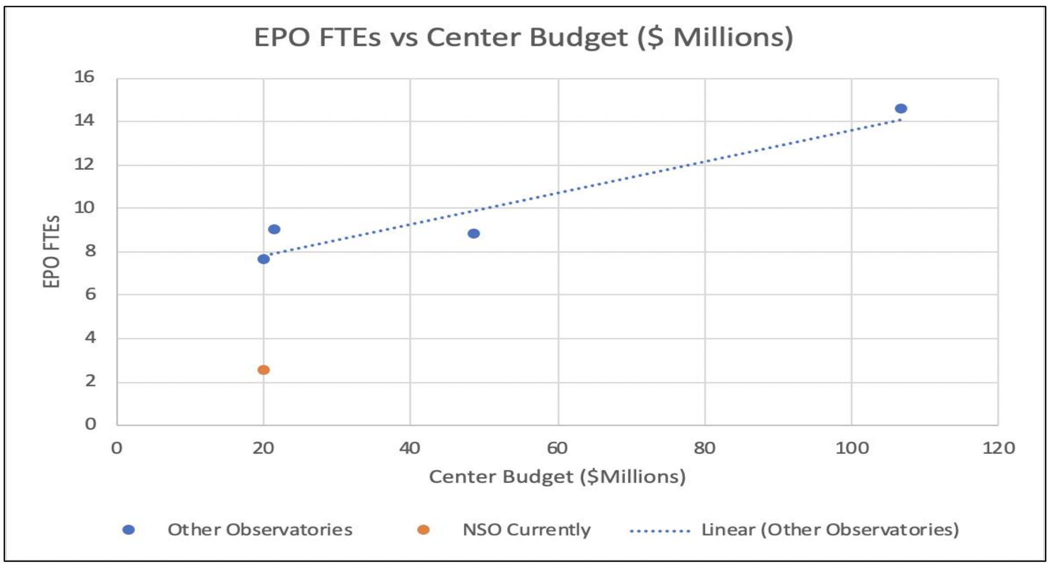


Figure 6-1. NSO is under-supporting EPO and communications efforts relative to other NSF funded observatories by a factor of almost four.

The DKIST Associate Director has agreed to fund two additional positions for the EPO team, both to be based in Maui starting in FY 2021 for a period of one year.

- **The Communications/Public Information Officer** will be responsible for developing, and implementing the media engagement strategy for NSO and projects therein as directed by the NSO's Head of EPO.
- **The Education and Public Outreach Assistant** will provide broad outreach and administrative support on a variety of education/community programs and efforts.

The long term status of these two positions is not well established at this time. The DKIST Associate Director has agreed to fund the positions for a period of two years. During the interim, we will be investigating ways to ensure the longevity of these roles at the observatory.

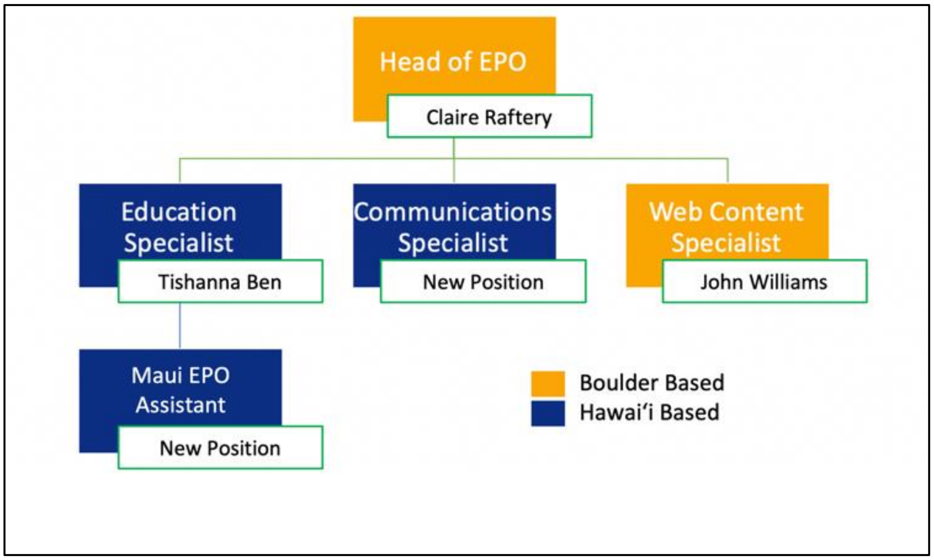


Figure 6-2. Proposed EPO organizational chart with the onboarding of two new EPO positions.

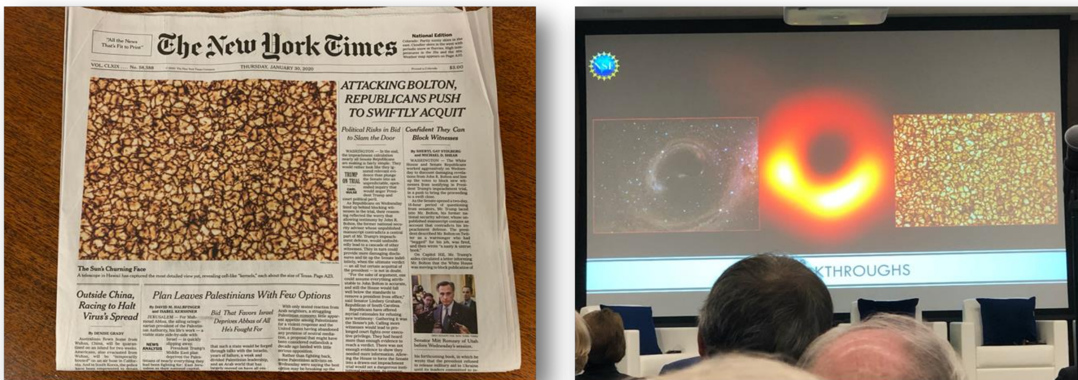
6.2 Communications

6.2.1 DKIST First Light

On January 29, 2020 in collaboration with the DKIST team, NSF Office of Legislative & Public Affairs (OLPA), NSF Division of Astronomical Sciences (AST), AURA and other stakeholders, the EPO team released the first images from NSF's Daniel K. Inouye Solar Telescope, receiving an overwhelmingly positive response. Meltwater reported that the images from the telescope received more than 1.6 billion interactions across media outlets within the first week of the release. The image was featured in news sites across the world, from Australia to the UK, as well as being featured on popular talk shows, such as The Daily Show with Trevor Noah and the Late Night Show with Seth Meyers.

Figure 6-3. Screenshot from "The Daily Show with Trevor Noah" (full video at http://www.cc.com/episodes/05s8wb/the-daily-show-with-trevor-noah-february-10--2020---tochi-onyebuchi-season-25-ep-25060, DKIST image 15 minutes in).

The image was featured on the front page of the New York Times the day after the release, an event that was celebrated to the highest levels of the NSF (the front page featured was highlighted by NSF Director, Dr. France Cordova).



New York Times, January 30th, 2020

Dr. France Cordova's "NSF Breakthrough" slide during NSF's 70th Anniversary Symposium

Figure 6-4. Left: Front page of the New York Times from January 30, 2020, featuring the first image from DKIST. Right: screenshot from a presentation by the Director of the National Science Foundation, Dr. France Cordova, celebrating NSF's breakthroughs. Slide features the first image from DKIST on the right hand side.

The image and video downloads amounted to more than 21 TB of data during the first week following the release, with the different products (images, videos and supporting materials) being downloaded more than 110,000 times from almost every country in the world.

In advance of the first light press release, NSO hosted 14 members of the press in attendance at the American Astronomical Society (AAS) Winter Meeting on a private tour of DKIST. The tour was arranged in partnership between NSO EPO and the AAS Press Office, in collaboration with the DKIST team. 14 of the journalists in attendance on the tour later generated news stories about the first image and additional pieces about the telescope progress. Since the onset of COVID-19 and the setbacks that has brought, interest from many of these journalists has been sustained, with occasional enquiries from them regarding the status of the telescope.

6.2.2 Press Releases and Blogs

In addition to the DKIST First Light press release, NSO has had three additional press releases and a series of blog posts. The blog is used to promote day-to-day activities and updates across the observatory, while press releases are reserved for timely, ground breaking news.

FY20 Blog posts (in Chronological Order)	# Views	Contributing Project
NSF's newest solar telescope produces first images	60,468	DKIST
Frank Hill Retires from the NSO	463	NISP
NSO Astronomers to play key role in two new spacecraft mission concept studies	191	NISP, DKIST
Sunspot cycle is stabilizing, according to worldwide panel of experts	1,576	NISP

FY20 Blog posts (in Chronological Order)	# Views	Contributing Project
NSO Team Works on Historical Sunspot Digitization	136	NISP
The Acceleration Mechanism for Solar Energetic Particles	102	NISP
Do we see a dawn of solar cycle 25?	272	NISP
NSF's Dunn Solar Telescope helps international team crack 60-year-old mystery of Sun's magnetic waves	252	DST
A new detection of Silicon+9 linear polarization for studying the solar corona	94	DKIST
Modeling the Effects of Observational Gaps in the Sun's Acoustic Modes	227	NISP
Dunn Solar Telescope Catches an Erupting Filament	241	DST
Alexei Pevtsov Named as New NSO Associate Director for Synoptic Program	76	NISP
NSO Goes Virtual – 3rd Data Training Workshop held online in preparation for observing call from NSF's Inouye Solar Telescope	113	DKIST
NSO scientists participate in celebration of the 25th anniversary of GONG at the Udaipur Solar Observatory in India	100	NISP
"Becoming a Super Solar Scientist!" – NSO WISER Live Stream for Planets Foundation's AstroFest	78	DKIST

Figure 6-5. Number of page visits to each of our FY20 written articles on the NSO webpage.

6.2.3 NSO Website Performance

In response to the DKIST First-Light image and expected increase in web traffic, we increased server resources temporarily and implemented a Content Delivery Network (CDN) from StackPath. This service delivers images, javascript and CSS to servers worldwide, putting resources nearer the website visitor and thus improves the speed of the website. This service has an added benefit of offloading delivery of the images, giving our servers more capacity to work at peak efficiency. This succeeded and got us looking more deeply at ways to improve performance and security. NSO.edu site infrastructure is based on WordPress. In August 2020, nso.edu moved to a dedicated WordPress host with features, such as website security, server infrastructure maintenance, CDN, and performance enhancements related to WordPress. The migration went smoothly with only minimal downtime. We immediately heard anecdotally of better performance on web pages. From a statistics and analytics perspective, we saw huge improvements. Our PageSpeed score increased from 68% (Jan. 21, 2020) to 92% (Aug. 27, 2020); YSlow improved from 81% to 89%. Home page load time stayed fairly consistent with 3.5s in January compared with 4.5s in November. With ongoing performance tweaks we expect to improve the load time by a couple of seconds.

As of November 1, 2020, NSO.edu pageviews are 680,657, a 176.48% increase from 2019.

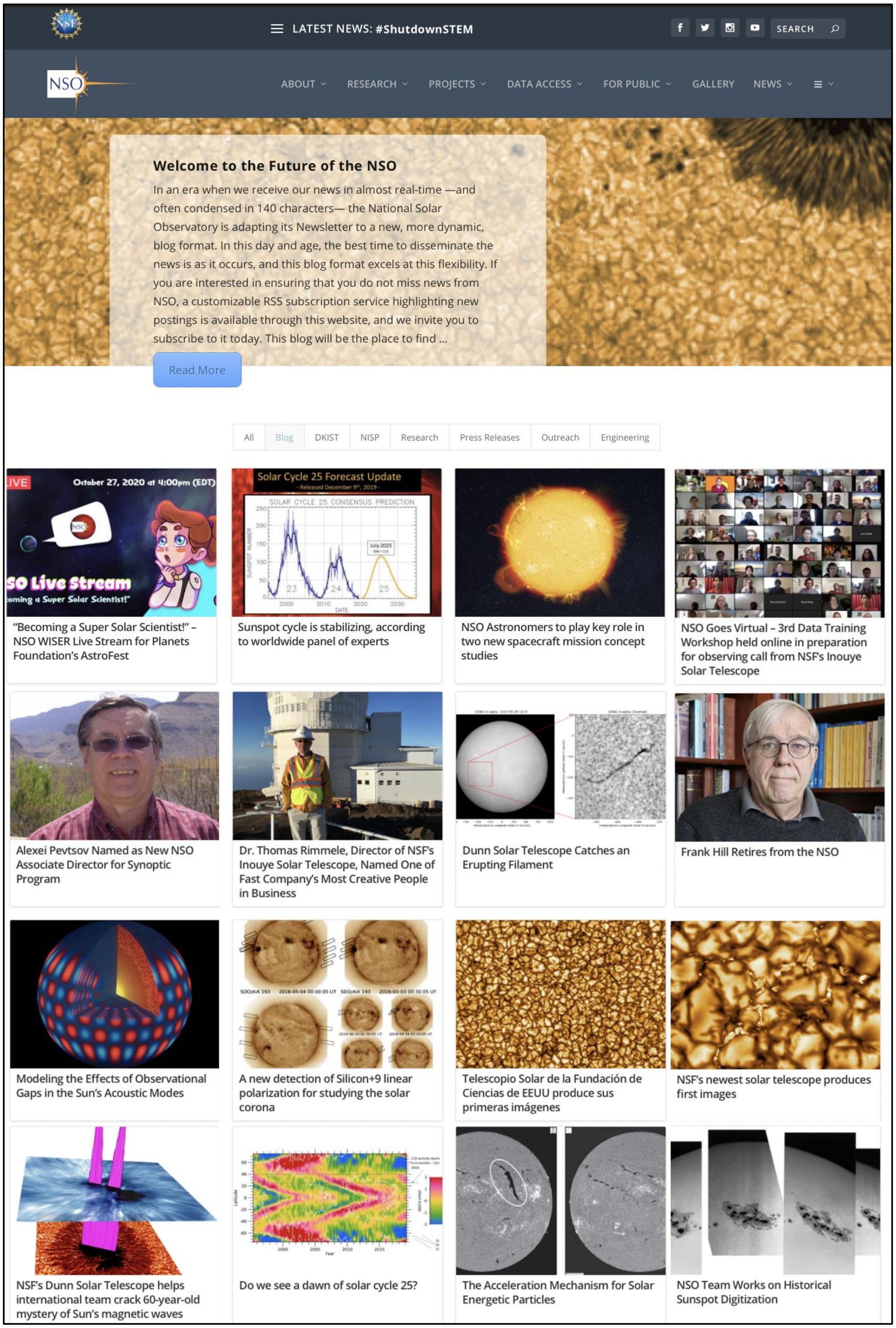


Figure 6-6. Overview of the press releases and blog posts from NSO during FY20.

6.2.4 Social Media

We had a surge in our social media during the periods immediately before and after the release of DKIST's first-light image on January 29, 2020. Here are data regarding the increase:

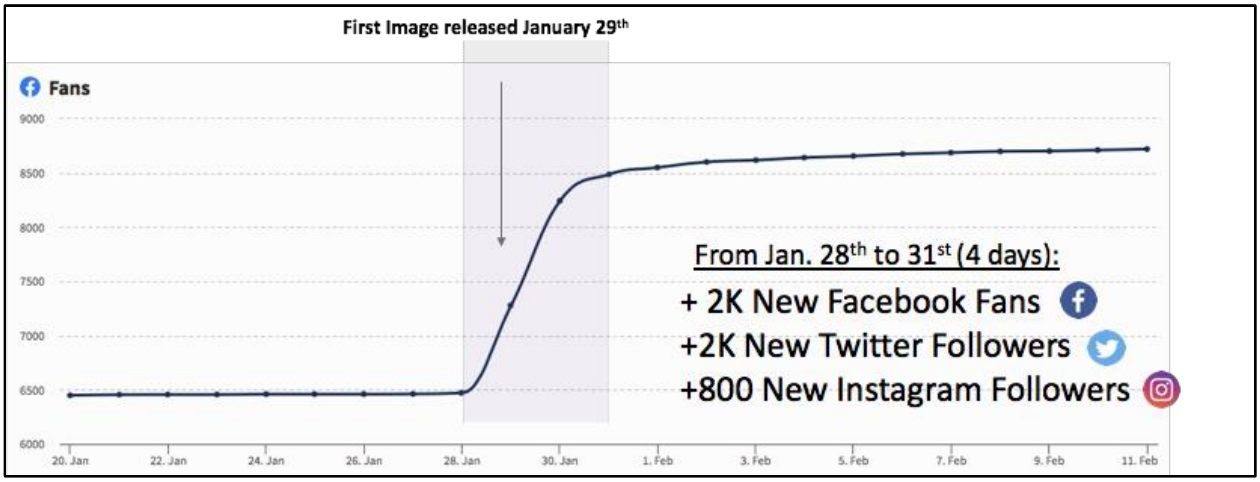


Figure 6-7. Data on social-media surge in January 2020.

Since the release, we've maintained and increased our following across platforms.

Followers on each platform at the end of FY20, with specific followers since DKIST first light:

- Facebook: 9.1 K fans; 531 new fans since DKIST first light.
- Twitter: +4.7 K followers; 290 new followers since DKIST first light.
- Instagram: 2.2 K followers; 505 new followers since DKIST first light.

6.2.5 FY 2021 Plans for Communications

Baseline plans for FY21 are to continue in a similar fashion to FY20, with focus on new development with DKIST, and (as appropriate) ngGONG. However, once the Communications Officer is onboard, we expect this component of our program to be substantially more robust and multifaceted.

6.3 K–12 Formal Education

6.3.1 Journey through the Universe Comes to Maui

NSO EPO worked in collaboration with Gemini Observatory in order to lead the expansion of Gemini Observatory's long-running "Journey through the Universe" program to public schools on Maui for the first time.

The program's "Journey Week" is a week of space science activities provided by astronomy scientists and educators that take place in K-12 classrooms. "Journey Educators" are professionals from partnering observatories and science organizations who not only teach STEM lessons but also provide students with the valuable opportunity to ask questions in person with STEM professionals.

Figure 6-8. NSO's Tishanna Ben instructing middle school students from Kalama Intermediate School in Kihei on a thermal engineering experiment during the 2020 Journey through the Universe in Maui.

Journey through the Universe has been running successfully for 16 years but has only ever been on the Big Island. In February 2020, NSO adapted the Gemini Observatory program to include Maui Island in Journey through the Universe. This pilot test included two schools in Maui: Kaimaliʻi Elementary, contact person(s) Wendy Wells (STEM Coordinator); and Kalama Intermediate School, contact person(s) Timothy Shim (Principal) and Kathryn Young (Astronomy/Math Teacher). Journey Week on Maui consisted of classroom visits (grades 3 - 8), a free NASA Solar System Exploration Research Virtual Institute (SSERVI) meteorite workshop hosted by NSO/DKIST for Maui teachers, and Air Force planetarium shows for elementary students (grades 3 - 5).

During Maui Journey Week (February 24–28, 2020), we visited a total of 28 classes at two different schools. This amounted to approximately 584 students. Students ranged in grade level from third to eighth grade. We had a total of six astronomy educators:

- Dr. Claire Raftery, Director of Outreach and Communications (NSO).
- Tishanna Ben, Education and Public Outreach Specialist (NSO).
- Brian Day, Lead for Citizen Science, Planetary Mapping, and Outreach (NASA SSERVI).
- Joseph Minafra, Lead for Innovation and Technical Partnerships (NASA SSERVI).
- Dr. James "JD" Armstrong, Maui Technology Education & Outreach Specialist (UH IfA).
- Richard D. Peterson, First Lieutenant/Principal Investigator, DOTS (USAF).

We had planned on conducting a wider ranging program during FY21, but the global pandemic has made this plan uncertain. Between travel restrictions and teachers being overwhelmed, this may prevent us from successfully implementing the program during FY21, but we still will explore the possibility.

6.3.2 NSO's Google Classroom

Google Classroom is a service for schools, non-profits, and students with a Google account. The service allows learners and instructors to efficiently connect virtually. The platform allows NSO EPO staff to create virtual classes, communicate with "students" (i.e., educators, parents, enthusiasts, and youth), and distribute lesson plans and resources.

NSO's K–12 STEM Resources Classroom is used as a "resource hub" for parents, teachers, and students where they can connect and receive free lesson & activity plans, videos, science education resources and more. To visit: www.classroom.google.com; enter the class code **acmluyv.**

The Classroom was initially developed as a resource for virtual connection during school outages due to the pandemic. However, the Classroom can also be offered to teachers as a classroom enrichment tool now that school has returned. A plan to roll out an updated "lesson enrichment" version specifically for active classroom teachers is under consideration. Additionally, an NSO Youth Classroom has been created for middle/high school students. It was developed as an activity and resource hub for students (grades 6–12). Students will receive astronomy activity plans and support from the National Solar Observatory, the most powerful telescope on Earth for studying our Sun! For Q & A and STEM tutoring, students can reach out to the instructor and/or fellow classmates by leaving a comment or via direct messaging. A management plan for the additional classes as well as for advertising this to teachers and students is under development.

6.3.3 Educators Portal

The NSO recently updated "STEM Education and Outreach" resources webpage: *www.nso.edu/for-public/educators*, which serves as an advertisement page for upcoming outreach events, directory for contacting outreach staff, and "go to" page for downloadable STEM materials, videos, NSO Google Classroom information and other resources. Additionally, the page houses our database of outreach materials such as posters, brochures, presentations, etc. for non-EPO staff at NSO, and others, to easily access when planning to do individual outreach volunteering.

6.3.4 Middle School Eclipse Leaders

Solar eclipses present a rare opportunity to attract youth and inform the general public about STEM. A plan was developed to work closely with a group of bilingual Hispanic 6–8-grade students from La Joya, South Texas during FY20 to educate them about the solar eclipse happening in Chile early in FY21. In collaboration with CU Boulder and AURA-O in Chile, we had planned on travelling to the Chilean path of totality with these middle school students. This particular group of students was identified for three reasons:

1. The next US total and annular solar eclipses will pass through south Texas in 2023 and 2024 close to La Joya, Texas, where the students were to be recruited.
2. South Texas is 97% Hispanic and is historically underrepresented in STEM.
3. In 2018, a full dome planetarium has been built in LJISD, Texas, which makes it a perfect base for organizing outreach activities in the area.

Chile, on the other hand, is home to the NSF-funded Gemini Observatory that host a large outreach program. Gemini and NSO are both organizations managed by AURA. The outreach events were expected to follow the structure of the 2017 total solar eclipse observations established by the NSO in Salem, Oregon.

Following the 2020 eclipse experience, NSO and CU Boulder planned to continue working with the same group of students in La Joya through the years in the lead up to the 2023 and 2024 eclipses to help them grow their confidence and STEM identity, in order to become "Eclipse Leaders" in their local communities during the next US total eclipse. By 2024, the students will be in high school, and ready to embark on the next phase of their careers.

The impact on the eclipse students will be significant. Participation in an international eclipse expedition with experts, development of content expertise and being seen as authority in STEM is expected to have a profound effect on the students' identity. The value of having young students conducting public outreach in Spanish will increases the accessibility for other members of the public in both Chile and Texas.

Unfortunately, with COVID-19 and travel restrictions, it became necessary to cancel the initial plans to travel to Chile. NSO EPO and the project PI are now discussing alternative options, beginning in FY21.

6.3.5 FY 2021 Plans for K–12

Due to COVID-19 and travel restrictions, it was necessary to cancel initial plans for travel to Chile for the Eclipse Leaders program. In order to adapt, NSO EPO and the project PI are developing plans to continue engagement with the students and the general public surrounding the eclipse. COVID-19 considerate outreach includes options such as:

- Virtual learning, projects and cumulative science fair.
- Undergraduates and EPO virtually train student eclipse leaders for online outreach with their peers and the general public.
- Students provide live commentary as the eclipse happens and viewers watch in near-real time.

We will continue to adapt and innovate new ways to engage with teachers and students as the pandemic progresses.

6.4 Higher Education

6.4.1 Research Experiences for Undergraduates (REU)

As a result of the 2020 global pandemic, the Boulder Solar Alliance Research Experiences for Undergraduates program was moved entirely online. NSO is a partner, along with eight other space-physics focused institutions in this program, which is PI'd by CU LASP. The program hosted 25 participants, six of whom conducted research with NSO mentors. Almost all of the program elements that would have occurred for an in-person program were implemented, with the exception of group meals (e.g., welcome BBQ), which were replaced by events with similar goals. EPO team members from NSO facilitated the program in partnership with facilitators from LASP.

Structure and Resources

Students were paired with mentors from one of eight institutes across Boulder, though the students themselves remained in their homes across the country. Time zones were a challenge at times, with students located in Ireland and in the United Arab Emirates, as well as across the continental United States. Mentors underwent dedicated training on effective remote mentoring practices in advance of the students arrival. This training was very positively received by mentors, especially those early in their career. Feedback suggested that mentoring remotely and depending on only virtual interaction was a daunting undertaking for some, and the training helped to put their mind at ease.

Following Boot Camp (introductory first week of classes, tutorials and group work), students and mentors conducted nine weeks of research in pairs, as they would in an in-person program. The facilitation team provided a list of useful collaboration tools, ranging from teleconferencing to remote desktop control that aided in the effectiveness of the research process. Mentors in particular reported that this made their project easier than an in-person experience in some ways, e.g., *"My student did not have any experience in programming, so the first two months I spent lecturing him about coding, and this worked out rather well. He could also record the lectures, which is a bonus!"* (anonymous feedback from REU 2020 mentor gathered by external evaluator).

Prior to the beginning of the program, the facilitation team polled the participants regarding their computational access in their homes. Given the high processing power and high-speed internet required for the successful completion of many projects, this was one of the bigger challenges to overcome. With permission from the NSF Program Officer, funds assigned for travel were reprogrammed to be used as additional stipends for students, with recommendation that they be used to purchase sufficient computers and internet access to support their research. Since the equipment was purchased using stipends, it is the students' to keep. All but one were able to furnish themselves with sufficient equipment to effectively conduct their research. One student had a challenging time with internet access since there was no high-speed internet providers in her location. She enhanced her cellular internet plan to the highest possible, however it was insufficient for the work she was doing and her mentor had to adjust her project to accommodate this limitation.

Cohort Development

Cohort development was one of the more challenging aspects of a virtual program. Since like-for-like activities would be ineffective for a remote program, the facilitation team devised and incorporated dedicated ways to build relationships between students. This included "coffee roulette" where students were randomly assigned to breakout rooms to chat for between five and ten minutes, group projects where students worked together on a collective problem.

During an in-person program, the students build early relationships via their dorm-mates (students share a four-bedroom apartment) and from there grow their connections across the cohort. Early in the program, we realized that some of the introverted and shy students were not engaging too well and put this down to the lack of voluntary interaction. As such, we decided to emulate the relationships that might form through in-person roommates, and "randomly" (based on time zone) assign the students to groups of four and assign them accountability tasks for each other, such as checking in once a week, having one social interaction as a group per week, and keeping track of each other's presence at professional development sessions. This had significant benefit to some students, while others did not find it too useful. Critically, many of the previously disengaged students found it a beneficial way to interact with others in the group.

Numerous students referred to the challenge of cohort development in their final surveys. Many requested "forced" interaction and rather than leaving the students to self-organize, that coordinators create events for them to socialize together. Additionally, there were requests for the roommate groups to be selected based on shared interests rather than time zone. We will take this into account in future years.

Boot Camp

The first week of the program — Space Bootcamp — continued as normal. The one exception was the group projects. During an in-person program, students would work together on a hardware project in order to build group dynamic and be introduced to collaboration techniques. Given this was impossible in a virtual setting, we partnered with Nicholas Gross, coordinator for the NASA Heliophysics Summer School program for graduate students. Nick shared many of the computer-based solar physics "labs" that they pursue in the graduate summer school and helped us to adapt them to meet the ability level of the undergraduates. The students worked together to tackle the problem sets (all computer-based observation and modelling problems) to learn collaboration skills, accountability and delegation. These were very positively received, with 90% of students rating the first week lab activities as somewhat or extremely valuable. Anonymous feedback included *"They really threw us into some difficult material which made us adapt and really use our brains to figure things out"*; and *"They reminded me to think like an experimentalist once in a while and observe data visually to try to find some pattern"*.

Professional Development

The weekly professional development series, typically run at lunchtime on Wednesdays, was run in a similar manner to an in-person session. However, we enhanced the professional development offerings to add a second weekly get together on Fridays, where scientists from across the Alliance presented fun or quirky concepts to the students. NSO presented two of these "Science Friday" talks: Dr. Valentin Pillet discussed the collaborative opportunities between DKIST, Parker Solar Probe, and Solar Orbiter; and Dr. Sarah Jaeggli presented a hypothetical thought experiment to examine how much popcorn could pop in its light beam. Finally, an ad hoc series of coffee chats were hosted by the facilitation team and domain experts from around the world. Participants in the program expressed an interest in specific topics (such as going to graduate school abroad, what a graduate admissions committee looks for, what it's like to be space weather forecaster) and the facilitation team invited someone to speak informally with those who were interested. This was also very positively received. The global pandemic actually enhanced our ability to support the students' networking opportunities by introducing them to experts worldwide. Some feedback from students included *"I thought they were all very useful, even if I already had prior knowledge about what was being talked about I generally learned something new"*; *"All were very helpful. So informative. The grad schools ones were the best presentations I've been to"*; and *"I loved meeting with different scientists all over the world sharing their experiences as well as the seminars. Please, never eliminate the seminars, they are so hopeful with understanding the graduate school process and research"*.

End-of-Year Conference

As usual, the students presented four times during the program — their elevator pitch in week two, a five-minute talk in week six, a 20-minute seminar in week 10, and a poster on the last day. The oral presentations were conducted using Zoom, and the 20-minute presentations were live streamed to YouTube to share with the broader community. These recordings have been viewed 514 times (as of October 2020, two months after broadcast). NSO EPO hosted and facilitated these sessions.

The most challenging aspect of the end-of-year conference was the poster session. Unlike other programs, we did not want the students presenting a five-minute mini-talk on their poster, since they had already given a 20-minute presentation earlier in the week. Instead, we aimed to emulate an in-person poster experience as closely as possible. NSO EPO devised a mechanism that would recreate this environment closely. Since then, other programs have adopted the same structure and are utilizing the techniques demonstrated by NSO. The process involved using the Zoom platform, with each student and their poster in individual breakout rooms.

The key concept in recreating a poster session experience in Zoom is that individuals can move from one breakout room to another on their own. At the time of the poster session, attendees could not freely move from the main room to the breakout room of their choice. The organizers needed to also make a "hallway" breakout room that serves as the initial destination. Recent updates to the zoom platform now make it possible to accommodate participants choosing their own breakout rooms, without the extra complexity required this summer.

Steps to allow participants to move between breakouts (now redundant due to zoom updates):

1. Share PDFs of all the posters ahead of time so that visitors can browse them. Number the posters.
2. Create a breakout room for each poster. Each poster presenter is assigned to their own room, named with the same number as their poster's PDF. For example, a room might be "1. Mary Smith – Solar Variation." The presenter then shares their screen. We recommend PDFs to allow easy zooming (no pun intended) during discussions. <u>Only the host can create breakout rooms. Allow enough time before the scheduled start time for the host to create these rooms.</u>
3. Create another breakout room (hallway).
4. Have visitors rename themselves to include their full name and institute for easy identification like a virtual name tag: "Marsha Mills – LASP." To make this change, click on the participant list, hover over your own name and select "More." Rename should be an option. If it is not, the host needs to enable that Zoom function for the meeting.
5. All non-presenter visitors are made co-hosts of the meeting and assigned to the hallway breakout room by the host.
6. From the hallway or any breakout room, people click the "breakout room" button and are then presented with a list of all the breakout rooms. They can click "join" to assign themselves to any of the rooms. If they accidentally chose "leave room" they will be sent back to the main room. Then the host can reassign them to the hallway.

The host remains in the main room to make visitors co-host and assign them to the hallway.

It is helpful for another person to stay in the hallway to direct traffic to the poster rooms and to answer questions. The hallway monitor can help suggest posters that match the visitor's interest and/or direct them to a poster that has had low traffic.

Having multiple coordinators (at least three) is essential. One assigned to the main room, one to the hallway, and one for technical help.

The most frequent challenge was people "leaving" a breakout room, which returns them to the main room, where they can't access all breakouts. Informing visitors to use the "Breakout Room" button instead would save valuable time.

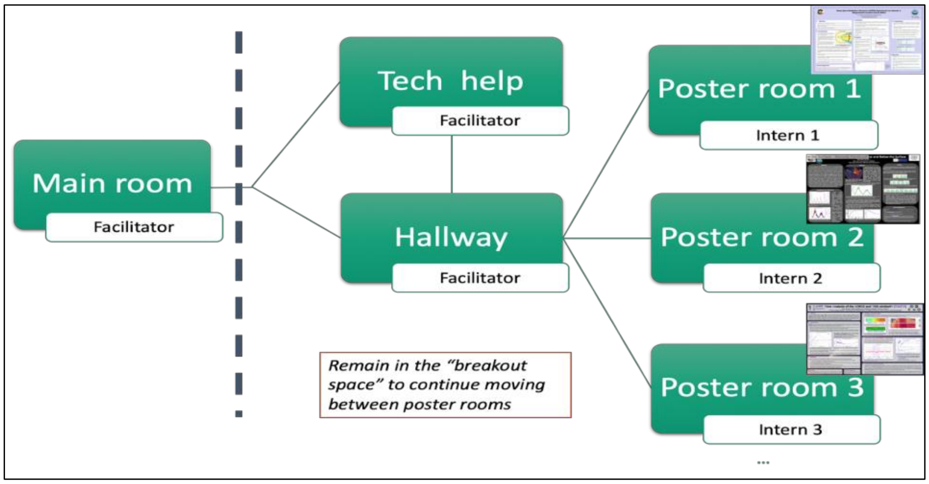


Figure 6-9. Schematic describing the layout of zoom breakout rooms used to facilitate a true-to-life poster session.

Evaluation

The program evaluation was performed by Christine Okochi as planned and came back with exceptional results, including:

- **100%** of students would recommend this program to others.
- **43%** of students thought the online environment positively affected their experience. Students found that meeting regularly with their mentors worked well in the online environment.
- 100% of students were satisfied with the responsiveness of the program staff and tech support they received during the summer.
- 95% of students agreed that the intro course was a good preparation in solar and space physics, a good use of time, and that the lectures were informative and useful.
- 90% of students rated the first week lab activities as *somewhat* or *extremely valuable*.
- Students rated the professional development sessions on giving a talk, applying to grad school, elevator speeches, 5-minute presentations, and science careers as the most valuable.
- Students rated the Science Friday sessions *Every Picture Tells a Story (team building)*, *Space Weather*, and *Multimessenger solar science with DKIST, Parker Solar Probe and Solar Orbiter* (presented by Dr. Valentin Martinez Pillet) as the most valuable.
- The optional Scientist Coffee sessions on poster-making (presented by Dr. Claire Raftery) was highest rated of that series.
- 100% of students agreed that they would consider working with their advising team again, felt that their mentor created a supportive virtual working environment, and that their project was a reasonable challenge.
- Most students (59%) reported spending 3 or 4 hours a week with their mentors; 29% of students reported spending 5 or more hours per week meeting with their mentors.

Students described their mentors with words such as "enthusiastic," "accessible," "helpful," and "understanding."

Select verbatim feedback from participants includes:

- *"The opportunities to experience many firsts in scientific research (ex. first poster, first paper, first conference, etc.) Also, the opportunity to network with professional scientists was a blessing as much as was networking with the young scientists that were my peers this summer. I have learned what kind of researcher I do and do not want to be and am excited to work with my research advisor at my home institution in pursuit of this goal."*
- *"I got to engage in actual research that wasn't developed specifically for students. I was pulled out of my comfort zone and learned more than I could have imagined. "*
- *"This program finally helped me decide what I want for my future. I always told people I vaguely wanted to do something with science. However, now I know I want to go to graduate school. And I know how to get there and what to do after. This program helped me so much. "*
- *"This was such an incredible opportunity. I look back and I cannot believe how much I've learned and how far I've come and the wonderful friendships and connections I've made and I am so proud of what I was able to do."*

6.4.2 NSO Supervision of CU Boulder Graduate Students and Postdocs

NSO scientists have continued broadening their engagement with students at CU Boulder in order to provide them with opportunities to learn about the Observatory's science and engineering efforts and be involved with its mission. Multiple NSO researchers are involved with mentoring graduate and undergraduate students on a variety of projects. These have often involved data obtained from NSO facilities, combined with data from other telescopes or spacecraft. The topics studied have contributed to the preparations for utilizing DKIST in various ways. Amanda White has been working with David Harrington on characterizing the polarization properties of the DKIST optics. Ryan Hofmann and Neeraj Kulkarni have been testing techniques for recovering information through inversions for photospheric and chromospheric spectral lines that will be observed by DKIST. Denis Tilipman is working with Maria Kazachenko to develop methods to track flows in the solar photosphere. Momchil Molnar and Johnathan Stauffer have been combining observations in the optical, infrared, millimeter, and UV to study the temperature and dynamics of the solar atmosphere. Hofmann and Molnar serve as DKIST Ambassadors as part of the NCSP. Several other graduate students collaborate with NSO staff as they pursue DKIST-related studies with CU Faculty. NSO staff also mentored four different research projects with CU undergraduates during the academic year.

Postdocs:
Shah M Bahauddin (Contact: Mark Rast) - NSF Grant funding.
Alin Paraschiv (Contact: Han Uitenbroek/Phil Judge) - NCSP funding.
Benoit Tremblay (Contact: Maria Kazachenko) - NSF grant funding.
Yuta Notsu (Contact: Adam Kowalski) - NSF grant funding.

Graduate Students:
(*) Primary advisor is an NSO (partial) staff member

Graduating 2021:
* Elizabeth Butler (Advisor: Adam Kowalski) - CU startup funds.
Piyush Agrawal (Advisor: Mark Rast) - NSF ASP grant funding (previous Hale Fellow).
* Amanda White (Advisor: Dave Harrington) - DKIST funding (previous Hale Fellow).
* Denis Tilipman (Advisor: Maria Kazachenko) - CU startup funds.

Graduating 2022:

* Momchil Molnar (Advisors: Kevin Reardon/Han Uitenbroek) - NCSP/DKIST Ambassador (previous Hale Fellow).

* Ryan Hofmann (Advisors: Kevin Reardon/Ivan Milic) - NCSP/DKIST Ambassadors (previously NSO funding).

Graduating 2024:

Lily Kromyda (Advisor: Bob Ergun) - Hale Fellow (ending 2020).

* Johnathan Stauffer (Advisor: Kevin Reardon) - Hale Fellow (ending 2021).

* Neeraj Kulkarni (Advisor: Han Uitenbroek) - Hale Fellow (ending 2021).

Graduating 2026:

* Kirk Long

Megan Kenny

Marcel Corchado

* Cole Tamburri

Undergraduates (2020 Spring Semester):

Yudai Katsumata (Advisor: Alin Paraschiv) – Undergraduate Research Opporunities Program (UROP) 2019 funding.

Eryk Halicki (Advisor: Kevin Reardon) - UROP 2019 funding.

James Crowley (Advisor: Ivan Milic) - UROP 2019 funding.

Anjali Antony (Advisor: Gianna Cauzzi) - independent study.

Kacie Kira Davis (Advisor: Kevin Reardon) - UROP 2019 funding.

6.4.3 NSO Learning Center

In support of NSO's ongoing commitment to learning and teaching across all levels, NSO EPO has created a "Student Learning Center", which archives instructional materials for higher education students. This includes lectures from DKIST workshops, the COLLAGE graduate student series, and other tutorials (*https://nso.edu/students/learning-center/).*

This is in addition to other higher education resources (such as the Hale Program and REU program) and our Educators forum for K-12 learners (*https://nso.edu/students/).*

6.4.4 FY 2021 Plans for Higher Education

Ongoing outreach efforts seek to inform prospective and incoming graduate students about the broad range of research opportunities at NSO. Through its close integration with the Astrophysical and Planetary Sciences (APS) department and Laboratory for Atmospheric and Space Physics (LASP) at CU, NSO is able to engage with graduate and undergraduate students on a variety of levels, fostering sustained interest in solar physics research. These efforts are also supported by the Hale Graduate Fellowships provided by the University of Colorado, the several faculty positions shared between NSO and CU, and requests for external funding to support graduate research.

With the ongoing COVID-19 pandemic, the exact landscape for higher education remains uncertain. The REU program is poised and prepared to run a second virtual experience, having largely succeeded in FY20, and with some innovations as a result of student and mentor feedback to improve a FY21 experience. We will continue to build and support the online archives of learning materials and other resources for students in higher education, as well as the DKIST Level 2 program, as appropriate.

6.5 Informal Education and Outreach

6.5.1 Collaboration with Haleakalā National Park

NSO EPO participated in a training program run by Haleakalā National Park Service (NPS) interpreters (those who interface with the public). This training focused on solar science and the Inouye Solar Telescope. During this session, we discussed the challenges faced by park interpreters on the interface between indigenous practices and the presence of the Inouye Solar Telescope on the mountain. This was a very constructive and respectful, if difficult, discussion. Out of this training, the National Park interpreters have invited NSO EPO to continue a partnership, and together we are conceiving of new programs that will complement both NSO and Haleakalā NPS.

6.5.2 Learn from Home Webinars

In response to the COVID-19 global pandemic, much of our engagement has moved online. We have leveraged this opportunity to get employees from across NSO to discuss their jobs and (when appropriate) their research. The goal of this #LearnFromHome series is to provide an insight into the wide variety of jobs at an observatory such as NSO. In particular, the EPO team aspires to raise awareness of the wide range of employment opportunities at NSO in order to increase access to underrepresented populations, in particular in Hawai‘ i.

Figure 6-10. Fliers advertising two NSO #LearnFromHome webinars.

6.5.3 Public Outreach

Our plans for outreach for FY20 were severely disrupted by the global pandemic. However, in light of COVID-19 and adapting systems, we're still managing to reach diverse audiences. Although we can't attend many outreach events in person, perhaps our reach will become wider and more diverse now that many events like these are much more accessible to people further away geographically. Examples of our participation in online outreach events include Inouye Solar Telescope's Facebook Live, Girls Scouts of Hawai‘i's Virtual STEM Fest, Planet Foundation's AstroFest, Mauna Kea Astronomy Outreach Committee (MKAOC)'s MKO at Home series, and Fort Collins Comic Con.

- **NSF Inouye Solar Telescope Facebook Live (2/21/20):** The event consisted of a live streamed interview with NSO/DKIST astronomers and scientists on-site in front of the NSF Inouye Solar Telescope. As of the end of FY20, the video has 8 K views. Happening shortly after the release of the telescope's first image, the live stream built off of the public's excitement surrounding the image by offering them an inside look at the telescope, and providing real-time answers to public questions. View the stream at

https://www.facebook.com/30037047899/videos/198817541504656.

Figure 6-11. Dr. Sarah Jaeggli and Dr. Thomas Schad live streaming from the NSF's facebook page in front of the Inouye Solar Telescope.

- **Mauna Kea Astronomy Outreach Committee (MKAOC)'s MKO at Home (5/15/20):** MKO at Home is a series of astronomy education and outreach videos, housed on YouTube, that were collected by MKAOC to offer the Hawaiʻi community as part of their first-ever virtual AstroDay. AstroDay is normally a day of astronomy exhibitions and activities hosted by MKAOC at the Prince Kuhio Hilo Mall. Due to COVID, the event could not be held in person, and was thus held online. This year's event also included a live stream panel of solar and stellar experts for the "International Day of Light" (5/15/20). An NSO solar expert was included on the panel as well.

- **Girl Scouts of Hawaiʻi STEM Camp (8/15/20):** STEM Camp offers Girl Scouts hands-on activities with STEM Professionals so that they can gain exposure to STEM career paths, and practice 21st-century life skills such as problem solving, creativity, and collaboration.

- **Fort Collins Comic Con (8/30/20):** Held entirely virtual in 2020, this convention is a comic-oriented gathering of guests, scientists, vendors, artists, authors, etc. The event provided NSO EPO a platform for highlighting and promoting research conducted at NSO. NSO EPO gave a live streamed presentation focused on Inouye Solar Telescope's first-light image. The session also included an "Ask Me Anything" Q&A session.

- **Planet Foundation's AstroFest (10/27/20):** As part of the larger event, AstroFest, NSO Women In Science Education and Research (WISER) provided a live stream panel. The target audience was girls aged 7–14. Participants joined to talk live with women scientists and industry leaders.

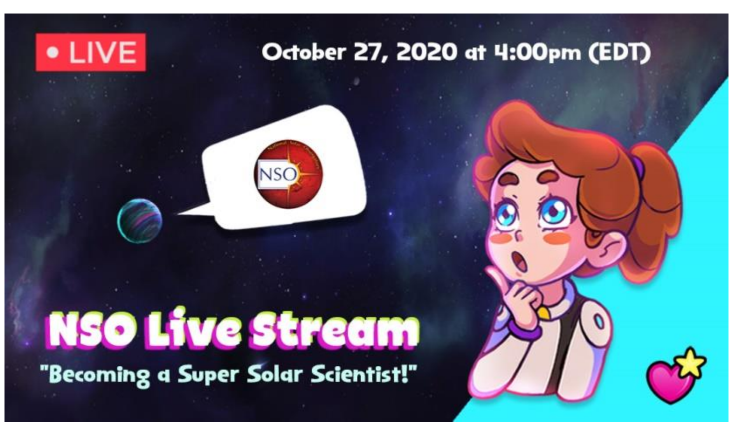


Figure 6-12. Flier advertising the Planet Foundation's AstroFest event with NSO.

6.5.4 FY 2021 Plans for Informal Education and Outreach

As with all FY21 plans, we will adapt to the needs and restrictions of our audiences during the pandemic. However, we anticipate the growth of the newly established partnership with Haleakalā National Park interpreters through FY21. We plan to begin by training their permanent and volunteer staff on the basics of solar astronomy, what DKIST offers to the astronomy community and society overall, and how to use daytime astronomy to engage their visitors. We will also continue to attend virtual outreach events and conference exhibitions (e.g., virtual AGU and virtual AAS winter meeting) to continue engaging the scientific community in updates and developments from NSO.

7 DIVERSITY AND INCLUSION

This section is a summary of FY 2020 activities that encouraged or increased diversity within NSO, its user community as well as the undergraduate and graduate student populations. Gender, ethnic, and racial metrics are provided, and the NSO's ongoing broadening participation efforts for FY 2021 are described.

Near the end of 2019, AURA hired a Chief Diversity Officer, Ameerah McBride, who reports to the AURA President. Ameerah has created the Equity and Inclusion Council[9] (EIC), which represents a change concerning the former approach taken by AURA through the former Workforce and Diversity Committee (WDC). The WDC has comprised both internal and external members, including the chairperson who was a non-AURA affiliate. The new EIC is an all-internal council and uses a separate process for external review and input. Its membership includes the Diversity Advocates (DA) from each AURA Center, representatives from the Human Resources team, and employees representing various positions within AURA. In addition to the main council tasks, the EIC was divided into two subcommittees. One focuses on recruitment and retention, and the other on AURA advisory board inclusivity. The EIC helps AURA leadership to build a resilient, welcoming, inclusive, and creative work environment that serves the broad astronomical communities. NSO and AURA are committed to achieving an inclusive environment within its observatories and to promoting programs and outreach that will engage a diverse community for the future.

NSO has appointed two Diversity Advocates, each with a focus that prioritizes, but is not limited to, diversity issues at their sites: Stacey Sueoka (DKIST, located in Maui) and Niles Oien (NISP, Boulder-based). The DAs meet with the NSO Director regularly to discuss diversity and inclusion activities and concerns. Both DAs are EIC members. There is a general expectation that DAs will serve for approximately two years. Two other NSO staff members, Carolyn Watkins and Sarah Jaeggli, also serve on the EIC. In addition to their regular duties, the DAs work part-time (10%, under the NSO Director) to support diversity and inclusion activities across the Observatory. In FY 2020, the DAs helped organize events such as a Slack-channel staff discussion during the US academia #ShutDownSTEM call on June 10, 2020. The discussion resulted in some actionable steps that NSO is pursuing—most notably, enhancing the distribution of new job advertisements in places accessible to underrepresented minorities (see below). NSO DAs are also in the process of developing an NSO broad presentation and discussion forum. This forum will likely involve an opportunity for all NSO staff to meet, hear presentations related to Diversity, Equity, and Inclusion (DE&I) issues, and engage in discussions about the topic.

In FY 2020, various degrees of discussions occurred at all AURA Centers about how to more effectively reach underrepresented minorities; as a result, the EIC formed a subcommittee focused on this task. The subcommittee established a two-year time frame to provide AURA with broad actionable recommendations. During that time frame, the subcommittee will review AURA's policies regarding inclusivity in recruitment and retention. This review is likely to involve considerations on where position postings are advertised, the wording of position postings, the hiring process, and exit

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[9] *https://www.aura-astronomy.org/diversity/*

interviews. Current approaches include regular hiring committee's engagement with Human Resources to ensure that best practices are followed during hiring processes, including diversity in the composition of hiring committees and frequent discussions about unconscious bias (see AURA's Diversity and Inclusion website). A step NSO is taking is to revise the list of places where we publicize new job openings, beyond the more specifically targeted sites of the solar and astronomical communities. In the past, NSO has posted in the following sites, which we'll continue to use as appropriate, to advertise available positions, in light of AURA EIC subcommittee discussions:

- National Society of Black Physicists (NSBP) (*http://www.nsbp.org/*).
- National Society of Hispanic Physicists (NSHP) (*http://www.hispanicphysicists.org/*).
- Society for Advancement of Chicanos & Native Americans (SACNAS) (*http://www.sacnas.org/*).
- Society of Women Engineers (*https://swe.org/*).
- Society of Black Engineers (*https://www.nsbe.org/home.aspx*).
- Society of Hispanic Professional Engineers (*https://www.shpe.org/*).
- American Indian Science and Engineering Society (AISES); (*https://www.aises.org*).

The DAs are also co-organizing monthly meetings of an NSO DE&I working group. The entire group has alternating site-specific sessions at Maui and Boulder. The staff at Sunspot and Tucson have been invited to these discussions as well.

7.2 Diversity Metrics of the NSO REU Program

Section 6.4.1 describes the highly successful 2020 Boulder-wide, LASP/CU-Boulder-led REU Program, in which NSO participated. Table 7-1 provides various diversity metrics of the REU cohort and shows how this program effectively promotes diversity in Science, Technology, Engineering and Mathematics (STEM).

Table 7-1. 2020 REU Program Diversity Metrics

		NSO participants (N=6)		All program participants (N=22)		All Applicants (N=244)	
		Number	% of accepted students	Number	% of accepted students	Number	% of applicants
Gender Identity	Male	2	33.33%	8	36.36%	127	52.05%
	Female	4	66.67%	14	63.64%	104	42.62%
	Nonbinary	0	0.00%	0	0.00%	4	1.64%
	Choose not to answer	0	0.00%	0	0.00%	9	3.69%
Race and ethnicity	White	2	28.57%	12	54.55%	180	73.77%
	Asian	3	42.86%	3	13.64%	26	10.66%
	Black	1	14.29%	2	9.09%	14	5.74%
	Hispanic	1	14.29%	2	9.09%	27	11.07%
	Pacific Islander	0	0.00%	1	4.55%	5	2.05%
	American Indian or Alaskan Native					4	1.64%
	Choose not to answer					9	3.69%

7.3 Akamai Workforce Initiative (AWI)

The Akamai Program constitutes one of the most sustained diversity efforts at the NSO with measurable successes.

Figure 7-1. Akamai 2019 intern cohort and staff.

7.3.1 Program Overview

Over the years, NSO has continued to support the local workforce pipeline in Hawaiʻi through the Akamai Workforce Initiative. The AWI is led by the University of Santa Cruz (UCSC) Institute for Scientist and Engineer Educators (ISEE), which in 2018 received the Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. The Akamai Program was founded in 2003 with a focus of supporting the workforce needs of the telescopes and technology industry in Hawai'i. Since its inception, the program has provided a total of 428 summer internship opportunities at both telescope and tech sites on Maui and the Big Island for STEM undergraduate students with ties to Hawaiʻi. As of 2020, more than 125 Akamai alumni are now working in STEM jobs in Hawaiʻi.

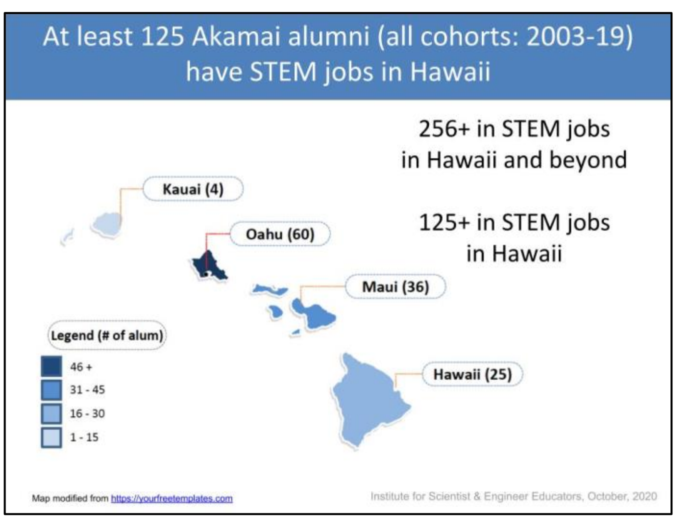

Figure 7-2. Akamai alumni with STEM jobs in Hawaiʻi.

The goal of the program is to develop a workforce that reflects the diverse population of the state; therefore, there is an emphasis on broadening participation to include more Native Hawaiians, women and other groups underrepresented in STEM. In 2020, ISEE surveyed alumni of the program from 2003–2019, where 37% of former interns were women, 23% Native Hawaiian, and 47% all underrepresented minorities. 82% of alumni fall under a subset category of alumni from 2003 to 2016, having completed the program 3+ years ago. Of those alumni, 81% are currently in the STEM workforce and 7% are enrolled in STEM as an undergraduate or graduate student. This is exceptional considering that nationally only about 40% of college freshmen who start as STEM majors complete a STEM degree. Another finding from the 2020 survey shows that all gender and ethnic groups stay in STEM at the same high rate of roughly 88%. For underrepresented minorities this is more than four times the national average of students who completed STEM degrees and double the national average for white and Asian students.

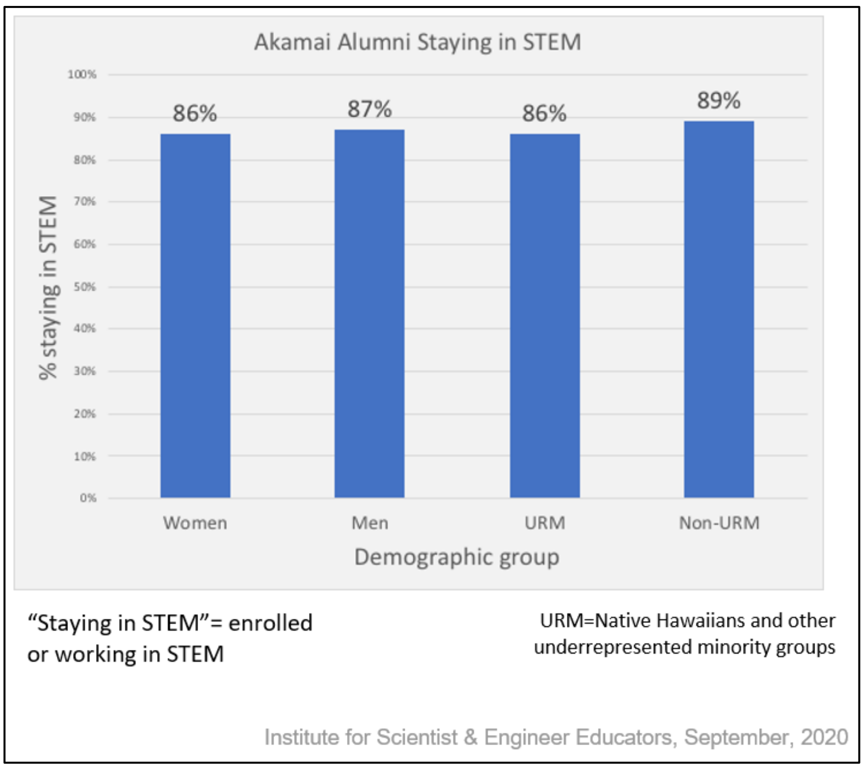

Figure 7-3. Demographics of Akamai alumni staying in STEM.

7.3.2 NSO Involvement

7.3.2.1 NSO Workshop

NSO has been involved with the program since 2011 as it prepared for construction of DKIST on Maui. More than 90 Akamai alumni participated in NSO career development workshops, including mock interviews, held on Maui from 2011–2013. This resulted in five summer internships at NSO, two hires at DKIST/NSO and two hires at other Maui tech organizations.

7.3.2.2 Akamai Intern Funding

NSO has provided financial support for 18 interns, 14 of whom did projects at DKIST, and the others at academic and technical institutions on Maui.

7.3.2.3 Mentoring

NSO staff participation as mentors not only benefits the interns, but the employees and the organization as well. The Akamai Program considers a productive project to be one that is educational for the student and addresses an authentic need of the mentor and their organization. To date, 18 DKIST staff have mentored Akamai interns, and thirteen of the staff have participated in the Mentor Workshop. The Mentor Workshop provides an opportunity for NSO employees to engage with professional STEM educators, to prepare and plan for the upcoming summer intern's project and interactions with the student. Three important themes are addressed in the workshop: Developing STEM Identity and Growth Mindset, STEM Practices & Ownership of Learning, and Assessment.

DKIST hires Maui Akamai alumnus as thermal engineer

Chriselle Galapon grew up on Maui, studied mechanical engineering at UH Manoa, and did an Akamai Internship in 2013 at the IfA. After earning her degree, she returned home to look for a job. Akamai staff referred her to an opening with DKIST. **Since 2015 she has been an Akamai mentor!**

"Chriselle is turning out to be a great hire as part of the Facility Thermal Systems (FTS) construction management team. She's coming up to speed fast and making a big contribution."

Figure 7-4. Maui Akamai alumnus Chriselle Galapon.

7.3.2.4 Akamai Program Staff and Mentor Council

In addition to direct funding, there is in-kind contribution through participation of NSO staff members. NSO's Dave Harrington and Stacey Sueoka participate as Akamai Program staff, as instructors during the PREP course as well as participating in project recruitment, selection committee and symposia presentation coaching. The Akamai Mentor Council advises ISEE on goals, activities, and outcomes related to mentoring within the Akamai Internship Program, and strengthening the mentor community associated with the program. Dave Harrington was a council member in 2017-2018, and Heather Marshall currently sits on the council as an NSO representative.

7.3.2.5 2020 Akamai Program Cancellation

Prior to cancellation of the 2020 program, five interns were matched with DKIST mentors. However, due to COVID-19, the 2020 intern cohort was unable to participate in the program. A major part of the program's success is the intern's experience at the workplace and interaction with the mentors and colleagues.

7.3.2.6 DKIST Involvement for 2021-2022

In hopes of an improved COVID-19 situation, the Akamai Program will resume in 2021. Currently, DKIST has committed to supporting five interns per year for 2021 and 2022.

7.3.2.7 Akamai Alumni at DKIST

The workforce pipeline is working! Five Akamai alumni currently work at DKIST, one recent hire is an alumnus from the 2018 internship program.

Figure 7-5. Former Akamai interns now working at DKIST. From left to right: Stacey Sueoka (Optical Engineer), Brialyn Onodera (Mechanical Engineer), Chriselle Galapon (Thermal Engineer), Mary Liang (Optical Engineer). Top right: Alex Meyer (Electrical Technician).

8 FY 2021 SPENDING PLAN

The NSO spending plan is based on receiving the FY 2021 President's Budget Request (PBR) of $21.79M for NSO. This quantity is augmented by $300K (to $22.09M) for the continued activities in Sunspot, where NSO is responsible for the facility. The PBR amount is reduced by $0.5M from the original Cooperative Agreement (CA) budget profile to reimburse the $2.5M upfront payment received in FY 2016 for the DKIST Science Support Center (DSSC) in Maui. These repayments occur over five years, ending in FY 2022. The NSO's Program allocations presented here follow the guidelines in Table 10.4-2 of the Cooperative Agreement proposal submitted by AURA in October 2013 but include the re-profile of the funds in the DKIST Operations Program discussed in Section 10 of the FY 2020 – FY 2024 Long Range Plan (LRP). This revised DKIST spending plan uses updated estimates of the cost of operating the facility.

The spending plan presented here is structured in five subdivisions: The Director's Office, which includes the EPO Program; the DKIST Operations Program; NISP; NCSP; and Sunspot. Original funding for the NCSP (tasked with the DKIST Level-2 data effort) corresponded to FY 2018 – FY 2019 but will operate in FY 2021 using the program's carry forward. We note that the funding for NCSP was obligated late in the corresponding fiscal years, generating large unspent funds in FY 2019 that continue into FY 2021. The NCSP will exhaust most of its funds in FY 2021, excluding some expenditures needed for the Level-1 and Level-2 data interface in FY 2022.

As in previous years, the NSO plans to continue operating the Sunspot site in FY 2021, thanks to a Supplemental Funding Request (SFR) not included in the PBR profile. An additional SFR for FY 2021 is discussed in Section 8.2.5 and considers a number of deferred maintenance items.

NSO uses AURA's WEBUD budgeting tool that details the expenditures associated with the subdivisions and the work packages for each fiscal year. The budgeting tool allows for the inclusion of the Basis of Estimates (BOE) to document the various costs. As in past years, WEBUD enables selecting one of the three funding sources: new NSF funds corresponding to a specific year (also selectable); carry forward; or grant funding. In this APRPP, the grant funding used by NISP is a composite of external research grants and includes NOAA funding provided to NISP for GONG operations. The NOAA and NSF Interagency Agreement (IAA) expires in FY 2021. As a result, NSO will submit to NOAA a new five-year budget outlining GONG operations costs for FY 2022–2026. This budget considers updated costs for operating the network, reflecting scalability and new site fees at various locations. After a successful renewal of the IAA, we expect to receive funding in late FY 2021 at a $1M level for operating the network in FY 2022.

Figure 8-1 describes the organizational structure of the Observatory and includes all the cost-account managers with financial responsibilities. Red lines in the chart correspond to the DKIST construction project.

As part of the improved business practices at NSO, we note that we implemented a change-control process in FY 2018 that we continue using in FY 2021 for documenting changes to the annual budget.

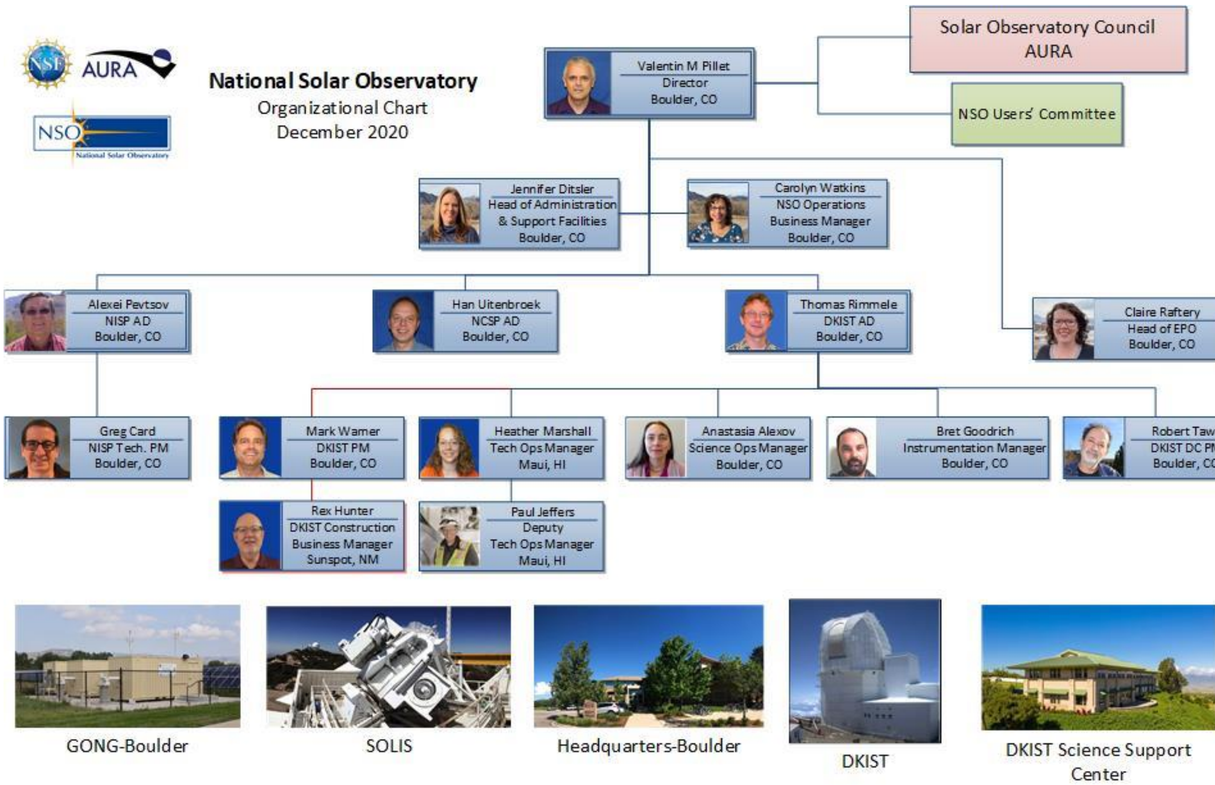

Figure 8-1. Organizational structure of the National Solar Observatory.

8.1 FY 2021 Budgetary Assumptions: NSF New Funds, Carry Forward, and Grants

Table 8-1 summarizes the funding that NSO expects to receive as new NSF funding and anticipated non-NSF support for operations in FY 2021. The NSO Program in FY 2021 was developed based on receiving $22.09M of NSF funding for the regular base operations, including DKIST. NSO receives additional operational support from other sources. In FY 2016, NSO received the first NOAA Space Weather Prediction Center (SWPC) contribution intended to cover the costs of operationalizing GONG (including preventive maintenance trips to the remote sites). The last year, including new funds from the existing five-year IAA, was FY 2020. NOAA/SWPC and NSF are in conversations to renew the IAA for another period of five years with a potential first contribution to the NSO in FY 2021.

Table 8-1. Expected NSO FY 2021 Funding	
(Dollars in Thousands)	
NSF Astronomy Division Funding	$21,790
Sunspot Site Operations	$300
Subtotal NSF Astronomy Division Funding	$22,090
NISP Grants (VSO, NASA Infrastructure, etc.)	$1,351
NOAA Support (to be used in FY 2022)	$1,000
Total NSO Funding	**$24,441**

NSO also receives support through various grants and contracts, mostly to NISP, with NSO and non-NSO principal investigators (PI). These funds are used to support research fellows for specific activities and enhance the program's capabilities, such as improved data products. These enhanced capabilities are generally made available to the user community. The FY 2021 budget includes an estimated $1.35M from grants associated with various activities, with most of the funds corresponding to several NASA collaborations, including the participation of NSO in the Virtual Solar Observatory (VSO). After Frank Hill's retirement, the new PI of the VSO is Alisdair Davey (from the DKIST Program). The NISP helioseismology group has been particularly successful at obtaining new grants in FY 2020 that represent a significant fraction of the external funding. This additional support helps alleviate funding pressures existing within NISP, as explained below.

In late FY 2018, NSO received a Supplemental Funding Request to the operations Cooperative Support Agreement (CSA) of $3.5M to produce DKIST Level-2 data products. This SFR is part of the NSF's 10 Big Ideas – Harnessing the Data Revolution Program. A second $3.5M contribution was received in FY 2019. The funding has been allocated to the NSO Community Science Program (NCSP) (see Section 8.2.4). The funds are budgeted in WEBUD as part of the program's carry forward with no contribution from the FY 2021 new NSF funds.

Successive SFRs for Sunspot operations, for an amount of $300K/year, support the site program that also charges the NMSU-led Sunspot Solar Observatory Consortium (SSOC). For FY 2021, NSO assumes another SFR of $300K for operations of the site. These funds cover only yearly operational costs, but do not include site maintenance aspects. This has created a deficit explained in Section 8.2.5. NSO is in conversations with the NSF to augment this year's SFR to account for this deficit.

Table 8-2. NSO Spending Plan

Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance
NSO	NSO HQ	NSO Headquarters	Yes	8.11	$1,871,946	$1,871,884	$0	($62)
NSO	DKIST OP	DKIST Operations	Yes	64.21	$17,522,750	$17,514,444	$0	($8,306)
NSO	NSO NISP	NSO NISP	Yes	11.77	$2,334,885	$2,334,660	$0	($225)
NSO	NSO SP	NSO SP	Yes	2.46	$427,082	$300,000	$39,140	($87,942)
NSO	NSO NCSP	NSO Community Science Program	Yes	0.00	$0	$0	$0	$0
NSO	NSO MF	NSO Fee	Yes	0.00	$69,012	$69,012	$0	$0
			Total	**86.55**	**$ 22,225,675**	**$ 22,090,000**	**$ 39,140**	**(96,535)**

Table 8-2 shows the six programs and the corresponding new NSF FY 2021 funds: NSO Headquarters; DKIST Operations; NISP; Sunspot Operations (NSO SP), NSO Community Science Program (NCSP); and the NSO Fee (NSO MF). The NSO Tucson Program does not receive any new funding, but we keep the accounts open to reconcile potential past expenditures. The spending plan totals of the respective programs include AURA's indirect rates. As in the past, there is a reduction in the allocations for each program corresponding to their use of the NSO Fee (last row). These respective program contributions to the NSO Fee have been negotiated with the NSF. The fifth column shows the FTEs supported by base funding. Column 6 details the entire spending plan, and Column 7, the expenditure targets. Note that Column 7 total corresponds to the FY 2021 NSF budget of $22.09M. Column 9 indicates the variance between the spending plan and the sum of the total revenues (numbers in parenthesis represent a deficit).

Table 8-3. NSO Distribution of Carry-Forward Funds								
Division	**Sub-Division**	**Name**	**Locked**	**FTE**	**Spend Plan**	**NSF Base Funding**	**Other Revenue**	**Variance**
NSO	NSO HQ	NSO Headquarters	Yes	3.38	$952,425	$953,995	$0	$1,570
NSO	DKIST OP	DKIST Operations	Yes	0.00	$32,256,748	$32,256,755	$0	$7
NSO	NSO NISP	NSO NISP	Yes	0.00	$1,314,922	$1,314,922	$0	$0
NSO	NSO SP	NSO SP	Yes	0.09	$350,924	$350,796	$0	($128)
NSO	NSO NCSP	NSO Community Science Program	Yes	6.85	$3,111,720	$3,113,680	$0	$1,960
NSO	NSO MF	NSO Fee	Yes	0.00	$57,169	$57,169	$0	$0
			Total	**10.32**	**$ 38,043,907**	**$ 38,047,317**	**$0**	**$ 3,410**

Table 8-3 provides the distribution of carry-forward funds for each program. The unspent budget originates primarily from delays in implementing various aspects of the transition to DKIST operations. The DKIST carry forward of $32M has been re-profiled in a manner explained in the FY 2020 – FY 2024 LRP and summarized in Section 8.2.2. For NISP, the $1.33M balance results from the SOLIS relocation delays and unused GONG refurbishment funds. Starting in FY 2020, the Sunspot Program carries a deficit described in Section 8.2.5. The carry-forward in this table of about $351K corresponds to the SFR received in FY 2020 for transporting the relocatable houses down to Alamogordo (a collaboration with the White Sands Habitat for Humanity, WSHFH). The NCSP is entirely budgeted in the carry-forward section as the program received the DKIST Level-2 data development funds in the previous years.

Table 8-4. NSO External Funds								
Division	**Sub-Division**	**Name**	**Locked**	**FTE**	**Spend Plan**	**NSF Base Funding**	**Other Revenue**	**Variance**
NSO	NSO HQ	NSO Headquarters	Yes	0.0	$0	$0	$0	$0
NSO	DKIST OP	DKIST Operations	Yes	0.0	$0	$0	$0	$0
NSO	NSO NISP	NSO NISP	Yes	6.30	$1,352,335	$1,351,012	$0	($1,323)
NSO	NSO SP	NSO SP	Yes	0.0	$0	$0	$0	$0
NSO	NSO NCSP	NSO Community Science Program	Yes	0.0	$0	$0	$0	$0
NSO	NSO MF	NSO Fee	Yes	0.0	$0	$0	$0	$0
			Total	**6.30**	**$ 1,352,335**	**$ 1,351,012**	**$0**	**($1,323)**

Table 8-4 combines the currently available grant funding ($1.35M) including the unspent funds from past years' contributions from NOAA/SWPC for GONG operations ($164K), pending the NSF/NOAA IAA renewal.

Providing a unified picture, Table 8-5 consolidates all FY 2021 funding sources from the tables above. We note, however, that the funds in Tables 8-2 and 8-3 correspond to the CSA AST-1400450 (NSF base funding for NSO operations), whereas Table 8-4 funds come from multiple sources originating in different agencies. The funding from different CSAs, or from other sources, are not interchangeable.

The fringe benefits and indirect rates were applied per the FY 2021 approved Provisional Indirect Rate Agreement letter from the NSF, dated July 26, 2019. The spending plan used escalation on payroll and non-payroll per the Cost Model Proposal submitted to the NSF on December 14, 2018, at a rate of 3%.

Table 8-5. Summary – All Funding Sources								
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance
NSO	NSO HQ	NSO Headquarters	Yes	11.49	$2,824,371	$2,825,879	$0	$1,508
NSO	DKIST OP	DKIST Operations	Yes	64.21	$49,779,498	$49,771,199	$0	($8,299)
NSO	NSO NISP	NSO NISP	Yes	18.07	$5,002,142	$5,000,594	$0	($1,548)
NSO	NSO SP	NSO SP	Yes	2.55	$778,006	$650,796	$39,140	($88,070)
NSO	NSO NCSP	NSO Community Science Program	Yes	6.85	$3,111,720	$3,113,680	$0	$1,960
NSO	NSO MF	NSO Fee	Yes	0.00	$126,181	$126,181	$0	$0
			Total	103.17	$ 61,621,918	$ 61,488,329	$39,140	($94,449)

Post-Retirement Benefits costs were based on FY 2020, escalated 3%, and allocated to the sub-divisions based on payroll distribution from WEBUD. Historical Unfunded Liabilities were budgeted as described in AURA's Cost Rate Proposal dated October 11, 2018 ($50K/year), allocated to the subdivisions based on projected payroll distribution per year. The University of Colorado Lease Office Space costs were based on FY 2020, escalated 3%, and allocated to subdivisions based on projected square-foot usage, including allocated common space.

The University of Colorado IT connectivity costs were based on FY 2020, escalated 3%, and allocated to subdivisions based on projected headcount. AURA/CAS Human Resources software application (Ultipro) costs were based on FY 2020, escalated by 3%, and allocated to subdivisions based on projected headcount. Insurance costs were based on FY 2020, escalated by 3%, and assigned to subdivisions based on headcount, vehicle location, and direct usage as applicable.

The NSO Fee is assumed at the current negotiated amount ($69K/year) per Cooperative Support Agreement Amendment #14. These funds are used for allowable expenditures that are not part of the scope of the Cooperative Agreement. The corresponding budget has been subtracted from the programs using it (HQ, DKIST, and NISP). Table 8-3 includes $57K carry forward in the NSO Fee account, reflecting the reduced use of these funds partly due to the COVID-19 pandemic.

8.2 Work Package Breakout

The on-line WEBUD tool allows various modes of visualizing the budget distributions and the BOE used in each subdivision. This section presents an overview of the most significant expenses projected for each program and the changes to the original CA proposal. The tables in this section show the major functional areas' spending plan in more detail, breaking out payroll and non-payroll by work packages. The tables are provided separately for the three different funding sources: NSF FY 2021 funds, carry forward, and grants when applicable.

8.2.1 Director's Office (NSO HQ)

Table 8-6 presents the FY 2021 NSF funds for the Director's Office budget. Staff included in the Director's Office budget are the Director, the NSO Director's Office Executive Administrator, the NSO Business Manager for Operations, a combination of several fractional FTEs from various administrative positions, a similar mix of fractions of IT personnel, including the lead IT manager, and the entire NSO EPO group. Non-payroll expenses account for AURA's oversight committee and obligations, supplies and materials, and other miscellaneous costs incurred by the Director. We note that in FY 2021, the Director's Office will support two NSO Diversity Advocates with base funding of $26.5K. A significant

Table 8-6. Director's Office Budget						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO HQ	**8.11**	**$1,284,924**	**$587,022**	**$1,871,946**	**$0**	**$1,871,946**
Director's Office	1.80	$488,698	$40,405	$529,103		$529,103
AURA Corporate Direct Charges			$42,442	$42,442		$42,442
Post Retirement Benefits			$29,042	$29,042		$29,042
AURA Committees	0.20	$26,507	$2,060	$28,566		$28,566
Business/Administration	2.35	$321,765	$37,386	$359,151		$359,151
Safety			$5,303	$5,303		$5,303
Recruit/Relo - New Positions			$0	$0		$0
Recruit/Relo - Existing Positions			$0	$0		$0
Carry Forward			$0	$0		$0
Insurance			$5,642	$5,642		$5,642
CU Recharge Fees			$3,800	$3,800		$3,800
Science Staff - Research	0.10	$13,416	$1,042	$14,459		$14,459
Research Assistants			$0	$0		$0
NSO Science-Collaborations			$0	$0		$0
NISP Operations Service			$0	$0		$0
DKIST Operations Service			$0	$0		$0
CSP Activities			$0	$0		$0
EPO - Scientists			$0	$0		$0
Joint CU/NSO			$0	$0		$0
Hale Post Doc			$26,943	$26,943		$26,943
HQ Operations			$303,714	$303,714		$303,714
Boulder Computing IT	1.25	$145,981	$38,376	$184,357		$184,357
Vehicles			$982	$982		$982
HQ Development & Relocation			$0	$0		$0
Instrument Development			$0	$0		$0
Education and Public Outreach	2.30	$270,895	$49,886	$320,781		$320,781
CMAG	0.11	17662	$0	$17,662		$17,662
Total:	**8.11**	**$1,284,924**	**$587,022**	**$1,871,946**	**$0**	**$1,871,946**
Target:						**$1,871,884**
Variance:						**($62)**

fraction of the budget ($303K, HQ Operations) pays for about a third of the lease of the 3rd floor at the CU Boulder SPSC building. This cost includes common areas.

The NSO EPO Program, under the Director's Office, consists of two FTEs, one in Colorado and one in Hawaiʻi. The Maui assistant focuses on promoting solar physics within the local community, particularly with K-12 students and teachers on the island. The EPO Program's total budget from the NSF FY 2021 new funds is $321K. In FY 2015, the late hire of EPO positions provided some carry-forward funds re-budgeted as a start-up package for the program. These resources are available primarily to increase the visibility of NSO in general, and of DKIST in particular, mostly by covering the cost of exhibit booths at AAS, AGU, and similar events. These start-up funds will likely end in FY 2022.

Table 8-7 discloses the Director's Office carry forward of $954K. The most relevant items covered by these carry-forward funds are:

1. In FY 2021, the bulk of the Director's carry-forward of $543K covers a historical deficit accumulated for GONG operations due to a mismatch in the period of performance of the

first NOAA-NSF IAA, to unaccounted escalation in the NOAA/SWPC funds, and to new site fees that have appeared in recent years. The funds will cover NISP personnel who will operate the network at a level of 3 FTE, and site fees. The Director's Office is able to support GONG operations at this level in part thanks to the savings in travel costs resulting from the COVID-19 restrictions.

2. Equipment moves to Boulder and Maui that have not occurred yet because of delayed divestiture of the DST. The carry-forward funds is $93K ('HQ Development & Relocation') for these pending transition activities.

3. Additional science support, $50K ('Science Staff-Research'), is reduced compared to past years. These funds are used to support a broad spectrum of scientific opportunities not directly included in the programs, such as computers and page charges for publications by NSO's emeritus scientists. There are no payroll components to this account in FY 2021.

4. The EPO start-up package, $44K ('Education, and Public Outreach').

5. Payroll funding, $28.8K ('CMAG') for the Compact Magnetograph project selected for phase A for the NASA Midex SOLARIS proposal (the Compact Doppler and Magnetograph, (CDM)).

6. Miscellaneous expenditures (Boulder vehicles, improvements to the HQ audio-video systems).

Table 8-7. Director's Office Carry Forward

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO HQ	**3.38**	**$385,212**	**$567,213**	**$952,425**	**$0**	**$952,425**
Director's Office	0.19	$14,442	$33,453	$47,895		$47,895
AURA Corporate Direct Charges			$0	$0		$0
SOLIS Tower Demolition			$0	$0		$0
AURA Committees			$0	$0		$0
Business/Administration			$7,326	$7,326		$7,326
Recruit/Relo - New Positions			$0	$0		$0
Recruit/Relo - Existing Positions			$0	$0		$0
Carry Forward			$0	$0		$0
Insurance			$0	$0		$0
CU Recharge Fees			$0	$0		$0
Science Staff - Research			$50,323	$50,323		$50,323
Research Assistants			$0	$0		$0
NSO Science-Collaborations			$0	$0		$0
NISP Operations Service	2.99	$344,068	$199,318	$543,386		$543,386
DKIST Operations Service			$0	$0		$0
CSP Activities			$0	$0		$0
EPO - Scientists			$0	$0		$0
Joint CU/NSO			$0	$0		$0
Hale Post Doc			$16,166	$16,166		$16,166
HQ Operations			$63,049	$63,049		$63,049
Boulder Computing IT			$15,287	$15,287		$15,287
Vehicles			$43,108	$43,108		$43,108
HQ Development & Relocation			$92,628	$92,628		$92,628
Instrument Development			$0	$0		$0
Education and Public Outreach			$44,480	$44,480		$44,480
CMAG	0.2	$26,702	$2,075	$28,777		$28,777
Total:	**3.38**	**$385,212**	**$567,213**	**$952,425**	**$0**	**$952,425**
Target:						**$953,995**
Variance:						**$1,570**

In FY 2021, NSO is consolidating all IT services into a unified unit that will be the second component of the matrix structure for the Observatory (the first being Administrative services). In this manner, the Head of the IT service will have the flexibility to allocate resources and expertise efficiently, while avoiding duplication of effort.

8.2.2 DKIST Operations Program

The DKIST Operations Program is under the direction of Thomas Rimmele as DKIST Associate Director. In FY 2021, the DKIST Operations Program, with 64 FTEs, is the most extensive operational program at the NSO. Table 8-8 presents the new NSF funds for FY 2021 ($17.51M) divided into work packages. The program's carry forward is shown in Table 8-9 ($32M).

The DKIST operations staffing plan was presented in the FY 2020 – FY 2024 LRP. Since submission of the LRP in 2019, the budget estimates for DKIST operations were updated, taking into account the delays of DKIST start of operations due to COVID-19, progress in planning of science and technical operations, and experience gained in these areas since the development of the LRP. The COVID-19 situation has resulted in a significant delay of the DKIST construction project. A Supplemental Funding Request (SFR) to cover the impact of COVID-19 on the construction schedule was submitted to NSF in December 2020. In the SFR, the end of construction was projected for April 15, 2021. The situation remains very much in flux and further delays are likely. For planning purposes, a May 1, 2021 date was used to update the DKIST operations budget estimates.

The NSO Solar Observatory Council recently issued a number of recommendations, including the recommendation to develop a five-year staffing plan and "*realistic cost profile for the number of staff required to achieve strategic and tactical objectives safely, efficiently, and without team burnout.*" This recommendation was given consideration while updating staffing and non-payroll budget estimates. As pointed out in the 2019 LRP, the summit technical operations estimate provided at the time of LRP submission carried significant uncertainty and risk (see LRP Section 5.3.2 : "The top priority remains the completion of the construction of DKIST on schedule. Hence, construction staff availability for operations planning is very limited, which affects primarily the planning of technical operations on summit. An example of where additional planning effort is needed and would be helpful for defining resource requirements is the detailed planning of maintenance of the complex summit facility. […] The lack of very detailed planning of the summit technical operations introduces uncertainty and risk in the resource estimates in this area." This same concern applied to some extent to new instrumentation development.

In FY 2020, staffing requirements and non-payroll cost estimates for all WBS elements of DKIST Operations were refined and updated. In particular, Technical Operations staffing plans were iterated with the newly appointed Technical Operations Manager (TOM) and the Deputy TOM. Experience gained from on-Sun campaigns such as the First Light Initiative provided additional and more realistic guidance for what technical support levels would be needed to operate DKIST. In order to enable a seven-day, sunrise-to-sunset observing schedule and including the two-hour daily drive time to and from the summit in work schedules, it was necessary to increase technical support staffing. We note that during construction the drive time is/was not counted as "work time". In addition, as a result of more detailed TechOps planning, the aggressive ramp down of "transition staffing" described in the LRP was deemed to be unrealistic.

The first proposal call for the Operations Commissioning Phase (OCP) was released in May, 2020. The support provided to the community during the proposal process via the newly developed help desk was and continues to be significant. In particular, the support required and provided by the DKIST science team turns out to be much higher than anticipated. The need for science support is expected to ramp up during the proposal preparation and execution phase, when selected proposals have to be converted to executable experiments, tested, and executed in service mode. Additional science support was added to the DKIST operations staffing.

Staffing plan updates resulted in a net increase of the total number of FTEs for years FY 2021–2024 from 354 (LRP estimate) to 385 FTEs, with the by far largest increase in Technical/Summit Operations.

Non-Payroll estimates were also updated, resulting in an increase of the annual non-payroll expenses in the areas of Maui Technical and Facilities operations and new instrumentation development. The initial estimates performed by systems engineering and management staff were updated with bottom-up estimates performed by the heads of the various engineering departments. The WBS element "New Instrumentation Development" also experienced an increase in non-payroll estimates. The feasibility and conceptual design study for the MCAO deformable mirror conjugate to 11km conjugate and slated to replace M7 resulted in an increased cost estimate by the vendor. An extensive effort including market studies and vendor visits was undertaken to obtain updated cost estimates for the infrared detector and camera upgrades and replacements. The cost of new, state-of-the-art IR detector technology is significantly higher than previously estimated.

The May 1, 2021 operations start date constitutes a 10-month delay compared to the July 1, 2020 start of operations assumed at the time when the LRP budget was developed. The resulting deferred operations expenses offset the cost increases. The LRP budget projected a budget deficit of $5.8M, which was projected to be realized at the end of the current CSA (FY 2023 – 2024). The net impact of cost increases and cost savings due to a later operations start is a reduction of the projected deficit to $4.5M, which would be realized in FY 2024. In case of further construction project delays, primarily due to COVID-19, additional cost savings due to deferred salary, travel and non-payroll expenses would be realized (within current operations CSA).

For FY 2021, a significant fraction of the new operations personnel corresponds to transfers from the construction team (now delayed due to COVID-19). New hires will occur as additional personnel for the Data Center and operations tools, technical staff, and additional scientific support staff, including graduate students and postdocs.

The DKIST scientific staff corresponds to personnel transferred from NSO programs in Sunspot and Tucson and new hires in Boulder and Maui made in past years. Scientists' service support for DKIST operations is budgeted (payroll and non-payroll) at $1.88M, of which scientists' research time is $1.1M. Five scientists and several postdocs are based in Maui, where they interact with our instrument partners on the island.

A DKIST Chief Operator in Maui leads the Science Operations Specialists (SOS) team on the island. Five SOS staff are already part of the team, and one additional position will be hired in FY 2021. The SOS team has trained at the Dunn Solar Telescope in Sunspot, where they are supported by the DST's telescope Chief Operator. New SOS team members may receive initial training at the DST, although, the bulk of training activities are now conducted at DKIST. The team reports to the DKIST Science Operations Manager, and the total payroll cost is $713K.

Table 8-8. DKIST Operations Program Budget						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
DKIST Operations	**64.21**	**$9,423,740**	**$8,099,010**	**$17,522,750**	**$0**	**$17,522,750**
Directorate	1.22	$309,123	$119,151	$428,274		$428,274
Observatory Operations Management: Business/Administration	2.01	$213,193	$72,807	$286,000		$286,000
Safety	1.26	$174,272	$57,047	$231,318		$231,318
Science - Research	6.99	$900,036	$173,244	$1,073,280		$1,073,280
Science - Operations Support	4.60	$643,909	$166,805	$810,714		$810,714
Science- DKIST EPO	2.00	$185,630	$14,423	$200,053		$200,053
Science - Joint CU/NSO			$169,021	$169,021		$169,021
Science - Development	2.91	$433,142	$74,747	$507,889		$507,889
Maui Tech & Facilities Management	0.76	$197,024	$106,809	$303,833		$303,833
DKIST Facilities-Maui	1.18	$155,526	$901,789	$1,057,316		$1,057,316
DSSC	0.12	$20,282	$286,775	$307,057		$307,057
DKIST Summit Engineering	14.32	$2,012,731	$643,252	$2,655,983		$2,655,983
DKIST Facilities-HQ			$310,284	$310,284		$310,284
Computing - IT			$264,753	$264,753		$264,753
Machine Shop			$34,400	$34,400		$34,400
DKIST Development	4.09	$698,441	$98,750	$797,191		$797,191
Development-MCAO	2.39	$415,019	$1,890,555	$2,305,574		$2,305,574
Development-Next Gen Inst/Upgrades			$845,039	$845,039		$845,039
IT Support	2.18	$306,665	$51,814	$358,478		$358,478
Data Center OPS	8.52	$1,370,862	$1,158,346	$2,529,208		$2,529,208
DKIST Science Ops	1.00	$212,280	$64,409	$276,689		$276,689
SOS	5.51	$713,770	$55,460	$769,230		$769,230
OpsTools	3.15	$461,835	$77,360	$539,195		$539,195
DKIST Ops PRB			$253,748	$253,748		$253,748
Historical Unfunded Liabilities			$37,720	$37,720		$37,720
NSO Insurance through AURA			$14,966	$14,966		$14,966
Ultipro			$25,604	$25,604		$25,604
DKIST Rental House			$102,991	$102,991		$102,991
Quality Control			$26,943	$26,943		$26,943
Total:	**64.21**	**$9,423,740**	**$8,099,010**	**$17,522,750**	**$0**	**$17,522,750**
Target:						**$17,514,444**
Variance:						**($8,306)**

With the availability of the DKIST Science Support Center in Maui, the DKIST Program has almost completed the ramp up on the island. New operations positions will be filled from the construction team, accounting for most of the staff cost for the 'DKIST Summit Engineering' ($2.7M). Coming from the construction effort, this team brings all necessary skills to support summit operations, including optical, mechanical, and electrical, and software engineers and technicians. The present staffing estimates reflect our current best understanding of Observatory needs. Those estimates will need dynamic adjustments based on the realities "on the ground" as they develop, most prominently the future evolution of the COVID-19 global pandemic.

In FY 2019, and coinciding with the development of the FY 2020 – FY 2024 LRP, the staffing plan and estimates for payroll and non-payroll expenses for the steady-state operations phase were updated based on current information of operations requirements. As a caveat, we note that a detailed bottom-up estimation of the summit technical operations effort, including maintenance, repairs, and upgrades, is still incomplete in some areas and will be finalized during FY 2021, in the final phases of construction. Estimates for non-payroll expenses such as electricity have also been refined based on more realistic (as implemented) system information available. The FY 2021 DKIST Ops budget contains five months of the cost of utilities for summit operations ('DKIST Facilities-Maui') totaling $1.06M and covering personnel, electricity, vehicles, offsite storage, and others.

The DKIST Data Center completed the staffing plan in FY 2020. Additional recruitments occurred for operational tools development. The Data Center team is focusing on the implementation phase. The team has re-profiled the original CA proposal's hardware expenditures to adjust to a highly dynamic market that forces all capital equipment acquisitions as late as possible. The purchases started in FY 2020 and continue this year, with almost $700K of new equipment. In FY 2021, the total Data Center, including 'OpsTools' development (also under the DKIST DC Project Manager), amounts to approximately $3M (Table 8-8, 'Data Center OPS', $2.5M, and 'OpsTools', $500K).

The DKIST Program budgets IT non-payroll cost in FY 2021 at a level of $265K, smaller than in the previous year when multiple hardware acquisitions in Maui occurred.

Table 8-9. DKIST Operations Program Carry Forward

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
DKIST Operations	**0.00**		**$32,256,748**	**$32,256,748**	**$0**	**$32,256,748**
Directorate			$23,491,920	$23,491,920		$23,491,920
Observatory Operations Management: Business/Administration			$0	$0		$0
Safety			$0	$0		$0
Science - Research			$0	$0		$0
Science - Operations Support			$0	$0		$0
Science- DKIST EPO			$0	$0		$0
Joint CU/NSO			$0	$0		$0
Science - Development			$0	$0		$0
Maui Tech & Facilities Management			$0	$0		$0
DKIST Facilities-Maui			$0	$0		$0
DSSC			$0	$0		$0
DKIST Summit Engineering			$0	$0		$0
DKIST Facilities-HQ			$0	$0		$0
Computing - IT			$0	$0		$0
Machine Shop			$0	$0		$0
DKIST Development			$0	$0		$0
Development-MCAO			$2,226,943	$2,226,943		$2,226,943
Development-Next Gen Inst			$6,537,885	$6,537,885		$6,537,885
IT Support			$0	$0		$0
Data Center OPS			$0	$0		$0
DKIST Science Ops			$0	$0		$0
SOS			$0	$0		$0
DKIST Ops PRB			$0	$0		$0
Historical Unfunded Liabilities			$0	$0		$0
NSO Insurance through AURA			$0	$0		$0
Ultipro			$0	$0		$0
Total:	**0.00**		**$32,256,748**	**$32,256,748**	**$0**	**$32,256,748**
Target:						**$32,256,755**
Variance:						**$7**

The DKIST Program has a substantial carry forward, as shown in Table 8-9. We note that several large contracts, including the MCAO DM, IR detectors and a custom-built Image Slicer, that were originally planned to be led in FY 2020 have slipped to FY 2021 and are contributing to the significant carry forward. The NSF's budget profile for the ramp up to operations of DKIST and subsequent steady-state operations was based on NSO's best understanding of DKIST Operations cost available at the time (2013). The LRP discussed the necessity for having to re-profile the DKIST operations budget. In summary, increased operations cost are offset by deferred spending due to delays in the start of operations, most recently due to COVID-19. The deferred spending resulted in the significant carry forward from FY 2020, which will be needed to cover operations expenses in FY 2021–FY 2024.

Anticipating the shortfall of operations funds in the out years, DKIST has taken a very conservative approach to new development activities. A planned start of a full second-generation instrument effort is on hold until the overall budget situation is fully understood. The instrumentation program will be limited to the DKIST MCAO development, major upgrades, and improvements to existing instrumentation. MCAO development is expected to spend [redacted] budgeted under carry forward), the majority of which is for the DM11km DM contract and payroll expenses. A total o [redacted] is budgeted for instruments upgrades.

Table 8-9 has one item categorized as "unbudgeted" (‘Directorate’, $23.49M). The DKIST Program will carry these funds forward into FY 2022 and beyond according to the budget re-profiling discussed with NSF and discussed in the FY 2020 – FY 2024 LRP (Section 10.2.2, Table 10-9). The carry-forward funds will be used in years FY 2022 – FY 2024 to offset the higher cost of operating the facility.

8.2.3 NSO Integrated Synoptic Program (NISP)

The NISP combines staff from SOLIS and GONG under Alexei Pevtsov as Associate Director. The NSF base funding for NISP in FY 2021 corresponds to $2.33M (Table 8-10), with an increase concerning FY 2020 according to the assumed escalation factor (3%) in the NSF provided CA profile. The Program continues to use the FY 2016 one-time contribution for GONG refurbishment, and the unused funds ($557K) are part of the Program's FY 2021 carry-forward budget (Table 8-11). The funding available for GONG operations, received in past years from NOAA, reflects the remaining funds from the current five-year IAA totaling only $164K (Table 8-12 ‘SWPC’ accounts). This reduced amount compared to the annual NOAA contribution reflects the original mismatch in period of performance and the increased cost of operating the network. The non-NOAA grant funding in Table 8-12 is similar to the amount received in FY 2020. It includes a new collaboration with the Stanford SDO/HMI group to develop an end-to-end simulator that reproduces the instrument’s performance.

Currently, NISP has a total of approximately 21 FTEs. The NSF base funding covers about 12 FTEs, and 6 FTEs are grant-supported (all scientists). GONG operations use 3 FTEs funded from the Director's carry forward (Table 8-7).

NISP comprises an Atmospheric Section and an Interior Section, each led by a project scientist/project lead who reports to the NISP Associate Director. Both project leads are only partially supported by the NSF base funding. The Telescope Operations and Instrument Development staff, supervised by the NISP Engineering Manager, supports both SOLIS and GONG instruments and upgrades. The base-funded fraction of scientific staff time supports the development of various NISP data products, monitoring the data quality, addressing routine/emergency issues related to data processing, and responding to the community's need for data access.

Table 8-10. NSO Integrated Synoptic Program Budget						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	**11.77**	**$1,568,178**	**$766,707**	**$2,334,885**	**$0**	**$2,334,885**
NISP Directorate	1.00	$200,265	$31,988	$232,253		$232,253
NISP Administration	0.67	$67,440	$5,490	$72,930		$72,930
NISP Project Management	0.10	$16,997	$1,321	$18,318		$18,318
Data Center	3.73	$481,218	$175,815	$657,032		$657,032
Scientific Staff	2.96	$409,376	$58,339	$467,716		$467,716
Engineering Operations GONG	2.04	$247,409	$19,224	$266,632		$266,632
Engineering Operations SOLIS	0.51	$67,030	$5,208	$72,238		$72,238
SOLIS Ops/Supt	0.01	$1,404	$231,078	$232,482		$232,482
Post Retirement Benefits			$28,823	$28,823		$28,823
Ultipro			$3,299	$3,299		$3,299
CU IT Connectivity Fees			$9,220	$9,220		$9,220
Unfunded liabilities			$4,934	$4,934		$4,934
CU and Machine Shop Lease Fees			$170,663	$170,663		$170,663
NSO IT	0.75	$77,040	$21,305	$98,345		$98,345
Total:	**11.77**	**$1,568,178**	**$766,707**	**$2,334,885**	**$0**	**$2,334,885**
Target:						**$2,334,660**
Variance:						**($225)**

GONG data are reduced daily by the NISP Data Center and made available for downloading by the solar community. While no new observations were taken by SOLIS instruments in FY 2020, the Data Center staff did several major reprocessings of SOLIS VSM data, including implementing two-line inversion photospheric vector magnetograms. The new inversion results were tested and underwent a detailed verification process. After the two-line inversion reprocessing was completed, all higher-level data products (e.g., synoptic maps) were re-created. The reprocessing was also accompanied by creating detailed documentation about the inversion and the data processing.

NISP base funding in FY 2021 covers scientific support to the Program ($468K), administrative staff, NISP Data Center activities ($657K), GONG developments ($266K), and the, still somewhat uncertain, higher cost of the relocation of SOLIS to Big Bear Solar Observatory. In FY 2021 the base funding contribution to SOLIS is $231K (Table 8-11) that supplements past years' carry forward.

NISP carry forward in FY 2021 (Table 8-11) totals $1.3M, split into $557K for GONG refurbishment, $177K for Data Center equipment, and $572K FY 2020 unspent funds due to the lack of progress in SOLIS construction at BBSO. The FY 2021 budget for all components of SOLIS at BBSO totals $863K.

Table 8-11. NISP Carry Forward						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	**0.00**		**$1,314,922**	**$1,314,922**	**$0**	**$1,314,922**
NISP Data Center			$177,785	$177,785		$177,785
GONG Refurbishment			$556,573	$556,573		$556,573
SOLIS Relocation			$571,612	$571,612		$571,612
CU IT Connectivity Fees			$8,952	$8,952		$8,952
Total:	**0.00**		**$1,314,922**	**$1,314,922**	**$0**	**$1,314,922**
Target:						**$1,314,922**
Variance:						**$0**

Table 8-12. NISP Budget with External Funds						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	**6.30**	**$746,486**	**$605,849**	**$1,352,335**	**$0**	**$1,352,335**
SWPC Payroll			$0	$0		$0
SWPC Learmonth (LE)			$0	$0		$0
SWPC Udaipur (UD)			$0	$0		$0
SWPC Tenerife (TD)			$0	$0		$0
SWPC CTIO (CT)			$0	$0		$0
SWPC Big Bear (BB)			$60,292	$60,292		$60,292
SWPC Mauna Loa (ML)			$103,990	$103,990		$103,990
SWPC Boulder			$0	$0		$0
SWPC Network			$0	$0		$0
Do Flows In The Upper Solar	0.79	$101,668	$6,636	$108,303		$108,303
Study of the Emission Heights			$0	$0		$0
The Continuing Expansion of the VSO	0.45	$57,634	$171,351	$228,985		$228,985
Probing the deep solar meridional flow	0.22	$27,904	$3,064	$30,968		$30,968
Meridional Flow Measurements	0.73	$97,662	$35,841	$133,503		$133,503
Subsurface Dynamics of Solar Active Regions	1.02	$133,643	($31,461)	$102,182		$102,182
Subsurface Zonal & Meridional			$0	$0		$0
Magnetic Data Driven Global	1.10	$76,058	$27,894	$103,953		$103,953
The Simplest Magnetograph	1.10	$136,386	$216,227	$352,613		$352,613
Consequences of Flows and Fields	0.14	$19,626	($3,278)	$16,348		$16,348
SDO Helioseismic and Magnetic Imager	0.75	$95,904	$15,294	$111,198		$111,198
Total:	**6.30**	**$746,486**	**$605,849**	**$1,352,335**	**$0**	**$1,352,335**
Target:						**$1,351,012**
Variance:						**($1,323)**

Table 8-12 details the additional, non-NSF/AST funding received by NISP in FY 2021. The FY 2021 budget has been, once again, greatly alleviated by a series of successful grants and subcontracts. The downside of this is that the NISP science workforce focuses efforts on the scope of the grants but reduces support to the Program's main scientific areas represented by GONG and SOLIS. While being brought online at BBSO, the hiatus in SOLIS data also helps relieve the pressure on the scientists' dedication to this instrument. However, other unexpected issues (such as the expiration of ephemeris tables for GONG operations) puts additional demand on scientists' time.

NISP faces considerable challenges over the next few years. Several factors have contributed to constrain the budget severely. The continued application of merit increases, aligned with the Observatory, but for a program in which funding was capped, has created a deficit in the program's payroll. The regular promotions for several scientists were delayed beyond the normal promotion periods established at the NSO. These promotions were made at the end of FY 2020 and required salary adjustments put further stress on the NISP budget. Additionally, the cost of SOLIS relocation to BBSO is now better understood, and it is at least $700K higher than the initial cost estimated by BBSO. The Program has negotiated a certain in-kind contribution from BSSO/NJIT, which allows restarting SOLIS construction in FY 2021. This activity requires re-profiling the funding from other FY 2021 budget lines to SOLIS construction.

Complicating things further, in FY 2020, NOIRLab/CTIO began charging site fees for the GONG shelter footprint. In FY 2021, this fee has been increased to about $65K per year. Site fees were also raised by two other GONG sites, although the NISP negotiated a one-year delay in increasing site fees with the Udaipur Solar Observatory, India. NOAA/SWPC support for GONG operations terminates at the end of FY 2021, and the Program began submitting updated budgets to NOAA/SWPC for the next five-year IAA, including these higher site fees.

8.2.4 NSO Community Science Program (NCSP)

Table 8-13 shows the one-year budget breakdown for the Program carried forward in FY 2021 and is budgeted following the original DKIST Level-2 proposal guidelines.

The Program's primary mission is the development of DKIST Level-2 data products. The actual creation of these data products will have to wait until the DKIST starts producing Level-1 data. In preparation for this phase, NCSP defined in FY 2020 the Level-2 data products requirements included in the original proposal. NCSP is searching for the best existing analogs from other telescopes (including DST service mode) and instruments to train the Level-2 pipelines.
The DKIST Level-2 proposal included three interrelated initiatives: a data product initiative; a community-oriented initiative; and a university-oriented initiative that continue in FY 2021. All three initiatives use logistics and outreach support provided by the NSO.

The Data-Products Initiative represents an effort that occurs at NSO and targets Level-2 data products after the Operations Commissioning Phase. It uses about 50% of the total funding throughout the Program. The original proposal included two scientists from NSO and three new postdoc positions to develop the scientific pipelines for producing Level-2 data. NCSP has changed this model to benefit from the existing expertise at NSO in the Level-2 area. Currently, the Program includes a more significant number of NSO scientists and only one postdoc. An additional three-year position acting as DKIST Level-2 Project Scientist, shared with LASP (CU-Boulder), started in FY 2020. The Project Scientist is responsible for ensuring that the Level-2 data aligns with the original requirements and serves as the scientific point of contact to interface with the DKIST Data Center. The Project Scientist funding is part of the $276K 'Service Support' (non-payroll) account as it uses a speed-type charge from CU Boulder. The payroll service support from NSO scientists to NCSP totals $221K ('Service Support'). The research time is $224K ('Science Support' payroll), including the postdoc, whose research links to the generation and use of Level-2 coronal data products.

Table 8-13. NCSP Carry Forward

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO Community Science Program	**6.85**	**$970,742**	**$2,140,978**	**$3,111,720**	**$0**	**$3,111,720**
Administrative Support	0.18	$21,465	$49,393	$70,858		$70,858
Science Support	1.94	$224,432	$206,646	$431,078		$431,078
Graduate Students Support			$899,398	$899,398		$899,398
Visitors Program-Short Term			$53,885	$53,885		$53,885
Visitors Progrm-Long Term			$0	$0		$0
Service Support	1.53	$221,276	$275,841	$497,117		$497,117
Data Center Support	2.85	$464,233	$422,459	$886,692		$886,692
Headquarters Expeditures			$153,042	$153,042		$153,042
Data Training Workshop			$77,258	$77,258		$77,258
Curriculum Preparation	0.35	$39,336	$3,056	$42,393		$42,393
Total:	**6.85**	**$970,742**	**$2,140,978**	**$3,111,720**	**$0**	**$3,111,720**
Target:						**$3,113,680**
Variance:						**$1,960**

NCSP has already acquired the two computer clusters based on two 1296 Core Cluster, Xeon 6150 2.7 Ghz, 192 Gb/node connected through Infiniband, built by HP. The CU-Boulder Office of Information Technology administers them for NSO free of charge. The 'Data Center Support' account for the DKIST Level-2 effort is split into $464K for payroll and $422K for data-distribution hardware.

The Community-Oriented Initiative has exhausted almost all the funds. FY 2021 will cover only the expenses included in the summer salary of the CU-Boulder three-year Hale visiting faculty position ('Visitors Program-Short Term'; $54K). The incumbent is responsible for the DL-NIRSP Level-2 data pipeline.

The University-Development Initiative helps grow the DKIST community and takes place at graduate programs in the country. Support for the DKIST Ambassadors ('Graduate Students Support') accounts for $899K of the FY 2020 budget. However, only a fraction will be spent in FY 2021, with the remaining amount encumbered in future years due to how NCSP established the Ambassadors contracts. The DKIST Ambassadors Program provides a matching-funds opportunity for students that spans over a total of four years, with NCSP covering only two years and the selected institution the other two. Thus, some of the actual expenditures will occur in FY 2022, depending on the matching funds model. NCSP has re-profiled COVID-19 related savings in the travel budget to account for some of the larger overheads occurring in the Ambassadors Program with the eight participating academic institutions.

The University-Development Initiative includes an additional $77K ('Data Training Workshop') for broad community training activities in the creation of Level-2 data products. The activity includes a travel budget to support these activities for, both, attendees and mentors (often NSO scientist) with the expectation that they can occur in person during the last quarter of FY 2021.

NCSP has a sub-award with the High Altitude Observatory that defines their scientists' participation in the Program started in FY 2020 and that continues in FY 2021 ($135K, a component of the 'Science Support' non-payroll cost).

8.2.5 Sacramento Peak (Sunspot)

In FY 2021, NSO plans to operate the Sunspot site and collaborate with the NMSU-led SSOC in the operations of the Dunn Solar Telescope. NSO initially estimated the cost of operating the site at $300K/year. This cost includes site support and administrative staff and utilities, excluding the DST and the Visitors Center (both operated by NMSU). Following the security incident in 2018, NSO relocated a site manager to the site, increasing the cost of operating the facilities and creating a deficit in the Sunspot Program. In FY 2021, the NSO Director's Office is re-budgeting savings from the reduced travel due to the COVID-19 to cover this deficit. However, a new source of unbudgeted expenditures has appeared due to various aging components at the facility (backup electricity generator, broken water lines, site wireless access, and others). These deferred maintenance items create a negative balance of $88K in the Sunspot budget (see Table 8-14). NSO is in conversations with the NSF to solicit an augmentation to the FY 2021 SFR to cover these costs.

NSO also charges the SSOC for costs that include the DST Chief Observer and telescope and Visitor Center utilities and maintenance, following the MOU guidelines between NMSU and AURA. The funds associated with these charges to the SSOC are outside of the budget presented here and are not in WEBUD.

Table 8-14. NSO Sacramento Peak Budget						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO SP	**2.46**	**$196,159**	**$230,923**	**$427,082**	**$39,140**	**$387,942**
Administrative Services	0.50	$52,159	$19,166	$71,325		$71,325
Scientific Staff			$0	$0		$0
Telescope Operations			$0	$0		$0
Instrument Development and Telescope Maintenance			$0	$0		$0
Computing Support			$120	$120		$120
Facility Maintenance	1.96	$144,000	$211,637	$355,638		$355,638
Housing			$0	$0	$39,140	-$39,140
Visitor Center			$0	$0		$0
Sunspot Relocatables			$0	$0		$0
Total:	**2.46**	**$196,159**	**$230,923**	**$427,082**	**$39,140**	**$387,942**
Target:						**$300,000**
Variance:						**($87,942)**

The program carry forward ($351K, Table 8-15) corresponds entirely to the SFR received in FY 2020 to cover the move of the relocatable houses to Alamogordo.

Table 8-15. NSO Sacramento Peak Carry Forward						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO SP	**0.09**	**$10,505**	**$340,418**	**$350,924**	**$0**	**$350,924**
Administrative Services			$0	$0		$0
Scientific Staff			$0	$0		$0
Telescope Operations			$0	$0		$0
Instrument Development and Telescope Maintenance			$0	$0		$0
Computing Support			$0	$0		$0
Facility Maintenance			$0	$0		$0
Housing			$0	$0		$0
Kitchen			$0	$0		$0
Visitor Center			$0	$0		$0
Sunspot Relocatables	0.09	$10,505	$340,418	$350,924		$350,924
Total:	**0.09**	**$10,505**	**$340,418**	**$350,924**	**$0**	**$350,924**
Target:						**$350,796**
Variance:						**($128)**

8.2.6 AURA Indirect Costs, Fringe Benefit Rate and Fee

Tables 8-16, 8-17, and 8-18 show the expenses NSO incurs for AURA for Facilities and Administrative (F&A) costs, Central Administrative Services (CAS), and Human Resources (HR) for FY 2021 NSF Funds, grant funding, and for FY 2021 NSO carry forward, respectively. Table 8-17 (grants) also includes the NSO Program Usage Recovery Rate.

The fringe benefits and indirect rates were applied per the FY 2021 approved Provisional Indirect Rate Agreement letter from the NSF, dated July 26, 2019.

Table 8-15. AURA Fees (FY 2021 NSO Base Funds)	
Indirect Cost Type	**Charge**
AURA CAS & HR Support	$887,737
AURA Corporate F&A	$558,325
Total	**$1,446,062**

Table 8-16. AURA Fees (FY 2021 NSO Grants)	
Indirect Cost Type	**Charge**
AURA CAS & HR Support	$52,958
NSO Program Usage Recovery Rate	$88,374
AURA Corporate F&A	$33,307
Total	**$174,639**

Table 8-17. AURA Fees (FY 2021 NSO Carry Forward)	
Indirect Cost Type	**Charge**
AURA CAS & HR Support	$1,224,505
AURA Corporate F&A	$770,166
Total	**$1,994,670**

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APPENDICES

APPENDIX A. SCIENTIFIC AND KEY MANAGEMENT STAFF

The NSO staff provide support to users including observational support, developing and supporting state-of-the-art instrumentation to ensure that users obtain the best data, and maintaining data archives and the means to accessing the data. Members of the scientific staff are defining how DKIST will be operated and how NSO will handle the data. In addition, both scientific and engineering staff serve as mentors for undergraduate and graduate students and postdoctoral fellows. They also organize community workshops on critical areas of solar research and planning. Staff science and instrument development allow NSO to stay at the forefront of solar physics and play a crucial role in fulfilling user support.

The current NSO scientific and management staff, as well as affiliated scientific staff, are listed below with their primary areas of expertise and key observatory responsibilities.

Scientific Staff

Christian Beck	Post-focus instrumentation; data reduction pipelines; high-resolution spectroscopy and spectro-polarimetry of the photosphere and chromosphere; development of inversion tools for chromospheric spectral lines; polarimetric calibration techniques; DKIST instrumentation and polarimetric calibration approaches.
Luca Bertello	NISP/SOLIS Data Scientist; solar variability at different temporal, spectral, and spatial scales; calibration of the observed solar magnetic field data to enhance the database that supports analysis of conditions in the corona and heliosphere; long-term synoptic observations in the resonance line of Ca II K for retrospective analyses of solar magnetism on multi-decade time scales; analysis of helioseismological data for better understanding solar interior structure and dynamics.
Serena Criscuoli	High-spatial resolution spectroscopy and spectropolarimetry of the photosphere and chromosphere; radiative transfer; numerical simulations; solar irradiance variations; scientific consultant for DKIST.
Gianna Cauzzi	High resolution imaging and spectroscopy of the lower solar atmosphere; chromospheric structure and dynamics, including wave dynamics and heating. Flare physics and lower atmospheric signatures. Imaging instrumentation based on Fabry-Perot interferometers; Chairs the Science Review Committee for the DKIST OCP.
Alisdair Davey	CMEs and associated phenomena; acceleration and heliospheric propagation of SEPs during solar flares and CMEs; use of computer vision/AI in identifying solar features and events; development of the VSO and the heliospheric data environment, including integration of data and modeling efforts.
Andre Fehlmann	DKIST infrared instrumentation specialist; IR instrumentation; precision spectro-polarimetry; coronal magnetic fields; student engagement and community outreach.

Sanjay Gosain	Observatory Scientist; astronomical instrumentation: optical design of instruments for polarimetry and spectroscopy; solar physics: flares, eruptive filaments and coronal mass ejections; chromospheric magnetic field of solar active regions; solar cycle evolution of magnetic field.
David M. Harrington	DKIST polarimetry scientist; instrumentation; spectropolarimetry, adaptive optics, novel optical systems, detector systems, applied research, community workforce development.
Sarah A. Jaeggli	3D structure of sunspot magnetic fields; atomic and molecular physics of the photosphere and chromosphere; radiative transfer modeling and spectral synthesis; instrumentation for spectroscopy and spectropolarimetry, including DKIST facility instrument development; engaging the community to perform multi-facility observations.
Kiran Jain	Helioseismology: oscillation mode characteristics; multi-wavelength helioseismology; subsurface dynamics; active regions; solar activity; Sun-Earth connection.
Maria Kazachenko	Inversion techniques to derive the electric fields and Poynting fluxes on the surface of the Sun using magnetic field measurements; data-driven simulations of the solar coronal magnetic fields; statistical properties of solar flares.
Rudolf W. Komm	Helioseismology; dynamics of the solar convection zone; solar activity and variability.
Adam F. Kowalski	Flare observations and radiative-hydrodynamic modeling; white-light flare radiation and continuum properties; connection between magnetic activity and flares on the Sun and younger M dwarf stars; teaching physics of stellar atmosphere modeling and observational astronomy and spectroscopic analysis; student mentor.
Jose Marino	DKIST wavefront correction; image restoration; solar adaptive optics and multi-conjugate adaptive optics; solar adaptive optics modeling and simulation; high-resolution solar observations; atmospheric tomography; point spread function estimation.
Valentín M. Pillet	NSO Director; solar activity; Sun-heliosphere connectivity; magnetic field measurements; spectroscopy; polarimetry; astronomical instrumentation with an emphasis on spectropolarimetry.
Gordon J. D. Petrie	NISP; solar magnetism; the polar magnetic fields and their responses to activity; magnetic restructuring and associated Lorentz force changes during flares; coronal magnetic field extrapolations; CMEs; DKIST critical science planning.

Alexei A. Pevtsov	NSO Associate Director for NISP; Chair, NSO Scientific Personnel Committee; solar magnetic fields; corona; sunspots; chromosphere; solar-stellar research; space weather and space climate.
Kevin P. Reardon	Dynamics and structure of the solar chromosphere, transition region, and corona; implementation of modern techniques for data archiving, processing, and discovery; application of imaging spectroscopy techniques; post-focus instrumentation development; spectropolari-metry of the solar atmosphere; transit studies of inner planets; history of solar astronomy.
Thomas R. Rimmele	NSO Associate Director for DKIST; DKIST Construction Project Director; sunspots; small-scale magnetic surface fields; active region dynamics; flares; acoustics waves; weak fields; adaptive optics; multi-conjugate adaptive optics; instrumentation.
Thomas A. Schad	Chromospheric and coronal magnetic field dynamics; precision spectro-polarimetry; infrared instrumentation, including DKIST facility instrument development; student engagement and community outreach; scientific lead, DKIST Instrument Control System.
Dirk Schmidt	DKIST adaptive optics, high spatio-temporal resolution observation techniques; development of adaptive optics systems, in particular multi-conjugate adaptive optics systems.
Lucas Tarr	Observational, theoretical, and numerical investigations of the low solar atmosphere to study energy propagation, storage, and release.
Sushanta Tripathy	NISP Interior Program Scientist; magnetoseismology of active regions; global and local helioseismology; solar activity cycle; ring-diagram analysis, sub-surface flows, cross-spectral analysis of oscillation time series.
Alexandra Tritschler	Senior Scientist; DKIST Operations Scientist; DKIST operations development; DKIST Observatory Control System Scientist; DKIST Target Acquisition System Scientist; DKIST Visible Broadband Imager; solar fine structure; magnetism; Stokes polarimetry.
Han Uitenbroek	Associate Director for NSO Community Science Program; atmospheric structure and dynamics; radiative transfer modeling of the solar atmosphere; DKIST Visible Broadband Imager.
Friedrich Wöger	Senior Scientist; DKIST Instruments Project Scientist. Image reconstruction techniques; adaptive optics; two-dimensional spec-troscopy, and spectro-polarimetry; DKIST instrumentation, in particular the visible broadband imager; DKIST wavefront correction system; DKIST data handling system.

Grant-Supported Scientific Staff

Shukirjon S. Kholikov	Helioseismology; data analysis techniques; time-distance methods.

Postdoctoral Fellows

Andrei Afanasev	Data-drive MHD modeling of solar active regions.
Tetsu Anan	Solar chromospheric heating; high-energy non-thermal particles; integral-field-unit spectro-polarimetry. Technical review committee member of DKIST OCP Cycle 1 proposals.
Shah M. Bahauddin	Application of neural networks to spectral inversions and photospheric dynamics.
Alin R. Paraschiv	Mathematical inversion problems in solar physics.
Yuta Notsu	Stellar magnetic activity and flares.
Benoit Tremblay	Machine learning techniques for inferring solar plasma motions.

Key Management Staff

Anastasia Alexov	DKIST Science Operations Manager.
Gregory Card	NISP Engineering & Technical Manager.
Jennifer L. Ditsler	Head of Administration & Support Facilities.
Bret D. Goodrich	DKIST Instrumentation Manager.
Rex G. Hunter	DKIST Construction Business Manager.
Heather K. Marshall	DKIST Technical Operations Manager.
Claire L. Raftery	NSO Head of Education and Public Outreach.
Robert E. Tawa	DKIST Data Center Project Manager.
Mark Warner	DKIST Program Manager.
Carolyn Watkins	NSO Business Operations Manager.

Graduate Students

Elizabeth Butler	University of Colorado	Analysis of solar flare observations from IRIS.
Suman Dhakal	George Mason University	Investigating magnetic and thermal structures of coronal cavities.

Graduate Students (cont.)

Wen He	University of Alabama at Huntsville	Topology and dynamic evolution of solar eruptive magnetic field.
Ryan Hofmann	University of Colorado	Comparison of inversion-derived temperature profiles with ALMA observations.
Neeraj Kulkarni	University of Colorado	Modeling of quiet Sun linear polarization signals.
Momchil Molnar	University of Colorado	Multiwavelength studies of the chromospheric dynamics using IBIS, ALMA, and IRIS.
Eleni Nikou	George Mason University	Emerging magnetic flux, flux cancellation and its driven changes to the chromosphere and corona.
Willow Reed	Montana State University	Study of reconnection through chromospheric response to flares.
Johnathan Stauffer	University of Colorado	Analysis of infrared carbon monoxide spectral signatures; spectrographic data characterization.
Denis Tilipman	University of Colorado	Study of quiet-Sun photospheric magnetic fields and dynamics.
Aparna Venkataramanasastry	Georgia State University	Predictions of solar flares and space weather events.
Shuo Wang	New Mexico State University	Inversions of He I 1083 with HAZEL.
Amanda White	University of Colorado	DKIST polarization performance & modeling.
Bryan Yamashiro	University of Hawaiʻi	Assessing the solar open magnetic flux from the surface up.
Yingjie Zhu	University of Michigan	CME diagnostics in the inner corona.

Table A-1. NSO Scientific & Key Management Staff Estimated Percent FTE by Activity (FY 2020)					
Name	Adm/Mgt[1]	Research[2]	Service[3]	Project Support[4]	TOTAL
[a]Afanasev, A.					
Alexov, A.	17.6			82.4	100.0
Anan, T.	3.6	94.0		2.4	100.0
[a]Bahauddin, S.					
Beck, C.		25.0		75.0	100.0
**Bertello, L.		55.3	27.4	17.3	100.0
Card, G.	0.9	0.2		98.9	100.0
Cauzzi, G.		27.3	72.7		100.0
Criscuoli, S.		46.3	20.2	33.5	100.0
Davey, A.		26.0		74.0	100.0
[c]Dima, G.		100.0			100.0
Ditsler, J.	87.8			12.2	100.0
Fehlmann, A.				100.0	100.0
Goodrich, B.	88.1			11.9	100.0
**Gosain, S.		68.7	5.9	25.4	100.0
Harrington, D.				100.0	100.0
Hunter, R.G.	100.0				100.0
Jaeggli, S.	68.2	28.1	1.0	2.7	100.0
**Jain, K.		62.4	0.3	37.3	100.0
[d]Kazachenko, M.					
*Kholikov, S.S.		100.0			100.0
**Komm, R.W.		69.2	1.7	29.1	100.0
[d]Kowalski, A.					
Marino, J.	0.9			99.1	100.0
Marshall, H.				100.0	100.0
Martinez Pillet, V.	100.0				100.0
[a]Notsu, Y.					
Parachiv, A.R.		99.0	1.0		100.0
**Petrie, G.J.D.		80.3		19.7	100.0
Pevtsov, A.A.	26.3	28.7		45.0	100.0
Raftery, C.	93.4		6.6		100.0
Reardon, K.P.		30.4	36.9	32.7	100.0
Rimmele, T.R.	100.0				100.0
Schad, T.A	9.8	50.0	0.2	40.0	100.0
Schmidt, D.		37.1		62.9	100.0
Tarr, L.		62.9		37.1	100.0
Tawa, R. E.				100.0	100.0
[a]Tremblay, B.					
**Tripathy, S.C.		57.9	0.8	41.3	100.0
Tritschler, A.	13.3	1.1		85.6	100.0
Uitenbroek, H.		15.3	75.7	9.0	100.0
Warner, M.	100.0				100.0
Watkins, C.	100.0				100.0
Woeger, F.	96.1			3.9	100.0

[1]Administrative and/or Management Tasks.
[2]Research, including participation in scientific conferences
[3]Includes Educational and Public Outreach (EPO), Internal & External Committees, NCSP activities.
[4]Includes Project Science Ops, Technical Ops.

*Fully grant supported.
**Partially grant supported.
[a]New hire 2021.
[b]Emeritus status in 2020.
[c]Completed employment in 2020.
[d]NSO-CU Boulder shared tenure-track faculty.

APPENDIX B.
NSO OPERATIONS BUDGET CHANGE-CONTROL PROCESS

March 28, 2018

Process Overview

The budget change request process for NSO Operations allows for the traceability of the current NSF approved FY Budget back to the original NSF approved FY Budget. The process ensures all changes to the NSO approved FY Budgets are controlled, documented and managed in a consistent manner. After the initial budget baseline is finalized and submitted to NSF, although there may be changes in respective Area budgets, the NSO bottom line budget amount should not change without the Director's approval.

All budget change requests for NSO Operations will go through the NSO Center "Budget Coordinator" (currently assigned to Carolyn Watkins, Business Manager) for processing. The Budget Coordinator obtains approval from the affected Associate Directors. The Budget Coordinator then coordinates with CAS for Webud and Casnet implementation. The Budget Coordinator maintains an "audit trail"/log with all budget changes.

Initiation of Budget Change Process

The change request process will be initiated if one or more of the following situations are requested:

- Budget moves from one work package/account to another (e.g., within or between divisions).
- Correction of errors in the Division budget/plan

Budget Change Request Submission

Budget change requests are to be submitted to the Budget Coordinator via email.
The change request should contain the following:

- Explanation of Requested Change
- Budget Funding Source (i.e. Base, Carry Forward, etc.)
- To and From Account
- Amount
- Supporting Documentation:

Any relevant files should be submitted along with the change request.

Budget Change Request Approval

The Budget Coordinator will obtain approval from the affected Associate Director(s). Budget request changes coming from the Center and Associate Director(s) to the Budget Coordinator which only affect that Area will be considered as approved.

Budget Change Implementation

Upon receipt of approval from all affected Associate Director(s), the Budget Coordinator will coordinate with CAS to implement the change into WEBUD and CASNET. The Budget Coordinator will review and verify that the requested changes are implemented as requested. The Budget Coordinator will have the sole ability to update WEBUD/CAS with the change request modifications.

Detailed Method of Implementation

1. The Budget Coordinator will make the approved budget changes in Webud.
2. On the 6th working day of each month, CAS will run a program to compare the most current amounts in Webud to the budget amounts in the last month-end published Casnet financial report.
3. Any differences would appear in the "My Budget Transfer Batches" tab of the Casnet Budget Ledger program as an "Unfinished" batch.
4. An email will be sent to the Budget Coordinator advising that a transfer needs to be reviewed.
5. In Budget Ledger, the Budget Coordinator will open the unfinished transfer using "Edit" to review. If it looks correct the Budget Coordinator will "Submit for Approval."
6. At this point the Budget Coordinator will review the batch and save to Excel or PDF for the record.

Tracking Budget Change Requests

The Budget Coordinator will maintain an "audit trail"/ log of all budget changes (spreadsheet tracking form). A report will also be available in CASNET.

APPENDIX C. NSO FY 2021 STAFFING SUMMARY

(In Full-Time Equivalents)

	Director's Office			NCSP	NSO	DKIST				NISP		TOTAL
	Tucson	*Boulder*	*Maui*	*Boulder*	*Sunspot*	*Tucson*	*Sunspot*	*Maui*	*Boulder*	*Tucson*	*Boulder*	
Scientists	-	1.00	-	4.00	-	-	-	7.00	7.00	-	7.00	26.00
Engineering/Science Support Staff	-	2.00	-	1.00	2.00	3.00	-	27.00	24.00	3.00	5.00	67.00
Administrative Staff	0.15	5.00	1.00	-	2.00	0.25	1.00	5.00	1.00	-	1.00	16.40
Technical Staff	-	-	-	-	1.00	-	-	15.00	1.00	-	3.00	20.00
Maintenance & Service Staff	-	-	-	-	2.00	-	-	4.00	-	-	-	6.00
												0.00
Total Base Program	0.15	8.00	1.00	5.00	7.00	3.25	1.00	58.00	33.00	3.00	16.00	***135.40***
Other NSF Projects (AO, FTS/CHEM)	-	-	-	-	-	-	-	-	-	-	-	0.00
Graduate Students	-	-	-	-	-	-	-	-	-	-	-	0.00
NASA Supported Science Staff	-	-	-	-	-	-	-	-	-	-	3.00	3.00
NASA Support Engineering Staff	-	-	-	-	-	-	-	-	-	-	-	0.00
NASA Supported Technical Staff	-	-	-	-	-	-	-	-	-	-	-	0.00
Emeritus Science Staff	3.00	1.00	-	-	3.00	-	-	-	1.00	-	-	8.00
Visiting Scientists	-	-	-	-	-	-	-	-	-	-	-	0.00
Total Other Support	3.00	1.00	-	-	3.00	-	-	-	1.00	-	3.00	***11.00***
Total Working at NSO	3.15	9.00	1.00	5.00	10.00	3.25	1.00	58.00	34.00	3.00	19.00	**146.40**
Scientists	-	-	-	-	-	-	-	1.00	-	-	-	1.00
Engineering/Science Support Staff	-	-	-	-	-	-	-	2.00	1.00	-	-	3.00
Administrative Staff	-	-	-	-	-	-	-	-	-	-	-	0.00
Technical Staff	-	-	-	-	-	-	-	3.00	-	-	-	3.00
Maintenance & Service Staff	-	-	-	-	-	-	-	-	-	-	-	0.00
Total Open Positions	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***6.00***	***1.00***	***0.00***	***0.00***	***7.00***
Total NSO FTEs	**3.15**	**9.00**	**1.00**	**5.00**	**10.00**	**3.25**	**1.00**	**64.00**	**35.00**	**3.00**	**19.00**	**153.40**

APPENDIX D. PUBLICATIONS

(OCTOBER 2019 THROUGH SEPTEMBER 2020)

Author—NSO Staff **Author**—REU
Author—Grad Student ***Author*** —Undergrad

The following is a list of known refereed papers, conference proceedings and non-refereed papers published during FY 2020 by NSO staff, as well as summer and academic-year graduate and undergraduate students. Papers resulting from the use of NSO facilities are also listed.

Refereed Publications

1. Aartsen M. G., Abbasi R., Ackermann M., et al. (2020), "Measurements of the Time-Dependent Cosmic-Ray Sun Shadow with Seven Years of IceCube Data -- Comparison with the Solar Cycle and Magnetic Field Models", arXiv e-prints, arXiv:2006.16298.

2. Abbasvand, V., Sobotka, M., Heinzel, P., Švanda, M., Jurčák, J., del Moro, D., Berrilli, F. (2020), "Chromospheric Heating by Acoustic Waves Compared to Radiative Cooling. II. Revised Grid of Models", *ApJ*, 890, 22, 7 pp.

3. Agaltsov A. D., Hohage T., Novikov R. G. (2020), "Global Uniqueness in a Passive Inverse Problem of Helioseismology", *InvPr*, 36, 055004.

4. Al-Haddad N., Lugaz N., Poedts S., Farrugia C. J., Nieves-Chinchilla T., Roussev I. I. (2019), "Evolution of Coronal Mass Ejection Properties in the Inner Heliosphere: Prediction for the Solar Orbiter and Parker Solar Probe", *ApJ*, 884, 179.

5. Allen, R. C. et al. (34 co-authors) (2020), "Solar Wind Streams and Stream Interaction Regions Observed by the Parker Solar Probe with Corresponding Observations at 1 au", *ApJS*, 246, 36.

6. Allred, J. C., Alaoui, M., **Kowalski, A. F.,** Kerr, G. S. (2020), "Modeling the Transport of Nonthermal Particles in Flares Using Fokker-Planck Kinetic Theory", *ApJ*, 902, id.16.

7. Alvarado-Gámez J. D., Drake J. J., Fraschetti F., Garraffo C., Cohen O., Vocks C., Poppenhäger K., Moschou S. P., Yadav R. K., Manchester W. B. (2020), "Tuning the Exospace Weather Radio for Stellar Coronal Mass Ejections", *ApJ*, 895, 47.

8. **Anan, T., Schad, T. A., Jaeggli, S. A.** and **Tarr, L. A**. (2019), "Shock Heating Energy of Umbral Flashes Measured with Integral Field Unit Spectroscopy", *ApJ*, 882, 161.

9. Aparna V., Martens P. C. (2020), "Solar Filaments and Interplanetary Magnetic Field Bz", *ApJ*, 897, 68.

10. Aschwanden M. J., Wang T. (2020), "Torsional Alfvénic Oscillations Discovered in the Magnetic Free Energy during Solar Flares", *ApJ*, 891, 99.

11. Auchère, F., Andretta, V., Antonucci, E., Bach, N., Battaglia, M. et al. (25 additional co-authors including **Martinez Pillet, V.**) (2020), "Coordination within the Remote Sensing Payload on the Solar Orbiter Mission", *A&A*, 642, A6.

12. Barnes, W. T., Bobra, M. G., Christe, S. D., Freij, N., Hayes, et al. (30 additional co-authors including **Reardon, K.** and SunPy Community) (2020), "The SunPy Project: Open Source Development and Status of the Version 1.0 Core Package", *ApJ*, 890, 68.

13. **Beck, C.,** Choudhary, D. P., Ranganathan, M. (2020), "Center-to-Limb Variation of the Inverse Evershed Flow", *ApJ,* 902, 30.

14. **Beck, C.** and Choudhary, D. P. (2020), "Temporal Evolution of the Inverse Evershed Flow, *ApJ*, 891, 119.

15. Berrilli, F., **Criscuoli, S.,** Penza, V., Lovric, M. (2020), "Long-Term (1749-2015) Variations of Solar UV Spectral Indices", *SoPh*, 295, 38.

16. **Bertello, L., Pevtsov, A. A**., Ulrich, R. K. (2020), "70 Years of Chromospheric Solar Activity and Dynamics", *ApJ*, 897, 181.

17. Bi Y., Yang B., Li T., Dong Y., Ji K. (2020), "Dynamics of Descending Knots in a Solar Prominence and Their Possible Contributions to the Heating of the Local Corona", *ApJ*, 891, L40.

18. Bilenko, I. A. (2020), "Relations between Coronal Mass Ejections and the Photospheric Magnetic Field in Cycles 23 and 24", *ApJ*, 889, 1.

19. Bisoi S. K., Janardhan P. (2020), "A New Tool for Predicting the Solar Cycle: Correlation Between Flux Transport at the Equator and the Poles", *SoPh*, 295, 79.

20. Bisoi S. K., Janardhan P., Ananthakrishnan S. (2020), "Another Mini Solar Maximum in the Offing: A Prediction for the Amplitude of Solar Cycle 25", *JGRA*, 125, e27508.

21. Blancato K. (2020), "Decoding Starlight with Big Survey Data, Machine Learning, and Cosmological Simulations", arXiv e-prints, arXiv:2009.10661.

22. Blancato K., Ness M., Huber D., Lu Y., Angus R. (2020), "Data-Driven Derivation of Stellar Properties from Photometric Time Series Data Using Convolutional Neural Networks", arXiv e-prints, arXiv:2005.09682.

23. Bobra, M. G., Mumford, S. J., Hewett, R. J., Christe, S. D., **Reardon, K.,** Savage, S., Ireland, J., Pereira, T. M. D., Chen, B., and Pérez-Suárez, D. (2020), "A Survey of Computational Tools in Solar Physics", *SoPh*, 295, 57.

24. Bonanno A., Fröhlich H.-E. (2020), "A New Helioseismic Constraint on a Cosmic-Time Variation of G", *ApJ*, 893, L35.

25. Boro Saikia S., Jin M., Johnstone C. P., Lüftinger T., Güdel M., Airapetian V. S., Kislyakova K. G., Folsom C. P. (2020), "The Solar Wind from a Stellar Perspective. How Do Low-Resolution Data Impact the Determination of Wind Properties?", *A&A*, 635, A178.

26. Buldgen G. (2019), "Global Helioseismology", *BSRSL*, 88, 50.

27. Calchetti D., Viavattene G., Berrilli F., Del Moro D., Giovannelli L., Oliviero M. (2020), "Tor Vergata Synoptic Solar Telescope: Preliminary Optical Design and Spectral Characterization", *JPCS*, 1548, 012005.

28. Cameron, R. H. and Jiang, J. (2019) "The Relationship between Flux Emergence and Subsurface Toroidal Magnetic Flux", *A&A*, 631, A27.

29. Caspi A. et al. (29 co-authors) and NASA WB-57 2017 Eclipse Observing Team (2020), "A New Facility for Airborne Solar Astronomy: NASA's WB-57 at the 2017 Total Solar Eclipse", *ApJ*, 895, 131.

30. Castro M., Baudin F., Benomar O., Samadi R., Morel T., Marques J. P., do Nascimento J. D., Lebreton Y., Barban C., Boumier P., da Costa J. S. (2020), "Modeling of Two CoRoT Solar Analogues Constrained by Seismic and Spectroscopic Analysis", arXiv e-prints, arXiv:2008.01163.

31. Chang Q., Xu X., Xu Q., Zhong J., Xu J., Wang J., Zhang T. (2019), "Multiple-point Modeling the Parker Spiral Configuration of the Solar Wind Magnetic Field at the Solar Maximum of Solar Cycle 24", *ApJ*, 884, 102. 10/2019

32. Chen, J., **Pevtsov, A. A.,** Su, J., Erdélyi, R., Deng, Y., Yang, S., Song, Y. (2020), "Formation of Two Homologous Transequatorial Loops", *SoPh*, 295, 59.

33. Chi Y., Scott C., Shen C., Owens M., Lang M., Xu M., Zhong Z., Zhang J., Wang Y., Lockwood M. (2020), "Using the "Ghost Front" to Predict the Arrival Time and Speed of CMEs at Venus and Earth", *ApJ*, 899, 143.

34. Christensen-Dalsgaard J. (2020), "Solar Structure and Evolution", arXiv e-prints, arXiv:2007.06488.

35. **Cliver, E. W.,** Hayakawa, H., Love, J. J., Neidig, D. F. (2020) "On the Size of the Flare Associated with the Solar Proton Event in 774 AD", *ApJ,* 903, 41.

36. **Cliver, E. W.,** Mekhaldi, F., Muscheler, R. (2020), "Solar Longitude Distribution of High-energy Proton Flares: Fluences and Spectra", *ApJL*, 900, L11.

37. Covas E. (2020), "Transfer Learning in Spatial-Temporal Forecasting of the Solar Magnetic Field", *AN*, 341, 384.

38. **Criscuoli, S.,** Rempel, M., Haberreiter, M., Pereira, T. M. D., **Uitenbroek, H.,** Fabbian, D. (2020), "Comparing Radiative Transfer Codes and Opacity Samplings for Solar Irradiance Reconstructions", *SoPh*, 295, 50.

39. Deheuvels S. (2020), "Probing Core Overshooting Using Asteroseismology", arXiv e-prints, arXiv:2001.04178.

40. Del Zanna, G., Storey, P. J., Badnell, N. R., and Andretta, V. (2020), "Helium Line Emissivities in the Solar Corona, *ApJ*, 898, 72.

41. Demidov, M. L., Hanaoka, Y., Sakurai, T., & Wang, X. F. (2020), "Large-Scale Solar Magnetic Fields Observed with the Infrared Spectro-Polarimeter IRmag at the National Astronomical Observatory of Japan: Comparison of Measurements Made in Different Spectral Lines and Observatories, *SoPh*, 295, 54.

42. Devi P., Joshi B., Chandra R., Mitra P. K., Veronig A. M., Joshi R. (2020), "Development of a Confined Circular-Cum-Parallel Ribbon Flare and Associated Pre-Flare Activity", *SoPh*, 295, 75.

43. Dev S., Savoy F. M., Lee Y. H., Winkler S. (2019), "Estimating Solar Irradiance Using Sky Imagers", *AMT*, 12, 5417.

44. Diercke, A., Kuckein, C., Denker, C. (2019), "Dynamics and Connectivity of an Extended Arch Filament System", *A&A*, 629, A48.

45. Diercke A., Denker C. (2019), "Chromospheric Synoptic Maps of Polar Crown Filaments". 11/2019, *SoPh*, 294, 152.

46. **Dima, G. I.** and **Schad, T. A**. (2020), "Using Multi-Line Spectropolarimetric Observations of Forbidden Emission Lines to Measure Single-point Coronal Magnetic Fields", *ApJ*, 889, 109.

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APPENDIX E. SCIENTIFIC STAFF RESEARCH AND SERVICE

(*Grant-supported staff)

Tetsu Anan, Postdoctoral Research Associate

Areas of Interest

Solar chromospheric heating; magnetic reconnections; diffusion of the magnetic field; electric field diagnosis; integral-field-unit spectropolarimetry.

Recent Research Results

T. Anan is developing an integral-field-unit spectropolarimetry Diffraction-Limited Near-Infrared Spectropolarimeter (DL-NIRSP) as a DKIST facility instrument. He published a paper reporting developments of another multi-wavelength spectropolarimeter, which allows us to obtain full Stokes spectra in multi-wavelength windows simultaneously (Anan et al. 2018, *PASJ*, 70, 102). He also published a paper on measurements of vector magnetic field in a flare kernel with a spectropolarimetric observation in infrared triplet lines of helium (He), and the estimation of lower cut-off energy of high-energy non-thermal electrons accelerated by the flare (Anan et al., 2018, *PASJ*, 70, 101). Moreover, Dr. Anan developed a method to make flat field of an integral-field-unit spectrometer, which is a prototype of the DL-NIRSP, and he presented shock heating rate per unit mass in umbral flashes derived from spectrometric data in the He triplet in a published paper (Anan et al. 2019, ApJ, 882, 161). Dr. Anan is analyzing another spectropolarimetric data of a plage region obtained through an integral field unit spectropolarimeter of the GREGOR telescope to study magnetic structures in the photosphere and the chromosphere associated with chromospheric heating over the plage region.

Future Research Plans

Dr. Anan will continue to develop the DL-NIRSP. He would like to publish a paper about the magnetic structures in a plage region to suggest which mechanisms heat the solar chromosphere. He is planning to study divergence of the magnetic field in the sunspot.

Service

Anan is a member of technical review committee for observing proposals submitted to operations commissioning phase cycle 1 of the DKIST.

Christian Beck, Associate Scientist

Areas of Interest

Post-focus instrumentation; data reduction pipelines; high-resolution spectroscopy and spectro-polarimetry of the photosphere and chromosphere; development of inversion tools for chromospheric spectral lines; polarimetric calibration techniques.

Recent Research Results

In continuation of the collaboration with D. P. Choudhary (California State University Northridge (CSUN)), Dr. Beck has published three more papers on different aspects of the inverse Evershed effect (*ApJ*, **874**, 6, 2020; *ApJ*, **891**, 119, 2020; *ApJ*, **902**, 30, 2020). A new version of the CAISAR inversion code using non-local thermodynamic equilibrium was released (*ApJ*, **878**, 60, 2019). Collaboration with New Mexico State University on data acquired at the Dunn Solar Telescope (DST) led to a publication on properties of an erupting filament (*ApJ*, **892**, 75, 2020) with implications for space weather forecasts.

Future Research Plans

With his full-time commitment to the Daniel K. Inouye Solar Telescope (DKIST) project, Dr. Beck's main focus for the near future will be on DKIST instrumentation and polarimetric calibration approaches. The collaboration with CSUN will continue and was expanded to include members of the solar physics group at the University of Alabama in Huntsville who have experience in magnetic field extrapolations. The main focus of the current research is on successfully combining high-resolution observations from telescopes such as the DST or DKIST with complementary full-disk observations when addressing scientific questions. First results have been published in Louis et al. (2020, *ApJ*, in press).

Service

C. Beck was a member of the DKIST Operations team during the 1st call for DKIST Operations, specifically for the DKIST Help Desk and the Technical Review Committee. During the past year, Beck has reviewed publications for *The Astrophysical Journal*, *Astronomy & Astrophysics* and the *Journal of Astronomical Telescopes, Instruments, and Systems*. C. Beck is a DKIST representative for the DKIST Critical Science Plan (CSP) workshops and specifically a point of contact for the DKIST Visible Spectro-Polarimeter (ViSP).

Luca Bertello, Scientist

Areas of Interest

Solar variability at different temporal, spectral, and spatial scales. Calibration of the observed solar magnetic field data to enhance the database that supports the analysis of conditions in the Sun's corona and heliosphere. Long-term synoptic observations in the resonance line of Ca II K for retrospective analyses of the solar magnetism on multi-decade time scales. Analysis of helioseimological data for better understanding the structure and dynamics of the solar interior.

Recent Research Results

Over the course of 2020, Dr. Bertello has been involved in several projects. A major task I have undertaken with my collaborators is the validation of a new SOLIS/VSM Milne-Eddington 2-line inversion code for the full-Stokes photospheric magnetic measurements taken in the Fe I 630.15 and 630.25 nm lines, resulting in an improvement of the current Carrington vector synoptic maps derived from those measurements. Those maps are the main drivers for current coronal and heliospheric models and play a critical role for space weather predictions. Another project was the generation of new and improved ephemeris tables used by the GONG data pipeline. Dr. Bertello has also developed an algorithm to merge together longitudinal (line-of-sight) and full-Stokes photospheric measurements of the solar magnetic field. The basic idea behind this effort is to exploit the best properties from each of these two types of observations. By merging them together into a full Carrington synoptic map, it is possible to create a composite map of the solar radial magnetic field that addresses some of the limitations found in previous approaches. A major achievement in Dr. Bertello's ongoing research activity involving historical Ca II K observations was a published paper describing results from the analysis of more than 40,000 observations taken at the Mount Wilson Observatory. In one study, Dr. Bertello found that the solar rotation profile has not changed significantly between 1915 and 1985, with both northern and southern hemispheres showing similar profiles. Dr. Bertello has also found no evidences for an asymmetry in solar chromospheric activity between the two hemispheres. During 2020, Dr. Bertello supervised the research activity of a REU student working on a project related to the analysis of atmospheric proxy seeing data derived from H-alpha observations taken at the six GONG sites. The main goal of the project was to rank those sites according to their seeing conditions. The project was successfully completed, and an abstract was accepted for a presentation at the 2020 AGU meeting. Finally, Dr. Bertello has been working with other colleagues for the implementation of a non-linear force free model in the NISP data pipeline.

Future Research Plans

One of Dr. Bertello's main future research plans is to better understand the nature of the solar dynamo, and the role played by the magnetic field in affecting the topology of the outer layers of the solar atmosphere and heliosphere. Another area of interest in Dr. Bertello's future research activity is the investigation of observational data on global properties of the Sun to better characterize the physical processes that should be incorporated in the next generation of solar (stellar) models. A significant portion of Dr. Bertello's future efforts will also be dedicated to the analysis of historical solar data, with particular emphasis on magnetic and Ca II K observations. Dr. Bertello maintains strong collaborations with several national and international institutes. This synergy has grown consistently over the years and has opened several new research channels.

Service

As the Data Scientist for SOLIS, L. Bertello's major responsibility is to provide the solar and heliophysics community with high-quality and reliable NISP data. During 2020, he has peer-reviewed publications for several different journals, and provided technical/scientific support for outside data users.

Gianna Cauzzi, Associate Scientist

Areas of Interest

High resolution imaging and spectroscopy of the lower solar atmosphere; chromospheric structure and dynamics, including wave dynamics and heating. Flare physics and lower atmospheric signatures. Imaging instrumentation based on Fabry-Perot interferometers.

Current and Future Research Plans

Dr. Cauzzi will continue to use observations of the lower atmosphere, obtained from ground- and space-based instrumentation, to analyze wave properties in the chromosphere and their relation to magnetic topology. She is also working on chromospheric spectroscopy of flare ribbons, as a diagnostic of density and other properties during the impulsive phase of flares of different strength. She is currently collaborating on a project aimed at characterize the properties of large scale Fabry-Perot interferometers, in particular for what concerns gravity induced cavity defects.

Service

Dr. Cauzzi is leading the NCSP effort of organizing and coordinating a series of schools and workshops devoted to introduce and train the US solar community to ground based solar data, in preparation for DKIST. Two workshops were held in 2020, and three more are in the preparatory stage for 2021. She chairs the OCM2 Working Group tasked to devise the procedures guiding the overall review process (including technical and scientific assessments) of Proposals submitted to DKIST Call for Proposals during the OCP. The procedures have been applied to the first round of proposals submitted during the OCP, and are now under revisions. She is currently the Chair of the Science Review Committee for the DKIST OCP (Operation Commissioning Phase) and has organized and completed this task for the first round of proposals, coordinating the work of over 20 international colleagues. She routinely serves as reviewer for various astrophysical journals (ApJ, A&A, Solar Physics), and international research agencies.

Serena Criscuoli, Associate Astronomer

Areas of Interest

High-spatial resolution spectroscopy and spectropolarimetry of the photosphere and chromosphere; radiative transfer; numerical simulations; solar irradiance variations.

Recent Research Results

Dr. Criscuoli recently worked on topics in the framework of the Areas of Interests mentioned above. She worked on historical reconstructions of the variability of solar irradiance in the UV spectral range, which is fundamental for modeling the impact of solar variability on the Earth's climate. She also worked on comparing radiative transfer codes and numerical schemes employed for the synthesis of solar and stellar spectra, and on a method to estimate long-term variations of the temperature gradient in the solar photosphere.

Service

Dr. Criscuoli is a scientific consultant for the DKIST. She played a leading role in defining some of the procedures of the DKIST Operations Commissioning Phase, and actively contributed to the execution of the first DKIST Call for Proposals (e.g. definition of the content of the call, curation of the website, help desk agent, member of the technical review committee).

Dr. Criscuoli also actively contributed to the DKIST level-2 project by supervising and contributing to the editing of technical requirement documentation. She was a referee for scientific journals and supervised undergraduate students.

Alisdair Davey, Associate Scientist

Areas of Interest

CMEs and associated phenomena such as EUV waves and Dimming Regions. The acceleration and Heliospheric propagation of SEPs during solar flares and CMEs. The use of computer vision/AI in identifying solar features and events. Development of the Virtual Solar Observatory (VSO), and the Heliospheric data environment, including integration of data and modeling efforts and meta-data standardization efforts.

Recent Research Results

Dr. Davey and colleagues continued development on a framework for the coronal analysis of shocks and waves (CASHeW). The framework combines analysis of NASA Heliophysics System Observatory data products and relevant data-driven models, into an automated system for the characterization of off-limb coronal waves and shocks and the evaluation of their capability to accelerate solar energetic particles (SEPs). With this framework, Davey and colleagues hope to contribute to the overall understanding of coronal shock waves, their importance for energetic particle acceleration, as well as to the better ability to forecast SEP events fluxes. Dr Davey worked with colleagues to investigate the high-temperature ($T > 4$ MK) emissions of non-flaring active regions, in the context of the coronal heating problem. Additionally, Dr Davey took part in an EarthCube sponsored workshop resulting in a white paper on Machine Learning in Heliophysics and Space Weather Forecasting.

Service

Dr. Davey worked on a number of topics for the VSO including bringing new data sets online for the solar physics community. He also maintains the Solar Physics E-print Archive and is the web master for the AAS Solar Physics Division. In 2019-2020, he was a referee for a number of scientific journals.

Andre Fehlmann, Assistant Scientist

Areas of Interest

Infrared instrumentation; precision spectropolarimetry; coronal magnetic fields; infrared camera systems; student engagement and community outreach.

Recent Research Results

A. Fehlmann delivered the Cryogenic Near-Infrared Spectropolarimeter (CryoNIRSP), a DKIST first-generation facility instrument, to the summit of Haleakala. He installed and aligned the instrument at the telescope and performed initial Site acceptance Tests. Fehlmann is also involved in optimizing the polarization calibration plan for DKIST.

Future Research Plans

Dr. Fehlmann will help refining and implementing the DKIST calibration plan and integrate and commission the facility instruments on the telescope. He is looking into maintaining and improving infrared camera systems for the facility. As a member of several teams, he will be involved in analyzing data from the initial DKIST observations.

Service

Fehlmann is a member of the DKIST science team and infrared instrumentation specialist for DKIST facility instruments. The development of an instrument performance calculator helps the community to plan observations with CryoNIRSP. He also serves on the technical review committee for the DKIST cycle 1 call.

Sanjay Gosain, Observatory Scientist

Areas of Interest

Astronomical instrumentation: optical design of instruments for polarimetry and spectroscopic imaging. Solar Physics: flares, eruptive filaments and coronal mass ejections; Solar magnetism: Chromospheric magnetic fields; evolution of vector magnetic field in active regions.

Recent Research Results:

NASA MIDEX Phase-A study award to design "Solaris", a solar polar mission: When viewed from the ecliptic plane, such as, from the Earth or L1, L4, L5 Lagrange orbits, solar poles are very poorly observed. An important piece of the solar dynamo puzzle which is currently missing, is the magnetic and velocity field properties of the polar regions. "Solaris" is a NASA midex proposal selected for Phase-A study, which aims to fly a spacecraft, out of the ecliptic plane, over the solar poles using Jupiter gravity assist. It aims to make important and hitherto missing measurements of surface magnetic and velocity fields which will enable our understanding of magnetism, surface and subsurface plasma flows in the polar regions. A key instrument of the Solaris mission is the so-called Compact Doppler Magnetograph (CDM) which is basically a compact GONG and was conceptualized and demonstrated by NSO in 2018. Solaris is led by SWRI, while NSO and LASP are key partners in the development of CDM instrument. Dr. Gosain's role in Solaris is to be the instrument scientist for CDM instrument and participate in phase-A studies, which involves understanding the systematics of the instrument and developing strategies for the instrument calibration. CDM prototype was installed at GONG light feeds and test observations were taken in November 2020. Lot of these phase-A studies by are also beneficial for the understanding of key systematics in GONG instrument and may prove valuable in the development of next generation GONG instrument.

Successful testing of new science camera for GONG helioseismology: Current GONG cameras are more than 15-years-old and have started to fail more frequently. Dr. Gosain led the effort of camera selection for replacement. As a part of the GONG Refurbishment project, this new camera was succesfully tested and observations were validated to meet science requirements. A batch of 11 cameras has been received and currently Dr. Gosain is helping in their acceptance tests. The camera will subsequently be upgraded with a third party for an anti-reflection coated cover glass over the CMOS sensor and then will be run at GONG TC for burn-in before further deployment.

Publications: (1) "The Solaris Solar Polar Mission", Hassler et al, in 22nd EGU General Assembly, held online 4-8 May, 2020, id.17703. (2) "Acceleration of Coronal Mass Ejection Plasma in the Low Corona as Measured by the Citizen CATE Experiment" Penn et al., in Publications of the Astronomical Society of the Pacific, Volume 132, Issue 1007, id. 014201 (2020)., 14 pp. (2020). (3) "DKIST Level-2 data production at NCSP" Uitenbroek et al., in Project Documentation Document SPEC–0230 Revision A.

Future Research Plans & Service

Dr. Gosain plans to: a) complete the demonstration of the GONG H-alpha tunable Doppler imaging system; b) complete the phase-A study of CDM instrument; c) participate in ngGONG proposal activities; d) participate in the commissioning of SOLIS instruments at Big Bear, CA; and e) carry out independent scientific research.

David M. Harrington, Associate Scientist

Areas of Interest

Instrumentation; spectropolarimetry, adaptive optics, novel optical systems, detector systems, applied research, community workforce development.

Recent Research Results

Dr. Harrington has been developing polarization system performance models, optical system models and calibration algorithms for large telescopes. He has also been working on the design and fabrication of a high precision lab spectropolarimeter for full Mueller matrix characterization of optics in the visible and near-IR. Other activities include: daytime sky polarization calibration technique development for large telescopes (AEOS, Keck, Dunn Solar Telescope); and data reduction and analysis pipelines for polarimetric instrumentation (HiVIS & InnoPOL on AEOS, LRISp on Keck, curvature adaptive optics and EMCCD imaging polarimeters).

Future Research Plans

Dr. Harrington is actively developing new techniques to calibrate, model and improve the polarimetric performance of astronomical telescopes and instruments. New lab equipment and methods are in development for characterizing and modeling large polarimetric optics. Software modeling improvements and new mathematical techniques will advance the state-of-the-art for calibration precision and accuracy. Applying new interdisciplinary techniques both from theory and components will keep DKIST on the cutting edge of technology. With DKIST first-light instruments and novel data sets, a wide range of science cases for a diverse community will be impacted by system improvements.

Service

Harrington is an active member of the DKIST Science Group and is the DKIST polarimetry scientist working with the instrument partner teams and Polarimetry Analysis & Calibration team to integrate and calibrate the first-light instrument suite. The DKIST user community is being engaged and educated in anticipation of the new DKIST polarimetric capabilities. Harrington is an active participant in the Akamai Workforce Initiative, which involves working with industry and academic partners, mentoring Hawaiʻi-connected local interns for summer and year-long projects and facilitating connections between industry and various STEM-focused educational programs.

Sarah A. Jaeggli, Assistant Astronomer

Areas of Interest

The 3-dimensional structure of sunspot magnetic fields; atomic and molecular physics of the photosphere and chromosphere; radiative transfer modeling and spectral synthesis; instrumentation for spectroscopy and spectropolarimetry, including DKIST facility instrument development; engaging the community to perform multi-facility observations.

Recent Research Results

In 2019-2020, Dr. Jaeggli worked with Dr. David Harrington to demonstrate the properties of polarized fringes in physical optics and results were published in Harrington et al. 2020 *JATIS*. In November 2020, Dr. Jaeggli was invited to talk at the American Physical Society Division of plasma physics and presented a cross-disciplinary talk on plasma regimes that DKIST will observe. Dr. Jaeggli is a part of two recently funded projects as an unfunded collaborator. Dr. Jaeggli was asked to join the team for development of a new EUV satellite-based spectrograph called the Multi-Slit Solar Explorer (MUSE), P.I. Dr. Bart de Pontieu. In 2020, this project was selected for a mission concept study. She is working in an advisory role with University of Hawaii scientists to apply machine learning to the inversion of spectropolarimetric data. This project was selected for funding under the NSF Astronomy and Astrophysics Research Grants program.

Future Research Plans

Dr. Jaeggli is currently collaborating with A. Kobelski, L. Tarr, and S. Savage on a multi-observatory dataset obtained during a joint campaign with the Dunn Solar Telescope. This massively multi-instrument dataset covers a fairly boring, but typical, region of the Sun and will be used to understand energy transfer from the photosphere to the corona at many wavelengths. A proposal for conducting this research was selected for funding under NASA's Heliophysics Supporting Research program and provides 1/4 FTE for Dr. Jaeggli. Sarah is also currently working on spectral synthesis of photospheric magnetic field and molecular diagnostic lines based on various MHD sunspot and quiet-Sun simulations. With these datasets, she hopes to understand the limits of ad-hoc methods of polarization calibration using the symmetry of polarized spectral line profiles, and also look at the magnetic and pressure forces at play in sunspots, their balance as inferred from spectra, and the real state of force balance based on the simulation. The resulting spectral data from the simulations she hopes to make publicly available to the community, to provide a benchmark for comparison of DKIST observations.

Service

Dr. Jaeggli is supporting the DKIST project, acting as instrument scientist on the DL-NIRSP team, and as a member of the polarization calibration team. As a DKIST scientist, she participated in the technical review of DKIST cycle 1 proposals.

Kiran Jain, Scientist

Areas of Interest

Helioseismology – oscillation mode characteristics, multi-wavelength helioseismology, sub-surface flows and dynamics, solar activity, active regions, helioseismic mapping of the farside, Sun-Earth connection.

Recent Research Results

K. Jain investigated the timing and depth of the current solar minimum below and above the solar surface, and compared the findings with those between cycles 23 and 24. It is found that the current minimum between cycle 24 and 25 is not as deep as the previous minimum, however it is much wider with more spotless days. In addition, the timing of minima in different layers below the surface is different from that observed in various activity measures in solar atmosphere.

Dr. Jain extensively studied the role of window function and missing images on the farside helioseismic mapping. It is found that the noise in farside maps increases with decreasing duty cycle and the reliability of active region detection reduces when the duty cycle decreases below 90%. These finding are supported by simulations.

In collaboration with HAO, Dr. Jain studied the features in magnetic toroids that might cause severe space weather events. These toroids are derived from synoptic magnetogram charts by employing a novel optimization method based on Trust Region Reflective algorithm.

Dr. Jain, in collaboration with an international graduate student, also studied the vorticity and kinetic helicity in the sub-surface layers using a set of X- and M- class flare productive isolated active regions in cycle 24, and explored their relation with the corresponding current helicity and magnetic flux. It is found that strong vorticity/kinetic helicity of active regions leads to larger twisting of the active regions, which presumably generates high-intensity flares.

Dr. Jain also participated in the comparison and validation of the results obtained from various rotation inversion techniques, an important initial step in the computation of unique rotation profile.

Dr. Jain carried out a detailed study on the performance of the GONG+ network by using data collected in last 18 years. She found that the mean and median network-wide daily duty cycle are 88% and 93%, respectively which are within 1σ of the simulated duty cycle suggested before commissioning of the network. It is clearly demonstrated that the yearly and monthly mean duty cycles vary from site to site and have strong weather dependence. These results support the need of at least six sites around the globe in order to obtain required high duty cycle (>90%) for helioseismic studies.

<u>Future Research Plans</u>

Seismic maps of the far side of the Sun have proven their capability to locate and track medium-large active regions at the non-visible hemisphere. Dr. Jain will work on improving the quality of far-side seismic maps and their prediction capabilities. She also plans on using the average signal from these seismic far-side maps, combined with similarly calculated near-side maps, to study the full-Sun magnetic index. This may be further utilized to model solar irradiance and ultimately to forecast in several days in advance.

Dr. Jain will continue to study the variability in acoustic mode parameters with the changing level of magnetic activity in order to improve the understanding of their complex relationship. In particular, she plans to explore various periodicities in acoustic oscillation frequencies and their origin in different layers of the solar interior and different phases of the solar activity cycle.

Dr. Jain will continue to work on the International Solar Rotation Project to derive a unique reference solar rotation profile.

Dr. Jain will further continue to work on multi-spectral data to obtain a better picture of the excitation and damping mechanisms of solar oscillations and to study the effect of inclined magnetic field on active regions to probe the characteristics of seismic waves propagating in layers above and below the solar surface. This work also provides case studies to support proposed ngGONG project.

Dr. Jain will work on various NASA-funded projects where major topics to be addressed are; sub-photospheric flows in active regions and their influence in solar eruptions, long-term variations in sub-surface flows with depths and hemispheric asymmetry.

<u>Service</u>

Dr. Jain continues to serve as a member of the NSO Scientific Personnel Committee (SPC) and NSO Diversity and Inclusion (D&I) working group. She worked extensively on improving the farside mapping of the Sun using GONG observations, an important data product for space weather prediction. In addition, she tested and verified various helioseismology data products and regularly monitored their quality. She further evaluated the performance of GONG sites using observations from 25 years of the GONG operations in context of the proposed ngGONG project and also worked on the specifications of Doppler measurements. Some of these results were presented at the Solar Observatory

Council (SOC) meeting in September, 2020. She hosts regular monthly meetings for the International Solar Rotation Project. She also mentored a BSA REU student in summer 2020 and supervised two other international Graduate students on their work based on the GONG data.

Maria Kazachenko, Assistant Astronomer

Areas of Interest

Inversion techniques to derive the electric fields and Poynting fluxes on the surface of the Sun using magnetic field measurements; data-driven simulations of the solar coronal magnetic fields; statistical properties of solar flares.

Recent Research Results

In 2020, Dr. Kazachenko continued working on the "Areas-of-Interest" topics as detailed below. Dr. Kazachenko has been collaborating with Dr. George Fisher and the members of the Coronal Global Evolutionary Model (CGEM) on the details of the electric-field inversions on the staggered grid; the results of this work have been published in Hoeksema et al. 2020 and Fisher et al. 2020. Together with her student Dennis Tilipman and Dr. Valentin Martinez-Pillet, Dr. Kazachenko has been working on developing tools to analyze the quiet-Sun magnetic field properties using high temporal and spatial resolution IMaX observations. Together with the Hale postdoctoral fellow, Benoit Tremblay, Maria has been working on Inferring Depth-dependent Plasma Motions from Surface Observations using Deep Learning DeepVel — the results of this work have been presented at the AGU meeting in CA and published in the Space Reviews. Together with a DKIST ambassador Andrei Afanasev, Dr. Kazachenko has tested PDFI electric field inversion software using Yuhong's Fan flux emergence simulations – the results of this work have been presented at the AGU and will be submitted to the Astrophysical Journal early next year. Together with Dr. Benjamin Lynch, Dr. Kazachenko has worked on analyzing the properties of the filament eruption using observations and the MHD simulations – the results of this study will be submitted to the Astrophysical Journal early next year. Together with Hugh Hudson, Dr. Kazachenko has published a first-author paper on using EVE/SDO observation to derive properties of active-region irradiance; the results of this work have been featured on the AAS Nova website. Together with an undergraduate student, Vincent Ledvina, Maria has studied analysis of the small-scale flux emergence and cancellation using SST observations – the results of this work have been presented at the AAS meeting and will be submitted to the Astrophysical Journal. Together with Dr. Criscouli and Dr. Rempel, Dr. Kazachenko has written two white papers on modeling the solar magnetic fields in solar corona. In 2020 Dr. Kazachenko submitted 5 proposals: one to Packard Fellowship as a PI, one to a Ford Fellowship (as a Co-I), one to NASA (as a Co-I, step 1) and two proposal to an ISSI workshop (as a Co-I): two ISSI proposals have been selected, we are still waiting to hear the other results. Together with her postdocs and students, Dr. Kazachenko submitted 6 observational proposals to DKIST as a Co-I: we are still waiting to hear the results.

Service

In 2020, Dr. Kazachenko continued to serve as a member of the Solar Physics Division Committee and a Chair of the Metcalf Travel Award Committee. As a result of the fundraising campaign, Dr. Kazachenko together with Prof. Richard Canfield, raised 100K from the SPD and the Metcalf family to establish the Metcalf travel award fund in perpetuity. Maria also continued to serve as a member the Daniel K. Inouye Solar Telescope (DKIST) Science Working group; Rast et al. 2020 paper has been submitted to the Solar Physics as a result of this work. Together with Dr. Georgios Chintzoglou, Dr. Kazachenko has written a proposal to organize an international Data-driving session at the next COSPAR meeting in Athens, Greece. In 2020 Maria mentored three graduate students (Marcel

Corchado, Dennis Tilipman, Cole Tamburri) and two postdoctoral fellows (Benoit Tremblay and Andrei Afanasev). She also continued to serve as a referee for scientific journals (Astrophysical Journal, Nature Communications) and NASA and NSF funding proposals

*Shukirjon S. Kholikov, Scientist

Areas of Interest

Helioseismology; data analysis techniques; time-distance methods.

Recent Research Results

Shukur Kholikov works primarily on time-distance applications using GONG++ data. He has developed a time-distance pipeline, which provides travel-time maps of daily GONG-network data and produces reconstructed images with specified filters. At present, the pipeline has been tested to produce several types of specific travel-time measurements to probe the deep layers of the Sun.

The main focus of the pipeline is deep meridional flow measurements. Meridional flow measurements were obtained by using GONG/MDI/HMI spherical harmonic (SH) time series for using travel-time differences from velocity images reconstructed from SH coefficients after applying phase-velocity and low-L-filters. This particular approach is the key tool for extending the local time distance applications to the deep convection zone diagnostic analysis. The depth profile of meridional flow obtained using the above described pipeline shows a distinct and significant change in the nature of the time differences at the bottom of the convection zone. Travel-time measurements are affected by center-to-limb (CTL) variations across the solar disk. Corrections of this artifact on meridional flow measurements revealed an evidence of return flow at ~60 Mm depth of the solar interior. Using several years of GONG data, detailed meridional flow profiles of both poleward and equatorward components were obtained. Initial inversions of measured meridional travel-time differences showed single-cell structure of the meridional flow in both depth and latitude. Recently, new inversions based on spherical Born kernels including lower thresholds for singular value decomposition were applied to the same dataset. In this case, refined results exhibit a multi-cell structure in depth. It should be noted that the magnitude of the meridional flow, circulation profile and its topology strongly depend on CTL—in particular, return component of flow is not possible to measure without an understanding of CTL origin and removing this artifact from measured time differences. Kholikov is working on new ways of obtaining and removing CTL systematics and explaining its nature.

At present, Dr. Kholikov is working on comparative analysis of the deep meridional flow between HMI, MDI and GONG projects. Preliminary results from these measurements show a new detail of depth-latitude profile of the meridional flow.

Another important research focus of Kholikov's is a new estimation of solar-core rotation. Based on multi-skip time-distance approach, acoustic time shifts due to internal solar rotation can be measured up to R=0.05, while rotation profile from global helioseismic inversions provide acceptable results only up to R=0.3. This project requires involving low-degree acoustic modes into multi-skip time-distance and using as many portions as possible of the solar disk from all available observations (GONG, MDI, HMI).

Future Research Plans

Dr. Kholikov will continue to improve the time-distance pipeline and provide the scientific community with specific GONG/HMI data for local helioseismology analysis. The main focus will be the deep equatorward return-flow measurements and its temporal variations involving GONG, MDI and HMI data series. He will incorporate HMI time series with extended solar disk usage to produce a new set of measurements of solar-core rotation.

Service

Dr. Kholikov will monitor the quality of available local helioseismic data products provided by NISP. He also provides time-distance measurements and high-degree SH time series of GONG data upon request.

Rudolf W. Komm, Scientist

Areas of Interest

Helioseismology; dynamics of the solar convection zone; solar activity and variability.

Recent Research Results

Dr. Komm continues to perform research in helioseismology. He is deriving solar sub-surface fluid dynamics descriptors from GONG data analyzed with a ring-diagram. Using these descriptors, he was able to derive, for example, the divergence and vorticity of solar sub-surface flows and study their relationship with magnetic activity. Komm is exploring the relationship between the twist of subsurface flows and the flare production of active regions and, in collaboration with S. Gosain, he started exploring the relationship between flare-activity, helicity, and lifetime of long-lived activity complexes. Komm is studying the solar-cycle variation of the zonal and the meridional flow in the near-surface layers of the solar convection zone, in collaboration with F. Hill, and R. Howe. He has focused on the variation of the flows during solar Cycles 23 and 244.

Future Research Plans

Dr. Komm will continue to explore the dynamics of near-surface layers and the interaction between magnetic flux and flows derived from ring-diagram data, and will focus on the relationship between subsurface flow characteristics and flare activity in active regions and long-lived activity complexes. He will continue to explore the long-term variation of subsurface flows, focusing on the differences between regions of high and low magnetic activity and, in collaboration with M. Dikpati (HAO). explore the influence of the meridional flow on dynamo models.

Service

R. Komm has improved a correction for systematic effects present in subsurface flow data and is working on turning the corrected subsurface flows into a data product. He also works on creating a data product from the measured helicity of the corrected subsurface flows. He works on creating daily and synoptic maps of these corrected fluid-dynamics descriptors.

Adam Kowalski, Assistant Astronomer

Areas of Interest

Flare observations and radiative-hydrodynamic modeling; white-light flare radiation and continuum properties; connection between magnetic activity and flares on the Sun and younger M dwarf stars; models of broadening in hydrogen emission lines that will be observed by the DKIST during flares; teaching the physics of stellar atmosphere modeling and observational astronomy and spectroscopic analysis; multi-wavelength observations of solar and M dwarf flares.

Recent Research Results

Adam Kowalski has recently updated the RADYN code to include an accurate prescription for hydrogen line broadening in solar flares, the quiet Sun, and flaring M dwarfs. He leads an effort to complete a model grid of M dwarf flares with this model improvement. Kowalski was first author of one article published in *ApJ* in 2018 and two articles published in *ApJ* in 2019.

His major results from 2018 – 2020 are the following:

- Kowalski, A.F., Butler, E., Daw, A.N., Fletcher, L., Allred, J.C., , De Pontieu, B., Kerr, G.S., Cauzzi, G. 2019b, "Spectral Evidence for Heating at Large Column Mass in Umbral Solar Flare Kernels I: IRIS NUV Spectra of the X1 Solar Flare of 2014 October 25", *Astrophysical Journal*, 878, 135 (18 pp). DOI: 10.3847/1538-4357/ab1f8b
- Kowalski, A.F., Wisniewski, J.P., Hawley, S.L., Osten, R.A., Brown, A., Farina, C., Valenti, J.A., Brown, S., Xilouris, M., Schmidt, S.J. and Johns-Krull, C. 2019a, "The Near-ultraviolet Continuum Radiation in the Impulsive Phase of HF/GF-type dMe Flares. I. Data", As*trophysical Journal*, 871, 167 (23 pp). DOI: 10.3847/1538-4357/aaf058
- Kowalski, A.F., Allred, J.C. 2018 "Parameterizations of Chromospheric Condensations in dG and dMe Model Flare Atmospheres" *ApJ* **852**, 61 (19 pp).

- Kowalski led a large collaborative effort on a seven-day multi-wavelength flare campaign on AU Mic. Observations were obtained over Oct 10 – 17, 2018 with XMM-Newton, Swift, the JVLA, the ATCA, the ARC 3.5m at APO, the SMARTS 0.9m and 1.5m telescopes, and 7 telescopes at LCO Global Telescope Network. New types of measurements are being made at every wavelength that we observed (X-rays, radio, near-UV, and optical). Kowalski is leading the effort to synthesize this unprecedented multi-wavelength data set of M dwarf flares. He was awarded a NASA Astrophysics Data Analysis (ADAP) grant totaling $600,517 to fund a postdoc and graduate student to complete the analysis of this dataset.

- Allred, Joel C., Alaoui M., **Kowalski A.F.**, Kerr G. S. 2020 "Modeling the Transport of Nonthermal Particles in Flares Using Fokker-Planck Kinetic Theory", *Astrophysical Journal* 902, 16
- David R. Graham, Gianna Cauzzi, Luca Zangrilli, **Adam Kowalski**, Paulo Simões, Joel Allred 2020, "Spectral Signatures of Chromospheric Condensation in a Major Solar Flare", *Astrophysical Journal* 895, 6, DOI: 10.3847/1538-4357/ab88ad.
- Wisniewski JP, **Kowalski AF**, Davenport JRA, Schneider G, Grady CA, Hebb L, Lawson KD, Augereau J-C, Boccaletti A, Brown A, et. al. "High-fidelity Imaging of the Inner AU Mic Debris Disk: Evidence of Differential Wind Sculpting?." ASTROPHYSICAL JOURNAL LETTERS. 883 (1) (September 20, 2019): ARTN L8.
- Lawson, K. D., Wisniewski, J. P., Bellm, E. C., **Kowalski, A.F.**, Shupe, D. L. 2019, "Identification of Stellar Flares Using Differential Evolution Template Optimization", *Astronomical Journal*, 158, 119.
- Zhu, Y., Kowalski, A.F., Hui, T., Uitenbroek, H., Carlsson, M., Allred, J.C. 2019, "Modeling Mg II h, k and Triplet Lines at Solar Flare Ribbons", *Astrophysical Journal 8*79, 19 (11 pp). DOI: 10.3847/1538-4357/ab2238.
- Froning, C. S**.,** Kowalski, A. F., France, K., Loyd, R.O.P., Schneider, C.P., Youngblood, A., Wilson, D., Brown, A., Thompson, Z.-B., Pineda, J.S., Linsky, J., Rugheimer, S., Miguel, Y. 2019, "A Hot Ultraviolet Flare on the M Dwarf Star GJ 674", *Astrophysical Journal Letters*, 871, 26.

Future Research Plans

Dr. Kowalski is leading an ApJ Letter reporting on the updated hydrogen broadening in RADYN, in preparation for DKIST/ViSP observations of solar flares. He is also leading a paper that presents on unprecedented broadband colors in the largest flare observed in the AU Mic flare campaign. He is finishing a review article on "Stellar Flares" to be published in the "Living Reviews in Solar Physics" in the first half of 2021. Other projects that are nearly finished are on the following topics: a large grid of radiative hydrodynamic flare atmospheres for the interpretation of M dwarf optical observations, a study of the high-cadence ROSA/DST data of a C9.7 solar flare, and a study of the effects of stellar flare neutrons on exoplanet habitability.

Service

Dr. Kowalski's service to the National Solar Observatory consists of frequently interacting with and mentoring undergraduate students, graduate students, and postdocs. He develops DKIST Science Use Case projects as potential PhD projects for students, he hosts workshops and seminars on solar physics topics, he works on advancing the science capabilities of the Dunn Solar Telescope, and he enhances synergies and collaborative efforts between NSO and the APS department at CU.

Jose Marino, Associate Scientist

Areas of Interest

Solar adaptive optics and multi-conjugate adaptive optics; solar adaptive optics modeling and simulation; high-resolution solar observations; atmospheric tomography; point spread function estimation.

Recent Research Results

Jose Marino continues the development of Blur, a fast and accurate adaptive optics simulation package capable of producing fast and accurate simulations of solar adaptive optics and multi-conjugate adaptive optics systems; and the development of KAOS, an adaptive optics software controller. Marino is involved in the project to design and build a multi-conjugate adaptive optics system for the DKIST currently under way. The project has entered the lab integration and testing phase for the wavefront sensor components of the system, while we continue the process of design and manufacturing of the high-altitude deformable mirrors. Marino is driving the specification requirements of the system and its components through multi-conjugate adaptive optics simulations using Blur and KAOS.

Future Research Plans

Dr. Marino will continue his participation in the project to design and build the multi-conjugate adaptive optics system for the DKIST. He will continue the development of Blur, the solar adaptive optics simulation package, and continue using it to gain insights into the operation of solar multi-conjugate adaptive optics systems.

Service

Marino served as a reviewer of two scientific papers during 2020, submitted to the journals *Optics and Lasers in Engineering*, and *Solar Physics*. In September 2020, he served as reviewer in the technical review of proposals submitted as part of the DKIST Operations Commissioning Phase (OCP) Cycle 1 observations proposal call. He gave two presentations during 2019 and 2020 to a class of CU Boulder students and the at the 2nd NSO Community Science Program Workshop.

Valentín Martínez Pillet, NSO Director

Areas of Interest

Solar activity; Sun-heliosphere connectivity; magnetic field measurements; spectroscopy; polarimetry; astronomical instrumentation.

Recent Research Results

Author of 128 refereed papers, 242 NASA/ADS entries, 5386 citations, H-index 42.

Before joining NSO as Director, Dr. Martínez Pillet was leading the Imaging Magnetograph eXperiment (IMaX) for the balloon borne SUNRISE solar telescope (a Germany, Spain and USA collaboration). IMaX/SUNRISE has flown twice from the Arctic circle within the Long-Duration Balloon program of NASA (June 2009 and June 2013). The data obtained during the first flight has produced the most accurate description of the quiet Sun magnetic fields, reaching unprecedented resolution of 100 km at the solar surface and a sensitivity of a few Gauss. These data have produced well over 80 papers in the last few years, describing a large variety of processes including the discovery of small-scale supersonic magnetized flows. These jets have been recently identified in the *Hinode* satellite data that provide full Stokes spectral profiles and allow for a detailed study of the atmospheric context in which they are generated.

Dr. Martinez Pillet was also leading (as co-Principal Investigator) the design and construction of the Polarimetric and Helioseismic Imager for the Solar Orbiter mission (a Germany, Spain and France collaboration).

Future Research Plans

As Director, Dr. Martinez Pillet has overall responsibility for the operation of NSO, to maintain and rejuvenate the NSO synoptic program, and prepare for observatory operations at the new NSO directorate site in Boulder, Colorado. Dr. Martinez Pillet plans to be involved in the analysis of the data from the Sunspot/DST taken as part of the synoptic filament observations program led by NMSU.

Service

Dr. Martinez Pillet is Director of the National Solar Observatory. In the past, he has provided services for a variety of international institutions, including: member of the High Altitude Observatory Science Advisory Board; member of the DKIST Science Working Group; member of the European Space Agency Solar System Working Group; former President of the International Astronomical Union Commission 12 on Solar Radiation and Structure; former President of the International Astronomical Union Division II The Sun and the Heliosphere; and member of the Editorial Board of the journal *Solar Physics*. In 2014, Dr. Martinez Pillet became a member of the Kiepenheuer Institut für Sonnenphysik (Freiburg, Germany) scientific advisory committee. KIS is a partner on DKIST contributing with a first-light instrument.

Dr. Martinez Pillet has been the PhD advisor of three students at the IAC (Tenerife) and supervisor of three postdoctoral scientists from various international institutions.

Alin R. Paraschiv, Postdoctoral Research Associate

Areas of Interest

Mathematical inversion problems in solar physics (spectroscopic and spectropolarimetric inversions, differential emission measures, magnetic field disambiguation’s, etc.), and the associated products resulted (physical unit calibrations, plasma temperature and density measurements, magnetic field inferrals, etc.).

Dr. Paraschiv has experience with line spectroscopy and filtergram observations in solar EUV, Radio, and X-ray wavelengths, and limited experience with MHD and analytical modeling. He is currently involved with ground-based observations, atomic theory and spectropolarimetry techniques.

Dr. Paraschiv is producing and delivering the Level-2 coronal magnetic field inversion and data pipeline for DKIST DL-NIRSP and Cryo-NIRSP observations. This inversion is one of the main goals of the Community Science Program (NCSP) that NSO manages.

Recent Research Results

Delivered a first set of specifications for the coronal level-2 inversion developed through the NCSP and contributed to the NSO DKIST SPEC_0230 documentation.
Delivered 1 NSO brown bag seminar and 1 HAO/NCAR colloquium on solar jets.
1 published paper on coronal jets work.
AAS/SPD 2020 meeting: Presented 2 posters and contributed to an additional 1 poster.
AGU 2020 fall meeting: Presented 2 posters and contributed to an additional 1 poster.

Future Research Plans

Co-author on 1 paper to be submitted in 2020 (atomic theory for coronal polarization). 3 additional papers (1-2 first author) are currently in preparation for submission in 2021 (1 manuscript on jet work and 2 manuscripts detailing the NCSP coronal inversion procedure).
Submit DKIST coronal observation proposals in OPS2 and OPS3 cycles.
Develop a new physical unit calibration procedure that is critical for the level-2 coronal inversion project.
Deliver a fully functional version of the inversion algorithm to the DKIST data center and help iron out the integration, if needed.
Remotely co-supervise one bachelor thesis project in Romania (machine learning for heliophysics).

Service

Undergraduate Student mentorship:
1 student, spring semester, Colorado University Astrophysics and planetary sciences internship program.
1 student, Summer REU internship program, NSO, Boulder Solar Alliance.
Served as panelist/proposal reviewer for 1 NSF solar terrestrial research (STR) related call.
Guest lecturer for CU PHYS 7810 Collage 2020 Course: 1 lecture on inversions for the solar corona.
Volunteer at HAO/NCAR Super Science Saturday outreach event (K-12 focused activity).
Wrote 1 science popularization article about DKIST for a romanian (home country) astronomy magazine.

Gordon J. D. Petrie, Scientist

Areas of Interest

Solar magnetic fields.

Recent Research Results

Working with Valentin Martinez Pillet and Julian Blanco Rodriguez (U. Valencia, Spain), Petrie continued development of the SOPHISM magnetograph instrument simulator for application to the Solar Dynamics Observatory's Helioseismic and Magnetic Imager (SDO/HMI). This simulator is fed with synthesized spectra for the Stokes parameters I and V calculated from an MHD simulation using the Stokes Inversion with Response functions (SIR) code for the HMI Fe I spectral line at 617.3 nm. Petrie refined this radiative transfer calculation to the full spatial resolution of the MHD simulation and eliminated some artifacts in the interpolation fro the regular spatial grid to the regular grid in log(optical depth). The center-limb variation of the modeled photospheric brightness was brought into better agreement with both theoretical values and measurements from the HMI instrument. The SOPHISM implementation for HMI was then found to produce good magnetic field data but spurious velocities. Petrie is addressing this problem by revisiting the instrument transmission profile functions in the simulator.

Early this year Petrie used GONG synoptic magnetograms and potential-field source-surface models to model the magnetic connection of Parker Solar Probe (PSP) to the early solar surface during perihelion encounters. In addition, Petrie participated in the ISSI team led by Louise Harra (PMOD, Switzerland), "Exploring The Solar Wind In Regions Closer Than Ever Observed Before". Initially Petrie contributed PFSS model results to this team effort. More recently, Petrie used the Yet Another Feature Tracking Algorithm (YAFTA) code to study the dynamic evolution of a coronal hole that is key to understanding the PSP in situ observations taken during its first perihelion. During this perihelion the spacecraft is believed to have been magnetic connected to a small low-latitude coronal hole. Using SDO Atmospheric Imaging Assembly (AIA) 193 angstrom images to identify the evolving coronal hole boundary, Petrie applied YAFTA to HMI magnetograms to identify ephemeral dipole structures that emerged and decayed within and nearby this coronal hole during the perihelion and to quantify the evolution of the magnetic flux of the bipoles, compared to the net magnetic flux of the coronal hole. The coronal hole area, magnetic flux, and dipole population clearly grew around the time that PSP became magnetically connected to it. The team is investigating how the opening of this magnetic flux is related to the transient phenomena ("switchbacks") observed at this time by the FIELDS instrument on PSP.

Service

Petrie analyzed errors in the GONG magnetograms, which are heavily used by space weather scientists at NASA, NOAA, AFRL and elsewhere. This included testing the zero-point correction and developing and applying polar field correction methods for different types of synoptic magnetogram produced by NSO. As solar cycle 25 strengthens, the global solar field is becoming ever more complex, and the GONG zero-point correction's performance in particular needs to be monitored.

Petrie participated in the NASA-NOAA Solar Cycle 25 Prediction Panel, who forcast that cycle 25 will be of similar strength to cycle 24.

Petrie participated in the successful NASA HSO-Connect proposal "CHOMP: Connecting Heliophysics Observatories and Models with PSP" led by Pete Riley (Predictive Science), where his role will be to analyze the Stokes profiles and inverted magnetic field data from DKIST/Cryo-NIRSP with reference to nearly-contemporaneous PSI MHD simulation data. Petrie submitted a proposal on high-resolution, multi-wavelength spectro-polarimetric observations of the solar polar field to the first proposal call for the DKIST Operations Commissioning Phase. Petrie continued to participate in SOLARIS science team activities.

Petrie has provided NSO data user support on accessing and applying NSO magnetograms for various users including AFRL, NASA/CCMC, NOAA/SWPC, Predictive Science, U. Michigan, as well as users in Europe. Petrie refereed manuscripts for journals including the *ApJ*, *A&A*, *SoPh*, *FrPhy*, *Nature*, *JPP* and the *JGR*.

Alexei A. Pevtsov, Astronomer

Areas of Interest

Solar magnetic fields, corona, sunspots, chromosphere, solar-stellar research, space weather and space climate.

Recent Research Results

A. Pevtsov worked on several projects aimed at (1) representing the solar magnetic activity using historical and modern data; (2) modeling the effect of observations from additional vantage points (Lagrange L_5, L_4, and L_3) on solar wind and coronal field models used in space weather forecast; and (3) formation of transequatorial coronal loops.

He and his colleagues used the photospheric magnetic field measured by NASA/NSO Spectromagnetograph, VSM/SOLIS and HMI/SDO to determine the axial dipole moments of active regions and their contribution to solar polar fields. It was found that, typically, about 30% of active regions have opposite-sign axial moments in every cycle, often making more than 20% of the total axial dipole moment. The total axial dipole moment and even the average axial moment of active regions is smaller in cycle 24 than in previous cycles.

Pevtsov and his colleagues used historical data from Greenwich Royal Observatory, Pulkovo observatory and its Kislovodsk Mountain Station to investigate the size and tilt properties of active regions. The results further confirmed bi-modal distribution of sunspot areas, and the difference in latitudinal variation of active region tilts for large and small groups. The intensity and evolution of the extreme storms in January 1938 and March 1946 have been studied using historical white light, Hα observations, and the world-wide reports of aurora at mid-/low- latitudes. The extreme solar storms are rare events, and using historical data increases the number of studied events. Combining modern state-of-the-art modeling and historical data as has been done in studies by Pevtsov and his colleagues enables derivation of physical parameters in the interplanetary space in pre-space exploration era. Furthermore, the analysis of historical data was used to support a novel model of solar cycle variability in the framework of an external quasi-sinusoidal influence on an oscillator with cubic nonlinearity and linear damping (Duffing oscillator). It was shown that while this interpretation of solar cycle is a mathematical approximation, it explains several properties of solar cycle variability.

Future Research Plans

Dr. Pevtsov will continue his research on properties and evolution of magnetic fields on the Sun. He will also continue with research aimed at better characterization of benefits of an instrument at Lagrange L_5 point for space weather forecasting, and the solar-stellar studies.

Service

Dr. Pevtsov is an NSO Associate Director and the Director of NSO Integrated Synoptic Program (NISP). In FY2020, he chaired the NSO's Scientific Personnel Committee. He served on a panel for NASA's Senior Review of the Heliophysics Operating Missions. He also reviewed research proposals for NASA and articles for several professional publications. A. Pevtsov continued serving on the Users' Committee for HAO's Mauna Loa Solar Observatory and the Advisory Board for the Historical Archive of Sunspot Observations (HASO) at the University of Extremadura (Spain). He is a co-chair for the International Astronomical Union (IAU) Inter-Division B-E Working Group on Coordination of Synoptic Observations of the Sun. He is a member of the Editorial Advisory Board for the *Open Astronomy* journal and the Editorial Board for the *Bulletin of Crimean Astrophysical Observatory*. Dr. Pevtsov also leads the ISSI International Team on Reconstructing Solar and Heliospheric Magnetic Field Evolution over the Past Century and the working group on Promoting international collaboration in multi-vantage observations of the Sun, with a special focus on unique scientific advantages of L_4+L_5 combined observations under auspices of the International Living with a Star Program. He is a co-moderator for S1 cluster and the lead for one action team for COSPAR ISWAT - International Space Weather Action Teams initiative.

Kevin Reardon, Associate Scientist

Areas of Interest

Dynamics and structure of the solar chromosphere, transition region, and corona; implementation of modern techniques for data calibration, analysis, and discovery; application of imaging spectroscopy techniques; post-focus instrumentation development; spectropolarimetry of the solar atmosphere; transit studies of inner planets; public outreach and student training; history of solar astronomy.

Recent Research Results

K. Reardon has continued efforts to study the small-scale dynamics of the solar atmosphere. He has been exploring new approaches and tools for analyzing ground-based solar data. He has contributed to training the community, through DKIST workshops, to train users in these techniques. He has provided scientific input on to the DKIST Data Center and the NSO Community Science Program. He worked with the team developing plans and approaches for the operations commissioning phase (OCP), in particular the proposal call process.

Reardon was awarded time on the Atacama Large Millimeter/submillimeter Array (ALMA) for his proposal "Probing the thermal properties of the chromosphere at high resolution" in the Cycle 7 observing program. He has helped organize several successful joint observations between ALMA and the DST since 2017. He is collaborating with CU graduate students Momchil Molnar and Ryan Hofmann and NJIT graduate student Yi Chai to analyze simultaneous observations from IBIS, FIRS, and ROSA combined with ALMA sequences at 1- and 3-millimeter wavelengths, as well as with the IRIS and *Hinode* satellites. The work with Molnar has revealed the diagnostic value of several key chromospheric spectral lines in the visible and probed the wave energy propagating into the upper atmosphere. Hofmann has used these same data to compare ALMA temperatures with those retrieved through non-LTE spectral inversions. In addition, he is working with another CU graduate student, Johnathan Stauffer, to perform a similar analysis comparing spectral inversions of IBIS data with information on the mid-atmosphere temperatures revealed by simultaneous observations of the CO molecule from the McMath-Pierce telescope. As part of these efforts, the calibration processes for IBIS data were used to refine the techniques for data reduction that will be needed for DKIST.

Reardon is also working with Oana Vesa, a graduate student at NMSU, on the analysis of a multi-wavelength time series of IBIS data to probe wave modes at different heights in the solar atmosphere, in particular surface gravity waves as an energy source for chromospheric heating. With this same data set, he is working with NSO post-doc Benoit Tremblay to test the suitability of machine-learning techniques to extract information on horizontal flow fields, especially at the higher resolutions provided by DKIST. Reardon also collaborates with Dr. Juie Shetye, now at NMSU, in analyzing observations from the Goode Solar Telescope (GST) at Big Bear Solar Observatory, exploring the data challenges that result from higher-resolution and larger detectors.

Reardon also studied techniques for destretching, atmospheric dispersion correction, image quality metrics, image reconstruction and data mosaicking which are valuable for the scientific usage of the DKIST data. He has analyzed the performance of several DKIST instruments.

Future Research Plans

Reardon will continue to work with graduate students Momchil Molnar (CU), Ryan Hofmann (CU), Johnathan Stauffer (CU), Oana Vesa (NMSU), and Yi Chai (of NJIT), as well as Dale Gary, Mark Rast, Steve Cranmer, Phil Judge, Lucia Kleint, and others to analyze the rich data sets from ALMA, IBIS, and other instruments in order to better understand the heating and dynamics of the solar chromosphere on the smallest scales. Reardon was a co-investigator on 15 investigations submitted in response to the DKIST first call for observing proposals and will support those science teams in the calibration and analysis any data obtained as part of those efforts.

He is part of an HSO Connect project led by Haimin Wang (NJIT), and a member of the Parker Solar Probe (PSP) Science Team, through which he will coordinate community science goals for DKIST observations related to multi-messenger investigations of the connections between the solar atmosphere and the solar wind.

Service

Reardon will continue working on the application of new methods for processing the challenging volumes of data to be obtained with the DKIST. This includes techniques for calibrating, compressing, and classifying the contents of those data. He is working with several instrument teams to characterize and calibrate some of the early commissioning data. These methods are being develop into a toolkit solar scientists can use to make the DKIST data better amenable to scientific analysis of the calibrated DKIST data. When data from early operations begins to arrive, he will work with community scientists to help them effectively access and exploit their observations.

Reardon will contribute to educating and engaging the community through DKIST and NCSP Data Training workshops (and other community interaction opportunities), helping potential DKIST users understand how to employ the facility capabilities in service of their science goals. He will help define data formats for sharing and delivering data from DKIST and Level-2 data products.

Reardon will continue to mentor students and engage them in the field of solar physics, while promoting a welcoming environment for all that promotes diversity and equity.

Reardon will continue to serve as a member of the SunPy board, supporting the development of SunPy and other open source software packages needed by the solar community.

Reardon continues to provide content to and to participate in NSO's public outreach efforts. He serves as a referee to several academic journals.

Thomas R. Rimmele, Astronomer

Areas of Interest

Sunspots; small-scale magnetic surface fields; active region dynamics; flares; acoustics waves; weak fields; adaptive optics; multi-conjugate adaptive optics; instrumentation.

Recent Research Results

As DKIST Associate Director with responsibility for the construction of the $344M DKIST as well as the ramp up to full operations of DKIST in 2019, Dr. Rimmele's time is fully committed to the extensive management, organizational and service tasks. Rimmele, however, maintains a strong interest in the development of AO technology.

Future Research Plans

T. Rimmele hopes to continue his efforts to perform observations at the highest spatial resolution in order to study the properties and the dynamics of small-scale magnetic elements. He will continue to develop multi-conjugate adaptive optics for implementation at DKIST. He plans to participate in the DKIST first-light observations with the primary objective of verifying the DKIST facility and instrumentation for science use on behalf of the community. He plans to actively engage in the execution of a number of Critical Science Plan experiments during early operations of DKIST. He will continue to improve the understanding of structure and dynamics of sunspots and test existing MHD models.

Service

Rimmele is NSO Associate Director for the DKIST. He mentors students and postdocs, supervises key NSO staff members and works closely with the DKIST Science Working Group and its chair. He guides the NSO multi-conjugate adaptive optics development effort. He continues to serve as referee of a number of papers submitted to astrophysical and technical journals.

Thomas A. Schad, Associate Astronomer

Areas of Interest

Spectropolarimetry diagnostics of magnetic fields and their relation to the chromospheric and coronal heating problem; infrared instrumentation, including DKIST facility instrument development; student engagement and community outreach.

Recent Research Results

Dr. Schad's recent work has provided a number of advancements relevant to remote sensing the coronal magnetic field using DKIST coronagraphic polarimetry. Schad & Dima (2020, Solar Physics, V295) developed an extensively benchmarked numerical code for the forward synthesis of polarized coronal emission lines and further applied this code to high resolution 3D MURaM coronal simulations to investigate analysis techniques in resolved features. Dima & Schad (2020, ApJ, V889) advanced a multi-line technique to achieve single point measurements of the coronal magnetic field without detailed atomic modeling, and Dima, Kuhn, & Schad (2019, ApJ, V889) reported new multi-line observations of coronal polarized emission lines. In addition, Dr. Schad has worked with Dr. David Harrington and colleagues on polarization modeling for DKIST (Harrington et al., 2020 JATIS 6c8001H)) as well as shock heating in chromospheric umbrae (Anan et al., 2019, ApJ, V882).

Future Research Plans

As DKIST early science operations approaches, Dr. Schad has been involved in a large number of proposing collaborations aimed at novel chromospheric and coronal observations using DKIST. This includes deep investigations of near-limb spicule magnetic fields and their connectivity to the mass and energy flow of the corona, the formation of carbon monoxide in the lower chromosphere and its role in chromospheric dynamics, as was as cool and hot coronal polarimetry. In addition, Dr. Schad continues to advance coronal diagnostics through modeling efforts and use of available observational data, while also collaborating on projects related to Deep Learning based photospheric spectropolarimetric inversions and filament magnetic fields and dynamics.

Service

Schad is an active member of the DKIST Science Group, is the scientific lead for the DKIST Instrument Control System, supports the facility instrument development and integration efforts, and provides support to the polarimetric calibration and analysis team. He was appointed the chair of the Technical Review Committee in 2020 in advance of the DKIST Cycle 1 proposal call. Schad also participates in outreach to the local and national community, participating in the Maui County science fairs, giving outreach talks to students, as participating in an NSF live outreach event. Schad also supervised Dr. Gabriel Dima during his duration as a DKIST postdoctoral researcher.

Dirk Schmidt, Associate Scientist

Areas of Interest

Adaptive optics, high spatio-temporal resolution observation techniques; development of adaptive optics systems, in particular multi-conjugate adaptive optics systems.

Recent Research Results, Future Research Plans & Service

Schmidt leads the multi-conjugate adaptive optics upgrade for DKIST.

Schmidt collaborates with the New Jersey Institute of Technology Big Bear Solar Observatory and leads the development of the Goode Solar Telescope multi-conjugate adaptive optics system ”Clear", which is the experimental pathfinder for the DKIST system, as well as the development of adaptive optics for use with solar prominences.

Service

Schmidt served as conference chair and editor of the 2020 Adaptive Optics Systems VII conference at the SPIE Astronomical Telescopes + Instrumentation symposium and as a reviewer on the Technical Review Committee for the first DKIST observations cycle.

Lucas Tarr, Assistant Astronomer

Areas of Interest

Observational, theoretical, and numerical investigations of the low solar atmosphere to study energy propagation, storage, and release. Focus on determining the 3D structure of the magnetic field and how it evolves in time.

Dr. Tarr uses analytical models, 3D MHD simulations, and ground- and space-based data to determine the magnetic topology of active regions as they evolve in time, how waves propagate though the solar atmosphere, the magnetic reconnection rate due to quiescent and eruptive processes, and how those processes contribute to heating the solar atmosphere and generating eruptions. His primary observatory responsibilities are in supporting the Operations Commissioning Phase of the DKIST, currently by developing the Call for Proposals, providing technical and scientific review of submitted proposals, and generating operational experiments based on user-submitted proposals.

Recent Research Results

Completed a study to assess the ability of nonlinear force free field extrapolation methods to reproduce known magnetic field configurations from simulations in stratified atmospheres. NLFF methods were unable to reproduce the known fields because of inconsistency between the MHD state near the lower (photospheric) boundary and the NLFF conditions. This indicates that the currently most widely used methdos for coronal field determinations are a best uncertain, and at worst simply wrong, and that more effort should be put into magnetohydrostatic extrapolation, data-driven MHD reconstructions, or spatially coupled 3 and 4D spectropolarimetric inversions.

Finished coaligning an expansive coordinated dataset targeting a bipolar magnetic field configuration in an enhanced network region using many observatories: Dunn Solar Telescope, ALMA, Hinode, and IRIS. Found numerous transient brightenings in the datasets corresponding to different heights and temperatures. Currently working to determine possible causality between the small scale events.

Publications revolving around these topics are close to submission.

Future Research Plans

Primary research goal: finish the initial development of a novel approach to data-driven MHD simulations and publish the initial results. A new NSO postdoc, Dylan Kee, will largely be taking over this project, with the following updates: add gravitational effects into the scheme, validate it against a variety of solar simulations, apply to active regions observed by HMI to determine their coronal topology (especially for delta sunspots), and incorporate other constraints into the method, e.g., helicity and energy flux.

Do comparison between different channels of the coordinated dataset, and to 3D MHD simualtions, to determine the direction of energy transfer associated with the transient dynamics (e.g., down from the corona to the chromosphere versus up from photosphere to the chromosphere).

Support a recently funded IfA/NSO/HAO grant to perform spatially correlated 3D reconstructions of spectropolarimetic data using a machine learning approach.

Use multi-height magnetometry from new DKIST data, as it becomes available, to determine our ability to reconstructing the three dimensional structure of the solar magnetic field.

Service

Served on Operations and Commissioning Module 1 team: responsible for developing the procedure to write the initial proposal call and update future versions. This was successfully implemented and tested as part of DKIST's first Call for Proposals in August.

Served on Operations and Commissioning Module 3: responsible for developing procedure to generate experiments from submitted proposals. This work is ongoing.

Served on Cycle 1 Technical Review Committee (will serve on all future OCM TRCs)

Served on Cycle 1 Science Review Committee (will serve on all future OCM SRCs)

Organized a request to do two sets of postdoc hires, one to support work on data driven MHD simulations, and the second to support DKIST science in general, with a particular emphasis on analyzing spectropolarimetric data. Served on both hiring committees and chaired one. Two hires are confirmed at this point, and one or two more are pending.

Led team for a supplemental funding request through the joint NSF/NASA WoU-MMA program. This request was aimed primarily at new capabilities for the CryoNIRSP instrument and FIDO system (the distribution optics). Expanded capabilities will allow Cryo to operate simultaneously with all other DKIST instruments and target a plethora of MMA-related diagnostics. This supplemental request was funded by NSF.

Sushanta C. Tripathy, Scientist

Areas of Interest

Global and local helioseismology; solar activity cycle; ring-diagram analysis, sub-surface zonal and meridional flows, Magnetoseismology of active regions; cross-spectral analysis of time series.

Recent Research Results

In order to investigate the sub-surface flows for complete solar cycle 23, S. Tripathy in collaboration with Drs. S. Kholikov and K. Jain used Michelson Doppler Imager (MDI) spherical harmonic (SH) time series and reconstructed velocity images through a novel approach of inverse SH decomposition technique. These velocity images were then processed through the ring-diagram pipeline to measure subsurface zonal and meridional flows covering a depth of 5-40 Mm during the period 1996 May through December 2010. It may be noted that the Global Oscillation Network Group (GONG) measures these flows starting from July 2001. The residual meridional flow converges near the mean latitude of magnetic activity and mimic the butterfly diagram of sunspot numbers. Further, the north-south asymmetry is also clearly visible in the meridional circulation. It is also noted that the meridional flow has a strong depth dependence that differs during the maximum and minimum activity periods. This work was funded by a NASA grant.

As part of the next generation GONG (ng-GONG) proposal, Dr. Tripathy has been investigating the mode conversion processes that requires seismology at different heights in the solar atmosphere. In this context, Dr. Tripathy and his collaborators have been characterizing the spatio-temporal power distribution around active regions (ARs). This year Dr. Tripathy and collaborators studied the AR 12683 as a function of the height in the solar atmosphere, wave frequencies, magnetic field strength and inclination of the magnetic field. The result suggested that the power halos seen in different ARs behave differently and warrants a statistical analysis of many active regions.

Dr. Tripathy & collaborators have studied the subsurface properties of several active regions in order to detect any possible signature that may differentiate between flaring and non-flaring active regions.

Dr. Tripathy and collaborators have also studied the temporal changes occurring in the convection and radiative zone by using oscillation frequencies from ground based and space-borne helioseismic instruments covering the solar Cycle 24 to identify the period of solar minimum in conjunction with solar activity. This work was partially carried out by the REU student and was presented at the SPD meeting. Dr. Tripathy is also participating in an international collaborative project to derive a better solar rotation profile using the longest and best possible splitting coefficients and inversion technique.

Future Research Plans

Dr. Tripathy will continue to analyze the formation of acoustic halos around several active regions using multi-wavelength data from Solar Dynamics Observatory. It is expected that a statistical analysis of several active regions will help us to comprehend the interaction of waves with the magnetic field as a function of the solar atmospheric height. Dr. Tripathy along with his collaborators also plan to use Doppler velocity observations taken in different wavelengths from MOTH-II instrument. With the availability of high-degree oscillation frequencies and other mode parameters for nearly two solar cycles, Dr. Tripathy plans to investigate the long-term behavior of these parameters to comprehend the structural and dynamical changes occurring in the solar interior. Dr. Tripathy will further work on various NASA funded proposals where he serves as a Co-I.

Service

S. Tripathy serves as the science lead for the interior group and is responsible for organizing the weekly NISP interior science meeting and monthly NISP science meetings. One of the major tasks of Dr. Tripathy in the current year has been vetting the output from the autovmbi pipeline which manages the first-stage reduction of the GONG calibration pipeline and creates the velocity, magnetogram and intensity images from the raw images taken at different sites. He also continues to provide support to the data analysis team. Dr. Tripathy actively participated in the new GONG camera selection procedure by validating the observations and providing other required scientific support. Dr. Tripathy also led several group discussions to specify the multi-height helioseismology requirements for the ng-GONG proposal submitted to NSF. This summer, Dr. Tripathy co-mentored an REU student. The REU program was conducted remotely and offered a new experience. Dr. Tripathy also participated in preparation of a white paper for Helio-2050 led by Dr. M. Dikpati of High Altitude Observatory.

Alexandra Tritschler, Senior Scientist

Areas of Interest

Operations of large astronomical facilities; operations tools used by users and operators of such facilities; high-resolution spectroscopy and spectropolarimetry of the photosphere and chromosphere of active regions; solar magnetic fields; fine-structure of sunspots; numerical simulations of magneto-convection in (and around) sunspots and using those as input for spectral synthesis; post-focus instrumentation.

Current and Future Research Plans

Dr. Tritschler's main interests will continue to be focused on the operations of astronomical facilities and the high-resolution aspects of the photospheric and the chromospheric atmospheric layers of solar active regions. She will continue to develop the operational modes and tools for DKIST

Science Operations. As time permits, she will further use ground-based high-resolution spectroscopic and spectropolarimetric observations to determine the properties of photospheric and chromospheric layers of active regions and to infer their three-dimensional dynamic and magnetic structure and to compare those results to forward modeling.

Service

Tritschler is the DKIST's Program Scientist for Operations and as such guides the development of DKIST Science Operations. She is responsible for the planning of the DKIST Operations Commissioning Phase and the development and specification of all operations tools to be used to efficiently operate the DKIST. Tritschler is developing the training plan for future DKIST observers in close collaboration with the Chief Science Operations Specialist and the Science Operations Manager, preparing them for DKIST operations. She has been mentoring numerous summer REU and SRA students over the years. She is actively involved in the organization and support of DKIST Critical Science Plan workshops. Tritschler has served and continues to serve on NSO and DKIST hiring committees, and has been a reviewer of publications for *ApJL*, *ApJ*, *A&A*, *SoPh, and AN.*

Han Uitenbroek, Astronomer

Areas of Interest

Radiative transfer modeling and structure and dynamics of the solar atmosphere; modeling and measurement of polarized light; spectro-polarimetric inversions under Non-LTE conditions.

Recent Research Results

Han Uitenbroek continues to work on expanding and improving his multi-dimensional numerical radiative transfer code RH, as well as work on the Non-LTE inversion code DeSIRe. The RH code has been made available to the community from the start and is widely used by the solar community and, in some cases, even outside that(https://github.com/han-uitenbroek). The RH code has now been incorporated as the forward engine in two recently developped Non-LTE spectro-polarimetric inversion codes: STiC (de la Cruz Rodriguez et al. 2019, A&A 623, A74) and the new inversion code DeSIRe, combining RH with the well-established LTE inversion code SIR of Ruiz Cobo . RH is also extensively used as Non-LTE spectral line modeling code for RADYN simulations.

Han supervises Colorado University graduate student Neeraj Kulkarni, working on modeling the Hanle effect in Sr I 470.6 nm line in 3-D MHD simulations to determine if the effect in this line can be used to distinguish between different solar dynamo theories.

Han contributed solar experience and knowledge of line formation in the Mg II h and k lines to a paper on the unusual visible dimming and concurrent near UV brightening of the supergiant Betelgeuse (Dupree et al. 2020, ApJ 899, 68D).

Future Research Plans

Development and maintenance of the RH code will continue. Concentration will be on the new inversion code DeSIRe.

Service

Han is the Associate Director for the NSO Community Science Program (NCSP). He leads the effort of DKIST Level-2 definition and implementation of standard inversions, leads the DKIST Ambassador program and helps guide the organization of DKIST Data Training workshops. He also serves on the OCM 1 and 2 panels defining procedures for the DKIST OCP, and took part in the review of the first OCP cycle 1 proposals.

Friedrich Wöger, Senior Scientist

Areas of Interest

Image reconstruction techniques; adaptive optics; two-dimensional spectroscopy, and spectro-polarimetry; DKIST instrument systems, in particular the DKIST Visible Broadband Imager (VBI); DKIST Wavefront Correction System (WFC); DKIST Data Handling System (DHS).

Recent Research Results

F. Wöger is guides and participates in the integration, testing and commissioning of major DKIST subsystem components, such as e.g. VBI, WFC, DHS, as well as all partner provided instrumentation, ensuring that these instrument systems perform to their individual requirements. He participates in the integration, testing and commissioning planning activities, their execution and reviewing their results.

Future Research Plans

Dr. Wöger began work on improved methods for image reconstruction for data acquired with 2D spectroscopic and spectro-polarimetric instruments, such as DKIST VTF data. These algorithms will be based on speckle interferometry and allow the post-processing of data to achieve diffraction-limited spatial resolution. He continues to work on developing accurate models for atmospheric transfer functions and is interested in investigating expanding current models for use with multi-conjugate adaptive optics systems.

Service

Wöger is the DKIST instrument systems scientist, and as such, is the scientific interface between the DKIST project and the partner institutes that build instruments for DKIST, and is providing guidance to all involved teams during all phases of their integration, testing and commissioning activities. He is involved in the DKIST VBI instrument effort as its principal investigator, overseeing its integration and commissioning at the DKIST site on Maui. Furthermore, as the DKIST Data Handling Scientist, he is supervising the DKIST data handling system development, ensuring the proper documentation and implementation of the requirements defined for the system and creating a complete data model for DKIST. As the DKIST Wavefront Correction Scientist, Wöger has guided the DKIST WFC team towards the Site Acceptance Testing by writing the WFC test plans that verify the WFC system performs to its requirements.

Woeger is currently supervising a calibration pipeline engineer who implements the prototype data calibration pipelines for the majority of DKIST's first light instrumentation. These pipelines will be provided to the DKIST Data Center for integration into its automated system.

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APPENDIX F. ACRONYM GLOSSARY

A&E	Architecture and Engineering
AAAC	Astronomy and Astrophysics Advisory Committee (NSF)
AAG	Astronomy and Astrophysics Research Grants (NSF)
AAS	American Astronomical Society
ACE	Advanced Composition Explorer (NASA)
ADAPT	Air Force Data Assimilative Photospheric flux Transport
AD	Associate Director (NSO)
AFRL	Air Force Research Laboratory
AFWA	Air Force Weather Agency
AGS	Atmospheric and Geospace Sciences Division (NSF)
AGU	American Geophysical Union
AIA	Atmospheric Imaging Assembly (SDO)
aka	Also Known As
ALMA	Atacama Large Millimeter Array
AMO	Access-Mode Observing (DKIST)
AMOS	Advanced Maui Optical and Space Surveillance Technologies (MEDB)
aO	Active Optics
AO	Adaptive Optics
AOA Xinetics	Adaptive Optics Associates – Xinetics Inc.
APRPP	Annual Progress Report and Program Plan (NSF)
APS	Astronomy and Planetary Science (CU Boulder Department)
AR	Active Region
ARRA	American Recovery and Reinvestment Act
ASP	Advanced Stokes Polarimeter
APDA	Astronomical Photographic Data Archives (PARI)
ATI	Advanced Technology Instrumentation (NSF)
ATM	Atmospheric Sciences (Division of NSF)
ATRC	Advanced Technology Research Center (University of Hawaiʻi)
ATST	Advanced Technology Solar Telescope (NSO)
AU	Astronomical Unit
AURA	Association of Universities for Research in Astronomy, Inc.
AWI	Akamai Workforce Initiative (Hawaiʻi)
AWS	Amazon Web Services
BE2E	Boulder End-to-End (DKIST)
BLNR	Bureau of Land and Natural Resources
BBSO	Big Bear Solar Observatory
BOE	Basis of Estimate
BO/ITL	Biological Opinion/Incidental Take License (U.S. Fish & Wildlife Service)
BSA	Boulder Solar Alliance
CA	Cooperative Agreement
CAS	Central Administrative Services (AURA)
CATE	Citizen Continental America Telescopic Eclipse (NSO Project)
CAM	Cost Account Manager (DKIST)
CCD	Charge Coupled Device
CCMC	Community Coordinated Modeling Center

CDAW	Coordinated Data Analysis Workshop
CDM	Compact Doppler Magnetograph (SWRI)
CDN	Content Delivery Network (NSO EPO)
CD-ROM	Compact Disk – Read Only Memory
CDR	Critical Design Review
CDUP	Conservation District User Permit
CEPP	Coronavirus Exposure Prevention (AURA)
CES	Coudé Environmental System
CfA	Center for Astrophysics (Harvard Smithsonian)
CfAO	Center for Adaptive Optics
CGEM	Coronal Global Evolutionary Model
CGEP	Collaborative Graduate Education Program (University of Colorado, Boulder)
CHU	Critical Hardware Upgrade
CISM	Center for Integrated Space Weather Modeling
CJS	Commerce, Justice, Science (Subcommittee, US House Appropriations Committee)
CLEA	Contemporary Laboratory Exercises in Astronomy
CMAG	Compact Magnetograph (NISP)
CMEs	Coronal Mass Ejections
CNC	Computer Numerical Controlled
CNSF	Coalition for National Science Funding
CoDR	Conceptual Design Review
COLLAGE	COLLAborative Graduate Education (University of Colorado, Boulder)
COS	College of Optical Sciences (University of Arizona)
CoRoT	COnvection ROtation and planetary Transits (French Space Agency CNES)
CoSEC	Collaborative Sun-Earth Connection
COSI	Code for Solar Irradiance
COSPAR	Committee on Space Research
COTS	Commercial Off-the-Shelf
CPR	Cost Performance Report (DKIST)
CR	Carrington Rotation
CRIM	Coudé Rotator Mechanical Interface
Cryo-NIRSP	Cryogenic Near-IR Spectropolarimeter (DKIST)
CS	Center Services (NSO)
CSA	Cooperative Support Agreement
CSAP	Center Services Action Plan (NSO)
CSF	Common Services Framework
CSIC	Consejo Superior de Investigaciones Cientificas (Spain)
CSP	Critical Science Plan
CSS	Camera Software
CSSS	Current Sheet Source Surface
CTL	Center-to-Limb
CU Boulder	University of Colorado, Boulder
CYRA	Cryogenic Infrared Spectrograph (NJIT, Big Bear Solar Observatory)
DA	Diversity Advocate
DAG	Directed Acyclic Graphs
DAS	Data Acquisition System

DB-P	Dual-beam Polarizer (McMath-Pierce Telescope)
DC	Data Center
D&D	Design & Development
DASL	Data and Activities for Solar Learning
DC	Data Center
DCAP	Data Center Action Plan (NSO)
DE&I	Diversity, Equity, and Inclusion
DEIS	Draft Environmental Impact Statement
DEM	Differential Emission Measure
DHS	Data Handling System
DIL	"Day in the Life" (DKIST)
DKIST	Daniel K. Inouye Solar Telescope (formerlyATST)
DL-NIRSP	Diffraction-Limited Near-Infrared Spectropolarimeter (DKIST)
DLNR	Department of Land & Natural Resources (State of Hawaiʻi)
DLSP	Diffraction-Limited Spectropolarimeter
DLT	Digital Linear Tape
DM	Deformable Mirror
DMAC	Data Management and Analysis Center (GONG)
DoD	Department of Defense
DOE	Department of Energy
DRD	Design Requirements Document
DRMS	Decision, Risk and Management Sciences (NSF)
DSF	Disappearing Solar Filament
DSPAC	DKIST Science Policy Advisory Committee
DSSC	DKIST Science Support Center
DST	Dunn Solar Telescope
DWDM	Dense Wavelength Division and Multiplexing
EA	Environmental Assessment
EAST	European Association for Solar Telescopes
EF	Evershed Flow
EGSO	European Grid of Solar Observations
EGU	European Geosciences Union
EIC	Equity and Inclusion Council (AURA)
EIS	Extreme-ultraviolet Imaging Spectrometer (*Hinode*)
EIS	Environmental Impact Statement
EIT	Extreme ultraviolet Imaging Telescope (SOHO)
EMR	Experience Modifier Rate (OSHA)
EPA	Environmental Protection Agency
EPD	Energetic Particle Detector
EPO	Educational and Public Outreach
ESA	European Space Agency
ESF	Evans Solar Facility
ESO	European Southern Observatory
EST	European Solar Telescope
EU	European Union
EUI	Extreme Ultraviolet Imager (Solar Orbiter)

EUV	Extreme Ultraviolet
EVMS	Earned Value Management System (DKIST)
FAA	Federal Aviation Administration
FAT	Factory Acceptance Test
FDP	Full-Disk Patrol (SOLIS)
FDR	Final Design Review
FEIS	Final Environmental Impact Statement
FIDO	Facility Instrument Distribution Optics (DKIST)
FIP	First Ionization Potential
FIRS	Facility Infrared Spectro-polarimeter
FMS	Flexible Manufacturing System
FLC	Ferroelectric Liquid Crystal
FLI	First Light Initiative
FOCS	Feed Optics Control Software
FOV	Field of View
FPGA	Field Programmable Gate Array
FTE	Flux Tube Expansion
FTEs	Full Time Equivalents
FTS	Facility Thermal Systems (DKIST)
FTS	Fourier Transform Spectrometer (McMP)
FY	Fiscal Year
GAM	Gravity Assist Maneuvers
GB	Giga Bytes
GBPs	G-band Bright Points
GBSON	Ground-Based Solar Observing Network
GEH	George Ellery Hale (CU Boulder)
GIS	Global Interlock System
GISS	Global Interlock System Software
GNAT	Global Network of Astronomical Telescopes, Inc. (Tucson)
GOES	Geostationary Operational Environmental Satellites (NASA and NOAA)
GONG	Global Oscillation Network Group
GOS	Gregorian Optical System
GSFC	Goddard Space Flight Center (NASA)
GST	Goode Solar Telescope (Big Bear Solar Observatory, California)
GUI	Graphical User Interface
HAO	High Altitude Observatory
HASO	Historical Archive of Sunspot Observations
HCP	Habitat Conservation Plan (HI State Division of Forestry & Wildlife)
HIDEE	Heliophysics Infrastructure and Data Environment Enhancements (NASA)
HIS	Heavy Ion Sensor
HLS	Higher Level Software
HMI	Helioseismic and Magnetic Imager
HO	Haleakalā Observatory
HOAO	High-Order Adaptive Optics
HPCF	High Performance Computing Facility (CU Boulder)
HQ	Headquarters

HR	Human Resources
HSG	Horizontal Spectrograph
HST	Hubble Space Telescope
HXR	Hard X-Ray
IAA	Instituto de Astrofísica de Andalucía (Spain)
IAC	Instituto de Astrofísica de Canarias (Spain)
IAU	International Astronomical Union
IBIS	Interferometric BIdimensional Spectrometer (Arcetri Observatory)
ICD	Interface Control Document
ICM	Inversion by Central Moments
ICME	Interplanetary Coronal Mass Ejections
ICS	Instrument Control System
IDL	Interactive Data Language
IEF	Inverse Evershed Flow
IfA	Institute for Astronomy (University of Hawai`i)
IFU	Integrated Field Unit (McMath-Pierce Solar Telescope Facility)
IHY	International Heliophysical Year
IMAP	Interstellar Mapping and Acceleration Probe (NASA)
IMaX	Imaging Magnetograph eXperiment (SUNRISE)
IMF	Interplanetary Mean Field
INAF	Istituto Nazionale di Astrofisica (National Institute for Astrophysics, Italy)
IPC	Integration Progression Criteria (DKIST)
IPS	Integrated Project Schedule (DKIST)
IR	Infrared
IRES	International Research Experience for Students (NSF)
IRIS	Interface Region Imaging Spectrograph
IRIS SMEX	Interface Region Imaging Spectrograph Small Explorer Mission (NASA)
ISEE	Institute for Scientist and Engineer Educators (UCSC)
ISIS	Integrated Science Investigation of the Sun (Parker Solar Probe)
ISOON	Improved Solar Observing Optical Network
ISP	Integrated Synoptic Program (NSO)
ISRD	Instrument Science Requirement Document
ISS	Integrated Sunlight Spectrometer (SOLIS)
ISWAT	International Space Weather Action Teams (COSPAR)
IT	Information Technology
ITAR	International Traffic in Arms Regulations
ITF	Infrared Tunable Filter
ITAR	International Traffic in Arms Regulations
IT&C	Integration, Testing, & Commissioning
JPL	Jet Propulsion Laboratory (NASA)
JSOC	Joint Science Operations Center (SDO)
JTTS	Journey to the Sun (NSO Teacher Workshop and Telescope Program)
KAOS	Kiepenheuer Adaptive Optics System
KCE	KC Environmental (Maui)
KIS	Kiepenheuer Institute for Solar Physics (Freiburg, Germany)
KPI	Key Performance Indicators (DKIST)

KPNO	Kitt Peak National Observatory
KPVC	Kitt Peak Visitor Center
KPVT	Kitt Peak Vacuum Telescope
KS	Kamehameha Schools
KTH	KTH Royal Institute of Technology, Stockholm, Sweden
LAPLACE	Life and PLAnets Center (University of Arizona)
LASCO	Large Angle and Spectrometric Coronagraph (NASA/ESA SOHO)
LASP	Laboratory for Atmospheric and Space Physics (University of Colorado, Boulder)
LAT	Lab Acceptance Test
LCROSS	Lunar CRater Observation and Sensing Satellite
LCVR	Liquid-Crystal Variable Retarder
LESIA	Laboratoire d'études patiales et d'instrumentation en astrophysique (Paris Observatory)
LFM	Large Facilities Manual (NSF)
LIC	Local Interlock Controller
LMSAL	Lockheed Martin Solar and Astrophysics Laboratory
LoHCo	Local Helioseismolgy Comparison Group
LOS	Line Of Sight
LRP	Long-Range Plan
LTE	Local Thermodynamic Equilibrium
LWS	Living With a Star
M1CA	Primary Mirror Cell Assembly (DKIST)
MAG	Magnetometer
MagEX	Magnetic Explorer (LASP CU-Boulder Mission)
MBP	Magnetic Bright Point
McMP	McMath-Pierce
MCAO	Multi-Conjugate Adaptive Optics
MCC	Maui Community College
MDI	Michelson Doppler Imager (SOHO)
ME	Milne-Eddington
MEDB	Maui Economic Development Board
METIS	Coronagraph (onboard Solar Orbiter)
MF	Management Fee
MHD	Magnetohydrodynamic
MKAOC	Mauna Kea Astronomy Outreach Committee
MKIR	Mauna Kea Infrared
MOU	Memorandum of Understanding
MLSO	Mauna Loa Solar Observatory (HAO)
MOI	Memorandum of Intent
MPI	Message Passing Interface
MPR	Midterm Progress Review
MREFC	Major Research Equipment Facilities Construction (NSF)
MRI	Major Research Instrumentation (NSF)
MSAC	Math and Science Advisory Council (State of New Mexico)
MSFC	Marshall Space Flight Center (NASA)
MSIP	Mid-Scale Instrumentation Program (NSF)
MWO	Mt. Wilson Observatory (California)

NAC	NSO Array Camera
NAI	NASA Astrobiology Institute
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NCAR	National Center for Atmospheric Research
NCOA	National Center for Optical-Infrared Astronomy
NPR	National Public Radio
NPS	National Park Service
NCSP	NSO Community Science Program
NDSC	Network for the Detection of Stratospheric Change
ngGONG	Next Generation GONG
NHPA	National Historic Preservation Act
NHWG	Native Hawaiian Working Group
NIR	Near Infrared
NISP	NSO Integrated Synoptic Program
NJIT	New Jersey Institute of Technology
NLFFF	Non-Linear Force-Free Field
NLTE	Non-Local Thermodynamic Equilibrium
NMDOT	New Mexico Department of Transportation
NMSU	New Mexico State University
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NPDES	National Pollutant Discharge Elimination System (EPA/HI Dept of Health)
NPFC	Non-Potential Field Calculation
NPR	National Public Radio
NPS	National Park Service
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NSBP	National Society of Black Physicists
NSF	National Science Foundation
NSF/AST	National Science Foundation, Division of Astronomical Sciences
NSF/ATM	National Science Foundation, Division of Atmospheric Sciences
NSHP	National Society of Hispanic Physicsts
NSO	National Solar Observatory
NSO/SP	National Solar Observatory Sacramento Peak
NSO/T	National Solar Observatory Tucson
NST	New Solar Telescope (NJIT Big Bear Solar Observatory)
NSTC	National Science Technology Council
NTT	New Technology Telescope (ESO)
NWNH	New World New Horizons (Astro2010: Astronomy & Astrophysics Decadal Survey)
NWRA/CoRA	NorthWest Research Associates/Colorado Research Associates
O&M	Operations and Maintenance
OCD	Operational Concepts Definition (DKIST)
OCC	Operations Commissioning Call (DKIST)

OCM	Operations Commissioning Module
OCP	Operations Commissioning Phase (DKIST)
OCS	Observatory Control System
OEO	Office of Education and Outreach (NSO)
OFCM	Office of the Federal Coordinator for Meteorology
OLPA	Office of Legislative & Public Affiars (NSF)
OMB	Office of Management and Budget
OP	Observing Program
OPMT	Operations Planning & Monitoring Tool
OSHA	Occupational Safety and Health Administration
O-SPAN	Optical Solar Patrol Network (formerly ISOON)
OSTP	Office of Science and Technology Policy (US Office of the President)
PA	Programmatic Agreement (State Historic Preservation Office/Federal Historic Preservation Office)
PA	Proposal Architect
PAARE	Partnerships in Astronomy & Astrophysics Research & Education (NSF)
PA&C	Polarization Analysis & Calibration
PAEO	Public Affairs and Educational Outreach (NOAO)
PB	Peta Bytes
PBR	President's Budget Request
PARI	Pisgah Astronomical Research Institute
PCA	Principal Component Analysis
PDR	Preliminary Design Review
PFSS	Potential Field Source Surface
PhET	Physics Education Technology (CU Boulder)
PHI	Polarimetric and Helioseismic Imager (Solar Orbiter)
PI	Principal Investigator
PLA	Project Labor Agreements
PM	Project (or Program) Manager (NSO)
PMCS	Project Management Control System
PRC	Portfolio Review Committee (NSF)
PRD	Partial Frequency Redistribution
PRI	Public Radio International
ProMag	PROminence Magnetometer (HAO)
PROSWIFT	Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (US Senact Act S,881)
PSP	Parker Solar Probe
PSPT	Precision Solar Photometric Telescope
QA/QC	Quality Assurance/Quality Control
QAS	Quality Assurance System
QBP	Quasi-Biennial Periodicity
QL	Quick-Look
QSA	Quasi-Static Alignment
QU	Queen's University (Belfast, Ireland, UK)
QWIP	Quantum Well Infrared Photodetector
RA	Resident Astronomer

RASL	Research in Active Solar Longitudes
RDSA	Reference Design Studies and Analyses
RET	Research Experiences for Teachers
REU	Research Experiences for Undergraduates
RFP	Request for Proposal
RHESSI	Reuven *Ramaty High Energy Solar Spectroscopic Imager (NASA)*
RISE/PSPT	Radiative Inputs from Sun to Earth/Precision Solar Photometric Telescope
RMS	Root-Mean-Square
ROB	Remote Office Building
ROD	Record of Decision
ROI	Region of Interest
ROSA	Rapid Oscillations in the Solar Atmosphere
RPW	Radio and Plasma Wave
SACNAS	Society for the Advancement of Chicanos an Native Americans in Science
SAN	Storage Area Network
SASSA	Spatially Averaged Signed Shear Angle
SAT	Sight Acceptance Testing
SCB	Sequential Chromospheric Brightening
SCM	Small Complete Mission (NASA)
SCOPE	Southwest Consortium of Observatories for Public Education
SDO	Solar Dynamics Observatory (NASA)
SDR	Solar Differential Rotation
SED	Stellar Energy Distribution
SSERVI	Solar System Exploration Research Virtual Institute (NASA)
SFC	Space Flight Center (NASA)
SFR	Supplemental Funding Request
SFT	Surface Flux Transport
SH	Spherical Harmonic
SI	Strategic Initiative
SIM	System Integration Module (DKIST)
SM	Service Manager (NSO Data Center)
SMEX	Small Explorer (IRIS)
SMO	Service-Mode Observing (DKIST)
SNA	Surface Normal Actuator
SNR	Signal-to-Noise Ratio
S&O	Support and Operations (DKIST)
SOA	Service Oriented Architecture
SOC	Solar Observatory Council (AURA)
SOHO	Solar and Heliospheric Observatory
SOI	Solar Oscillations Investigations (SOHO)
SOLARC	Scatter-free Observatory for Limb Active Regions and Coronae (U Hawai‘i)
SOLIS	Synoptic Optical Long-term Investigations of the Sun
SONG	Stellar Oscillation Network Group
SOP	Science Operations
SORCE	Solar Radiation and Climate Experiment
SOS	Science Operations Specialist (DKIST)

SOT	Solar Optical Telescope
SOT/SP	Solar Optical Telescope Spectro-Polarimeter (*Hinode*)
SOW	Statement of Work
SPA	Surface Parallel Actuator
SPC	Scientific Personnel Committee (NSO)
SPD	Solar Physics Division (AAS)
SPEs	Solar Proton Events
SPICE	Spectral Imager of the Coronal Environment (Solar Orbiter)
SPIES	SpectroPolarimetric Imager for the Energetic Sun (Dunn Solar Telescope)
SPINOR	Spectro-Polarimeter for Infrared and Optical Regions
SPRING	Solar Physics Research Integrated Network Group (European Union)
SPSC	Space Science Center (University of Colorado, Boulder)
SRA	Summer Research Assistant
SRD	Science Requirements Document
SREC	Southern Rockies Education Centers
SSA SWE	Space Situational Awareness – Space Weather Segment (European Space Agency)
SSEB	Source Selection Evaluation Board (Federal Government)
SSL	Space Sciences Laboratory (UC Berkeley)
SSOC	Sunspot Solar Observatory Consortium
SSP	Source Selection Plan (DKIST)
SST	Swedish Solar Telescope
SSWG	Site Survey Working Group (DKIST)
STARA	Sunspot Tracking and Recognition Algorithm
STEAM	Science, Technology, Education, Arts, and Mathematics
STEM	Science, Technology, Engineering and Mathematics
STEP	Summer Teacher Enrichment Program
STEREO	Solar TErrestrial RElations Observatory (NASA Mission)
STIC	Stockholm *Inversion* Code
STS	Science for a Technological Society (2013 Solar and Space Science Decadal Survey)
SUC	Science Use Case
SUCR	Summit Control Room (DKIST)
SUMI	Solar Ultraviolet Magnetograph Investigation (NASA, MSFC)
SUP	Special Use Permit
SV	Science Verification
SW	Solar Wind
SWA	Solar Wind Analyzer
SWEAP	Solar Wind Electrons Alphas and Protons (Parker Solar Probe)
SWG	Science Working Group (DKIST)
SWMF	Space Weather Modeling Framework
SWORM	Space Weather Operations, Research and Mitigation (NTSC)
SWPC	Space Weather Prediction Center (NOAA)
SwRI	Southwest Research Institute
SWx-*TREC*	Space Weather Technology, Research and Education Center (CU Boulder)
SXR	Soft X-Ray
TAC	Telescope Time Allocation Committee
TB	Tera Bytes

TBD	To Be Determined
TCS	Telescope Control System
TEOA	Top End Optical Assembly (DKIST)
TI	Tenant Improvement
TMA	Telescope Mount Assembly
ToO	Target of Opportunity
TOP	Technical Operations
TRC	Technical Review Committee
TRACE	Transition Region and Coronal Explorer
UA	University of Arizona
UH	University of Hawaiʻi
UBF	Universal Birefringent Filter
UCSC	University of California Santa Cruz
UK	United Kingdom
UPS	Uninterruptible Power Supply
UROP	Undergraduate Research Opporunities Program
USAF	United States Air Force
USF&WS	US Fish and Wildlife Service
USNO	United States Naval Observatory
UV	UltraViolet
UVCS	UltraViolet Coronagraph Spectrometer (SOHO)
VBI	Visible-light Broadband Imager (DKIST)
VCCS	Virtual Camera Control System (Dunn Solar Telescope)
VFD	Variable Frequency Drive
VFISV	Very Fast Inversion of the Stokes Vector (Inversion Code, HMI)
ViSP	Visible Spectropolarimeter (DKIST)
VLA	Very Large Array
VSM	Vector SpectroMagnetograph (SOLIS)
VSO	Virtual Solar Observatory
VTF	Visible Tunable Filter (DKIST)
VTT	Vacuum Tower Telescope (Tenerife, Spain)
WBS	Work Breakdown Structure
WCCS	Wavefront Correction Control System
WDC	Workforce and Diversity Committee (AURA)
WFC	Wavefront Correction (DKIST)
WHI	Whole Heliospheric Interval
WHPI	Whole Heliosphere and Planetary Interactions
WISPR	Wide-Field Imager (Parker Solar Probe)
WIT	Women In Technology (MEDB)
WoU-MMA	Windows on the Universe Multi-Messenger Astrophysics (NSF Program)
WOW	World of Work (Patsy T. Mink Summit, Hawaii)
WSA	Wang-Sheeley-Arge (Solar Wind Model)
WSDL	Web Service Description Language
WSHFH	White Sands Habitat for Humanity
WWW	World Wide Web