NSF

NSO National Solar Observatory

AURA

2022 Annual Progress Report

2023 Annual Program Plan

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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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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 or Heliosphere. As the Daniel K. Inouye Solar telescope (DKIST) starts operating in FY 2022, NSO provides renewed scientific and instrumentation leadership in high-resolution studies of the solar atmosphere in the visible and infrared, and continued synoptic observations of solar variability, and helioseismology.

Major components of the National Solar Observatory strategic planning include:

- Operating the National Science Foundation's 4-meter DKIST on behalf of, and in collaboration with, the solar and astronomical community.
- Consolidating and training the DKIST operations team.
- Operating the 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 operational 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 2022, NSO will consolidate the plans for a starting the NSO's Data Center.

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 the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act[1].
- Finalizing the upgrade of 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.
- Continuing defining the transition of the Dunn Solar Telescope (DST) operations to a consortium led by New Mexico State University (NMSU). NSO will continue managing the Sacramento Peak site facilities in FY 2022.
- Increasing diversity of the solar workforce. This FY 2021–2022 APRPP summarizes past and future activities at the Observatory to increase diversity within the NSO, its user community, and the

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

undergraduate and graduate student populations, which include geographic, gender, ethnic, and racial metrics.

Some of the programmatic highlights of the NSO Program in FY 2022 include:

- After absorbing the delays caused by the COVID-19 pandemic, ending the construction of the DKIST on Haleakalā and start the Operations Commissioning Phase (OCP).
- As part of the DKIST construction scope, finalizing the science verification of the DKIST instruments (see Figure 1-1).
- Completing the transition of staff from the DKIST construction project to the operations team.
- Executing the first set of experiments derived from observing proposals prioritized by the DKIST Time Allocation Committee (TAC) following the first OCP call (OCP1).
- Commissioning the DKIST Data Center (DC) by receiving, processing, and delivering data obtained during OCP1.
- Releasing the second call for DKIST proposals (OCP2).
- Resuming operations of the SOLIS suite of instruments at Big Bear Solar Observatory (BBSO).
- Completing the GONG refurbishment project and starting the deployment of the newly acquired detectors.
- Furthering the science case and management aspects of the ngGONG project.
- Providing closure to the DKIST Level-2 data products requirements and advance the interfaces with the DKIST Level-1 data.
- Testing the Level-2 pipelines with data from OCP as available.

A few of the major actions to advance solar physics that NSO will undertake in FY 2022 include:

- Following the conclusion of the ASTRO2020 decadal, *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*, stating that (see also Appendix B):

  "The survey committee concluded that an appropriate role for astronomy and astrophysics decadal surveys is to comment on the value of ground-based solar physics projects for astronomy and astrophysics priorities, with the solar and space physics decadal survey being the more appropriate body to prioritize and rank ground-based solar physics projects within the context of the full range of multi-agency activities in solar physics.",

  coordinating activities that engage the solar community in the production of white papers that reflect the value of ground-based solar physics in preparation for the upcoming solar and space physics decadal.
- 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. Participate in the search of the third three-year termed visiting appointment described 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.

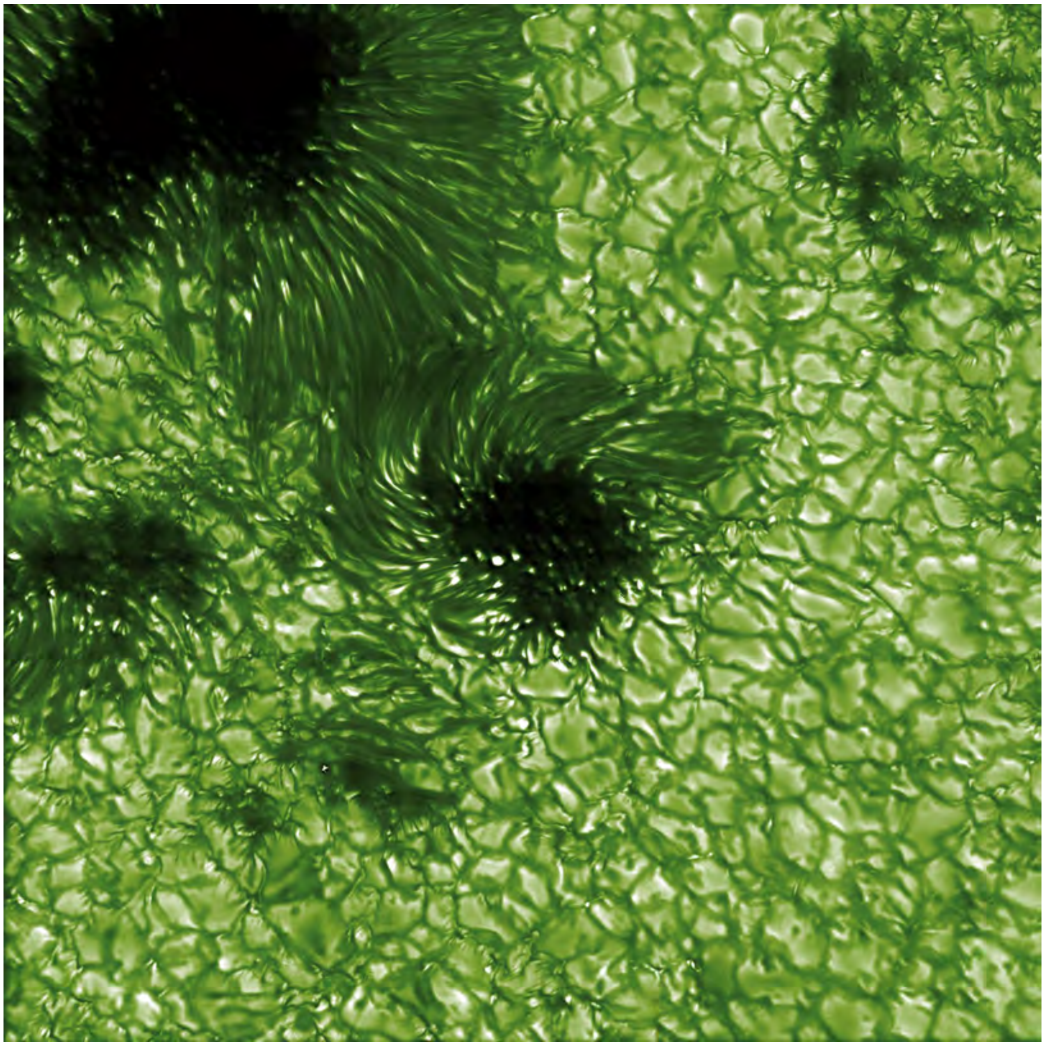


Figure 1-1. *A complex sunspot group observed with the Visible Broadband Imager (VBI) instrument at 450.3 nm on May 11, 2021, as part of the science verification phase of the DKIST construction project.*

As it appears in the President's Budget Request (PBR) for FY 2022, the anticipated observatory funding is $25.46M, split into $19.58M for DKIST operations and $5.88M for base-program actions, including HQ operations and NISP base-funded activities. This funding level represents an increase to the original budget profile from the CA of $3M, split equally between DKIST operations and base-program activities. The new funds originate from the recommendations of the 2019 review panel for the NSO Mid-Term Progress Report and FY 2020–2024 Long Range Plan (LRP hereafter) exercise. The spending plan chapter explains the use of the new funds. We note, however, that this budget increase would only become effective after the corresponding appropriation process in Congress.

Since FY 2017, NISP has received support for GONG operations from the National Oceanic and Atmospheric Administration (NOAA). In FY 2021, NSO submitted 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. For FY 2022, the support for GONG operations from NOAA corresponds to a new renegotiated level of about $1M that reflects partially updated costs of operating the network.

NSO received in FY 2021 four supplemental funding actions. In decreasing order of magnitude, they correspond to the second DKIST construction COVID-19 delay ($9M), a new Windows of the Universe-Multi-Messenger Astronomy (WoU-MMA) supplement ($2M), and two supplements to support Sunspot operations ($380K). The last two are divided between regular site activities ($300K) and deferred maintenance ($80K) including repairs to the backup power generator, facility main water line support, and site wireless access points.

The FY 2021 submission to the NSF's 10-Big Idea WoU-MMA program followed the successful proposal from the previous year to enhance DKIST capabilities for collaborating with the inner heliospheric missions Parker Solar Probe (PSP) and Solar Orbiter. On this occasion, the FY 2021 supplement targeted new data products that incorporate novel observations from DKIST and NISP to improve current coronal and heliospheric modeling efforts. Synoptic magnetograms combining GONG and Solar Orbiter data will provide a more up-to-date boundary input for coronal modeling (see Figure 1-2). The revolutionary DKIST coronal magnetic field measurements will serve as benchmarks to contrast with these models. For this comparison to be useful, significant coverage of the solar corona is needed, and the proposal includes the definition of the appropriate set of coronal synoptic observations. The degree of improvement achieved using these novel data will be validated using the near-Sun in-situ measurements of the two spacecraft. The funds span three years, including the total solar eclipse in April 2024, crossing the continental US from south to north. The eclipse occurs with PSP and Solar Orbiter in quadrature as seen from Earth. This configuration of the spacecrafts represents an excellent opportunity to validate the predictions based on the new data products.

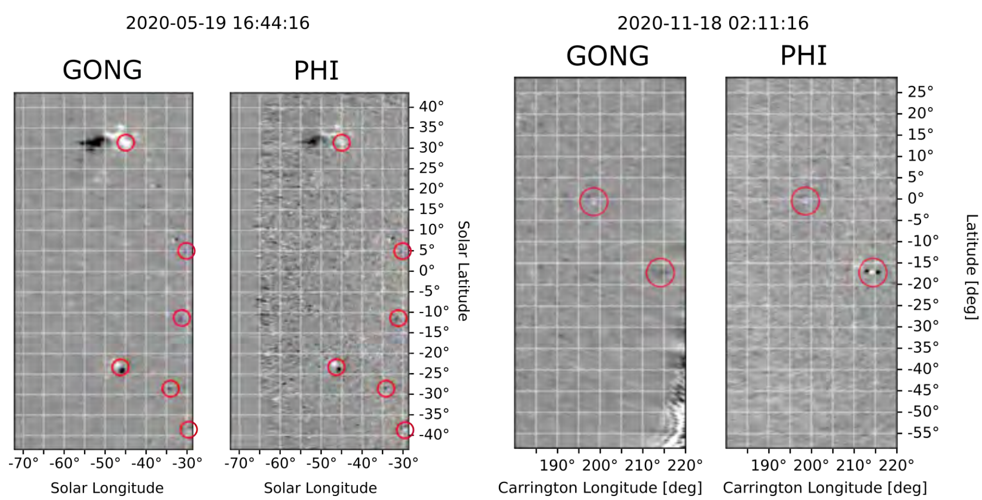


__Figure 1-2.__ Two co-alignments of the Solar Orbiter Polarimetric and Helioseismic Imager (PHI) magnetograph data with nearly simultaneous GONG data that demonstrate the ability to recognize similar solar features in the two data sets. Left image was taken with a 15-degree line-of-sight separation between Solar Orbiter and the Earth. Right image with 122-degree angle. (Courtesy of K. Jain and D. Orozco.)

The $9M supplement covered the second (and last) delay in the DKIST construction project due to the COVID-19 limitations. This supplement required approval by the National Science Board of the NSF. In total, the construction effort suffered a delay of 12.5 months due to the ongoing pandemic shifting the handover to operations to mid-November 2021. Other than the inefficiencies due to the COVID-19 restrictions at the summit, the delays also originated from the evolving complexities in travel conditions, the longer lead arrival time for critical components, and difficulties in the hiring processes to cope with staff turnover.

The continued occurrence of COVID-19 infection waves forced the observatory to operate in restart Phase 1 until June 2021. As described in the NSO's Restart Procedure, Phase 1 allowed all productive work to occur following strict safety protocols and with the necessary means for staff contact tracing. During Phase 1, business travel occured only to sites with NSO presence (including international GONG locations) and as permitted by local and international regulations. It required approval by the NSO Director or designee in consultation with the AURA Vice President for Operations. The AURA-coordinated Coronavirus Exposure Prevention Plan (CEPP) provides reference protocols for productive work during all restart phases. NSO implemented these protocols, adapting them to evolving local conditions. Both the NSO’s Restart Procedure and the AURA CEPP received updates as needed. Most importantly, the CEPP added in September 2021 vaccination status guidance from the Center for Disease and Control (CDC). In June 2021 and following an overall improvement in the local pandemic conditions at all states with NSO presence, the Observatory moved into Phase 2 after the preceptive AURA restart review. As mandated by the CEPP, all sites follow local pandemic guidance, which, at the time of the review, restricted Phase 2 to offering more flexible access to the offices by using a web-based calendar that provides tracing and activity logs. Daily acknowledgment of the CEPP health questionnaire is automatized via the web access system. When Phase 2 started, NSO set up a 30% booking capacity limit tracked by the web calendar. However, due to the additional COVID-19 complications created in the second half of 2021, the use of office space by the staff has been consistently below the 30% cap. Additionally, Phase 2 restated business travel to non-NSO sites using different levels of approvals for domestic and international travel described in the CEPP. In FY 2022, NSO will continue coordinating with AURA on policies and protocols for managing the COVID-19 pandemic, including the early FY 2022 Presidential mandate on vaccine requirements for Federal employees and contractors. The existing versions of the CEPP and the NSO's Restart Procedure include ways to relax COVID-19 restrictions as the pandemic wanes, while continuing to adapt to local regulations and mandates.

The NSO directorate continued the frequency of all-hands meetings to interact with the staff and explain the status of the Observatory as it relates to the COVID-19 situation. NSO transitioned from monthly all-hands to bimonthly events, during which leadership describes the contents and modifications of the CEPP and the Observatory's Restart Procedure. Participation in the events always remained high (more than 80% of the staff), and the regular flow of information has helped maintain staff morale. In 2021, NSO rolled out a wellness survey that showed that staff productivity and motivation remained high but were impacted by the pandemic. NSO will continue monitoring morale in FY 2022 with similar surveys also addressing staff expectations for remote and hybrid work.

As a major Observatory milestone in FY 2021, the DKIST construction project successfully passed the NSF’s Final Construction Review (FCR) in July 2021. The NSF convened an external review panel for four days with a mix of presentations, Q&A, assignments, and general discussion sessions. The NSF charged the panel to examine project management and performance; cultural and environmental compliance; safety and security; and final project acceptance. The review panel concluded that:

“…the project will be able to deliver a fully functional observatory and complete the required documentation for closeout of the project in the first half of CY2022.”

And further emphasized in their final remarks that:

"The Project has developed, in addition to an extremely worthwhile facility, methods, and means of project management and construction that can and should be a hallmark for future federally funded projects, especially for the National Science Foundation. These hallmarks include cultural and environmental compliance, safety standards and practices, project documentation, and risk management and retirement; to name the highlights."

NSO intends to benefit from this highly invaluable and unique Observatory-created reference hallmarks for future developments such as the ngGONG project.

FY 2021 saw progress in all Integration, Test & Commissioning (IT&C) activities, moving the construction project close to the handover to operations. All telescope assembly subsystems are installed, and the corresponding optics aligned. The team upgraded the heat stop and tested its functionality during multiple on-Sun campaigns. The primary telescope mirror was coated for a second time, applying the lessons learned from the first coating exercise with a very satisfactory result. The Wavefront Correction System (WCS) is fully functional and performs within specs following the system's Site Acceptance Testing. The instruments, 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)—finalized the Science Verification Phase (SVP) data acquisition currently under analysis. Contract closeout will follow the reception of the SVP reports and the corresponding documentation. The Cryo-NIRSP on-Sun campaign detected the Si IX coronal line unambiguously at 3934 nm. This detection confirms the extraordinary capabilities of DKIST for coronal magnetic field observations. The final stages of the SVP instruments required the presence of collaborators from partner institutions (Figure 1-3) that had to be trained on all the COVID-19 safety protocols described in the CEPP and the NSO's Restart Procedure, further complicating the logistics of these key activities.

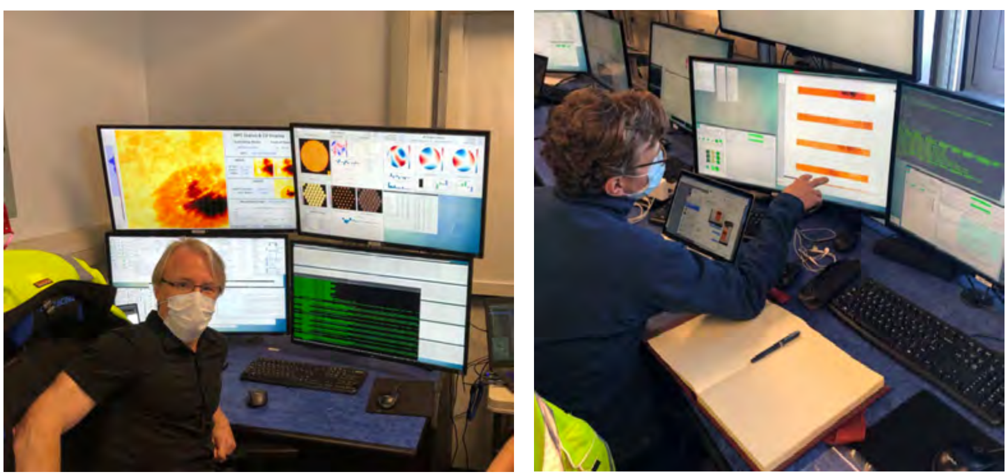


Figure 1-3. *Left: the DKIST WCS team during one of the SVP activities. Right: HAO's ViSP project scientists during one the SVP visits to the summit.*

The first call for proposals as part of the Operations Commissioning Phase (OCP) occurred in the summer of 2020. This call (OCP1) offered the instruments VBI, ViSP, and Cryo-NIRSP in on-disk configuration. The DKIST Time Allocation Committee (TAC) ranked 101 proposals following the technical and science reviews. Every submission was studied by three reviewers, and the results averaged. As a step towards a full dual anonymous TAC process, during OCP1, the PI team was not disclosed to reviewers. The TAC prioritization was based on scientific merit, OCP objectives, and policy guidance. The DKIST team notified[2] the results of the review to the PIs in early 2021.

US scientists led about 50% of the proposals received for OCP1. A similar percentage of US participation is present in the list of approved proposals, but we note that there is a large presence of US Co-Is in almost all international proposals as encouraged by the DKIST access policy. However, a problem was detected in OCP1 as some US university solar programs did not get proposals accepted. This imbalance demonstrates the need to continue training the US community to prepare for ground-based solar research before the new call (OCP2) is released.

The original plan for OCP was to issue three calls for observing proposals. However, driven mainly by the number of technical activities that must be completed before regular operations start, the DKIST team decided to limit the number of calls to only two. The timing for OCP2 is not defined yet and has been delayed due to the COVID-19 construction delays. It is expected to occur in the first half of CY 2022. OCP2 will offer a more extensive list of instruments' configurations, this time including off-limb observations but still with similar constraints (shared-risk) and objectives (pipeline validation) as OCP1. NSO will offer proposal preparation training workshops targeted to the US community more familiar with proposal submission for NASA missions. The workshops will address how to effectively use DKIST for a specific science problem by using individual instrument capabilities and combinations of them, explaining ground-based settings, the impact on the definition of a realistic observing program, and reviewing the existing facility's online materials.

The activities developed during the last phases of the DKIST IT&C, including multiple on-Sun campaigns, have consolidated the facility's operational costs. Experience gained from on-Sun campaigns provided additional and more realistic guidance about the technical support staff needed to operate DKIST 7 days/week. Summit technical operations staffing plans have been iterated with the newly appointed Technical Operations leadership team. More planning of technical operations (e.g., shift schedules) is a priority as construction ramps down. As a result, a consolidated cost of operating DKIST that includes this information is now available. We expect to iterate these cost estimates during OCP as the team gains experience in managing the facility.

In FY 2021, the software and hardware infrastructure of the DKIST Data Center evolved to the point of being ready to receive data from the first OCP observations. All steps starting with summit data ingestion, storage, workflow engine and pipeline operations, and delivery to the community via the web portal are in their final development stages with different levels of verification. The most crucial remaining challenge is the automated operations of the science processing pipelines impacted by two factors. First, the reception of the pipelines only occurs after instrument verification completion, which reduces the amount of time the codes are available to the Data Center. Second, the science verification phase tested only a limited set of all available modes of operations. The degree of manual vs. automated labor associated with the calibrations for the complete set of observing modes is unknown and represents a risk. The Data Center includes a risk entry accordingly to increment the team if the risk is finally realized during OCP.

[2] *https://nso.edu/dkist/accepted-science-programs/*

The early phases of OCP will generate data that will create relevant quality metrics as it moves through the workflow. The Data Center will use these metrics to evaluate if the data are ready for delivery to the proposals' PI, or if it needs corrective actions. These actions can involve the calibration team, the instrument and telescope operations teams, or both. A ticket-based system is in place to ensure the proper, timely response to all actions as they appear.

During FY 2021, all three initiatives comprising the DKIST Level-2 data project—channeled through the NSO Community Science Program (NCSP)—have made significant progress. The Data-Product Initiative concentrates on the Level-2 data the program will routinely produce. NCSP released in FY 2020 the first version of the Level-2 data products requirements. In FY 2021, the requirements document served as the starting point of discussions with the DKIST Data Center to define the ingest mechanisms and the Level-2 output metadata that links to the originating Level-1 data.

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 contribute their expertise to their host institutions and broaden the DKIST user base. Eleven of the Ambassadors participated in at least one observing proposal submitted to the OCP1 call, six of them as lead investigators. The Ambassador program was initially created to provide community training on highly specialized data products in the form of physical parameters on the Sun, an area not originally included in the scope of the DKIST DC. NSO is considering broadening the Ambassador experience to cover all aspects of the DKIST science cycle, from proposal preparation to assessing the quality of the Level-1 data and producing higher-end data products. This holistic scope requires closer integration of the Ambassador experience with the DKIST science team. Thus, depending on the availability of funds for future Ambassador calls, NSO is considering integrating these calls as part of the DKIST Program instead of the more specific NCSP.

Finally, and as part of the Community-Oriented Initiative, NCSP organized additional remote training opportunities in FY 2021. Expanding on the successful series of previous workshops, NCSP held in July 2021 the first training course dedicated to the chromosphere and spectral line formation in this poorly known layer of the Sun. The course described various approximations for creating thermal, velocity, and magnetic information from chromospheric observations, including hands-on exercises using Python notebooks. A total of 41 US scientists, 35 of them in their early career, participated in the workshop. The program plans to conduct an additional follow-up workshop in FY 2022 that concentrates on the use of the He I 1083 nm spectral region.

In FY 2021, the COVID-19 pandemic continued to pose challenges for the sustained operation of the GONG network. However, the NISP technical team efforts secured at least five stations operational for most of the year. Local and international travel restrictions made it difficult for the NISP team to perform regular Preventive Maintenance (PM) trips to the GONG sites. The NISP technical team used a combination of support from local partners, remote login checks, and, as permitted, PM trips to ensure the required duty cycle for the network. Four PM trips were performed in CY 2021 to the stations in Mauna Loa (Hawaiʻi), Big Bear (California), Tenerife (Spain), and Cerro Tololo (Chile). GONG at Big Bear Solar Observatory required replacement of the main camera due to intermittent camera noise. The Hawaiʻi station required the replacement of the H-alpha filter. The rotating waveplate for wavelength tuning of the GONG station on Tenerife stopped working and demanded a prolonged PM trip that was impacted by problems with the supply chains. More recently, Cerro Tololo was visited to solve a persistent leakage on the magnetogram signal of spurious nature related to the pointing of the instrument. In Learmonth (Australia), the local team replaced a power supply and other components sent from the Boulder headquarters. The Udaipur (India) staff painted the GONG shelter. Thanks to these measures, the GONG network kept a duty cycle above 90% throughout the year. In FY 2022, NISP is planning additional PM trips to the stations in India and Australia, pending the pandemic's evolution and related travel restrictions.

In FY 2021, GONG operations reached a major milestone with the signing of a renewed five-year interagency agreement (IAA) between NOAA and the NSF for GONG operations. Via this IAA, NSO/NISP will receive slightly above $1M/year for operating the network starting in FY 2022. We note that NOAA obligates the funds the year prior to when the funding becomes available to NSO. This timing created a funding mismatch in FY 2021 that was covered using Observatory carryforward funds as agreed with the NSF. A component included in the scope of the IAA is the transfer of the GONG pipelines to NOAA's Space Weather Prediction Center (SWPC) and integrating them into an operational framework. In FY 2021, the project made significant progress in establishing the pipelines at SWPC that now receive the real-time magnetogram data from all GONG stations.

As an additional contribution to the previous five-year IAA, NSF supplemented the GONG program with a $2.5M one-time contribution for refurbishing the network. The refurbishment included upgrades to the main instrument and other non-optical but critical stations' components. NISP acquired a new set of cameras which will be deployed starting in FY 2022. The existing detectors are approaching their expected end-of-lifetime, making this upgrade essential in extending the network lifetime an additional five years. Other more ambitious components of the refurbishment project (tunable H-alpha filter) have been impacted by vendor issues, and technical complexities that demand a rescope of the project are detailed later in this document. The NISP technical and Data Center teams are developing the data acquisition system for the new detectors and modifying the existing pipelines to the new output data format.

Another area where NISP has made significant progress in FY 2021 is constructing the new SOLIS site (Figure 1-4) at Big Bear Solar Observatory (BBSO, California). Over the past three years, the project went through a somewhat convoluted permitting process with minimal site work, only as allowed by the existing permits. This situation dramatically changed in FY 2021, with the construction project starting on May 1st, a civil engineering end date of January 2022, and an occupancy permit early this year. In FY 2022, the NISP team will proceed with optical alignments of the SOLIS suite of instruments and the end-to-end tests, including the transmission of the data to the NISP DC at the Boulder offices. SOLIS will start producing its unique synoptic data by the end of FY 2022.

Figure 1-4. *The new SOLIS site at Big Bear Solar Observatory (BBSO, California) as it stands in early CY 2022. (Courtesy of G Card.)*

The future of NISP relies on replacing the GONG network and SOLIS with a suite of instruments that fill the community's needs and provide 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 will be 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 is the first ground-based synoptic network that considers Space Weather needs from its inception. It will also ensure the continuity of decades-long helioseismological observations that monitor the solar interior.

In FY 2021, NSO and HAO submitted a joint proposal for the design phase of ngGONG to the NSF's Mid-scale Research Infrastructure-I call. This submission followed the invitation by the NSF after reviewing the preliminary proposal. The proposal received excellent reviews but was not funded. The cost and lack of an institutional framework that includes all interested parties have hampered progress with the ngGONG project. The proposed new network is the most qualified response of the research community to the needs expressed in the PROSWIFT Act that demands improved ground-based observations of the Sun. In FY 2022, and in collaboration with the HAO, NSO will strengthen the ngGONG proposal by discussing the scientific and operational requirements including all relevant stakeholders. NSO will also promote in FY 2022 the required conversations between all Space Weather end-users of solar data to build an agreement that ideally should address the construction phase and long-term operations. Additionally, the proposal management standards will be upgraded to those expected for a Major Research Equipment Facility Construction (MREFC) project. With an anticipated cost of the network above $100M, the MREFC line represents a more realistic funding line than what’s used so far by the Mid-Scale Program.

During the period FY 2019-2021, the NSO and New Mexico State University (NMSU) shared Sunspot Solar Observatory responsibilities with both institutions having a presence on-site. NMSU led the DST scientific operations and the educational and outreach activities, including operations of the Visitors Center. FY 2021 was the last year of the period of performance of the NSF's grant supporting NMSU's operations of the DST. NSO and NMSU submitted a joint supplemental funding proposal for continued scientific operations during FY 2022. The proposal provides continuity for these activities but also targets simplifying the administrative processes by consolidating expenditures for facilities and utilities at NSO. It also contains a subaward to cover specific expenditures of NMSU. The proposal considers two distinct groups of activities. The first group describes site operational aspects as in previous years. The second group includes major one-time deferred maintenance items categorized by their relevance to site safety and future activities of interest to NMSU. Examples are water distribution checkouts and repairs, work as detailed in the NSF 2018 Final Environmental Impact Study (FEIS) for the site, and road improvements.

The joint proposal also includes preparatory work to transfer the site's management to NMSU at the end of the current CA (FY 2024). In preparation for this transfer, the chancellor's office created the NMSU Sunspot Observatory Committee (NSOC) with a mandate to discuss the administrative framework for potential site management after 2024. The NSOC will define site maintenance and decommissioning priorities for NMSU and elevate them for discussion with the NSO and NSF.

The NSF is evaluating the level of funding that they will provide in FY 2022, in response to the joint NSO and NMSU proposal.

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 was augmented with a part-time graphics designer and webmaster. Compared to similar observatories, our EPO team is demonstrably smaller, minimizing the impact of the Observatory scientific programs on the public. The FY 2020–2024 LRP review pointed out this concern and requested additional funding for the Program. To adequately promote the DKIST early science phase, the NSO EPO Program plans to advertise another position funded initially this year from DKIST. Following the LRP recommendations of the review panel, the NSO is soliciting an increase in the Program's base funding in future years that can sustain this position. An augmented team will be critical as we move into the DKIST operations phase and aim to increase 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 2021. The global COVID-19 pandemic mandated a very different approach in the summers of 2020 and 2021. Yet, 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 2022, the EPO team plans to leverage this REU experience by enabling online networking activities ensuring educational best practices for remote events.

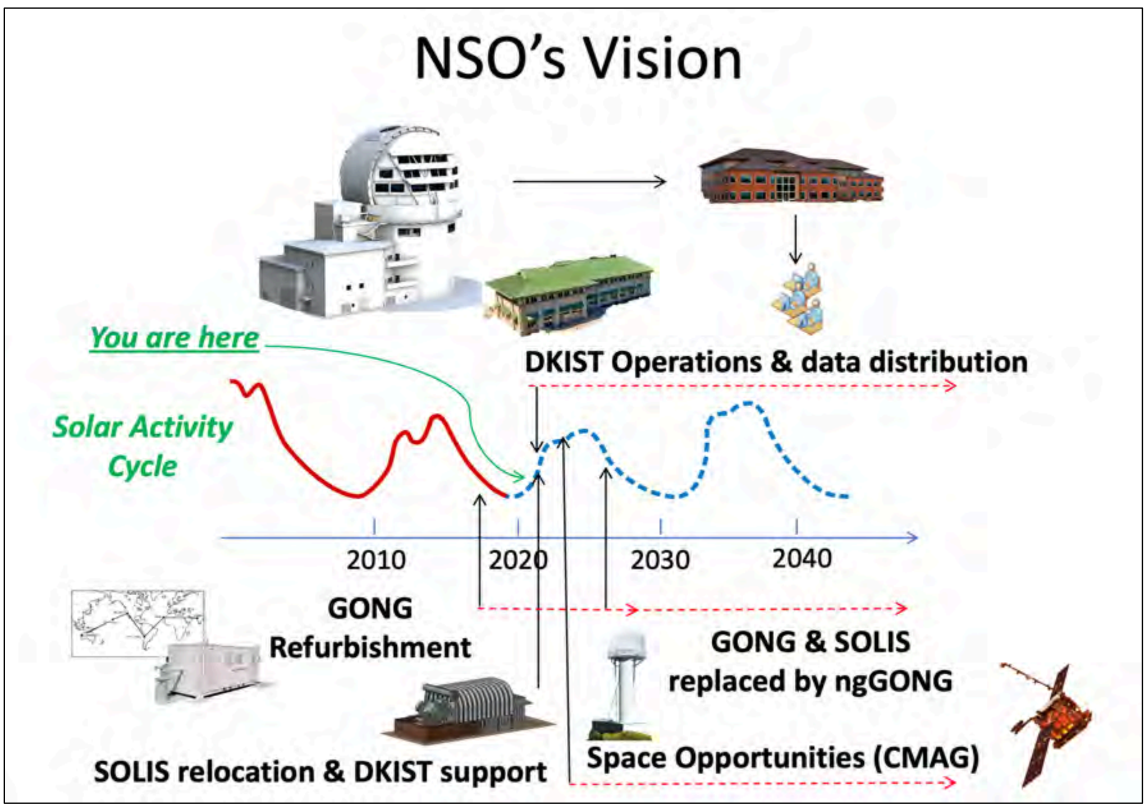


Figure 1-5. The long-term vision of NSO over half the lifetime of DKIST.

NSO FY 2023 Program

- **Daniel K. Inouye Solar Telescope (DKIST)**
  - Continue the execution of experiments from the first OCP call (OCP1).
  - Rank the proposals from the second OCP call (OCP2) via the Time Allocation Committee.
  - Start the execution of proposals from OCP2.
  - Continue the DKIST Data Center implementation plan.
  - Continue developing Multi-Conjugate Adaptive Optics.
  - Continue the DKIST instrumental upgrades.
  - Elaborate the DKIST contribution to the new Cooperative Agreement proposal.
- **NSO Integrated Synoptic Program (NISP)**
  - Operate the GONG network. Continue the network data distribution.
  - Complete the SOLIS site at Big Bear and start operations.
  - Continue refurbishing the GONG network, prioritizing new detectors deployment.
  - Engage stakeholders (NOAA, AF, international partners) in the ngGONG preparatory design phase.
  - Elaborate the NISP contribution to the new Cooperative Agreement proposal.
- **NSO Community Science Program (NCSP)**
  - Execute and test the DKIST Level-2 data products pipelines.
  - Start the implementation of the Level-1/Level-2 hardware interface.
  - Elaborate the NCSP contribution to the new Cooperative Agreement proposal.
- **Sacramento Peak Observatory**
  - Operate the site.
  - Define the transfer of additional operational responsibilities to NMSU.
- **NSO Directorate**
  - Define the requirements and timeline for the NSO Data Center.
  - Lead community-based multi-messenger solar physics opportunities.
  - Lead the NSO proposal for the new Cooperative Agreement.
- **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.
  - Elaborate the EPO contribution to the new Cooperative Agreement proposal.

2 FY 2022 SCIENTIFIC RESEARCH & DEVELOPMENT HIGHLIGHTS

2.1 An improved instrumental polarization correction technique for solar spectropolarimetry in the photosphere and corona

Optical systems often exchange polarization from one state to another (*e.g.*, linear to circular) depending on the optical materials, coatings, and geometries for a given wavelength of light. To successfully interpret the source physics producing polarized signals (whether they come from astronomical sources, laboratory plasmas, medical imaging, etc.), it is necessary to calibrate the instrument to remove this polarization crosstalk. It is not always possible to perfectly calibrate polarimetric data from astronomical telescopes. Sometimes calibration data is missing or the polarimetric performance of a section of the instrument may be difficult to characterize. In the case of solar observations, specific properties of solar spectral lines and continuum can be exploited to determine and correct polarization, via so-called *ad hoc* corrections.

Ad hoc correction techniques have been previously applied to remove instrumental polarization from spectropolarimetry of the solar photosphere. The assumption underlying these techniques is that the crosstalk from one polarization state to another is small and independent from the other crosstalk terms. These techniques become inaccurate as the level of crosstalk grows, and they are not capable of describing a real optical system. Furthermore, they are not applicable to coronal polarized sources, as targeted by the Daniel K. Inouye Solar Telescope.

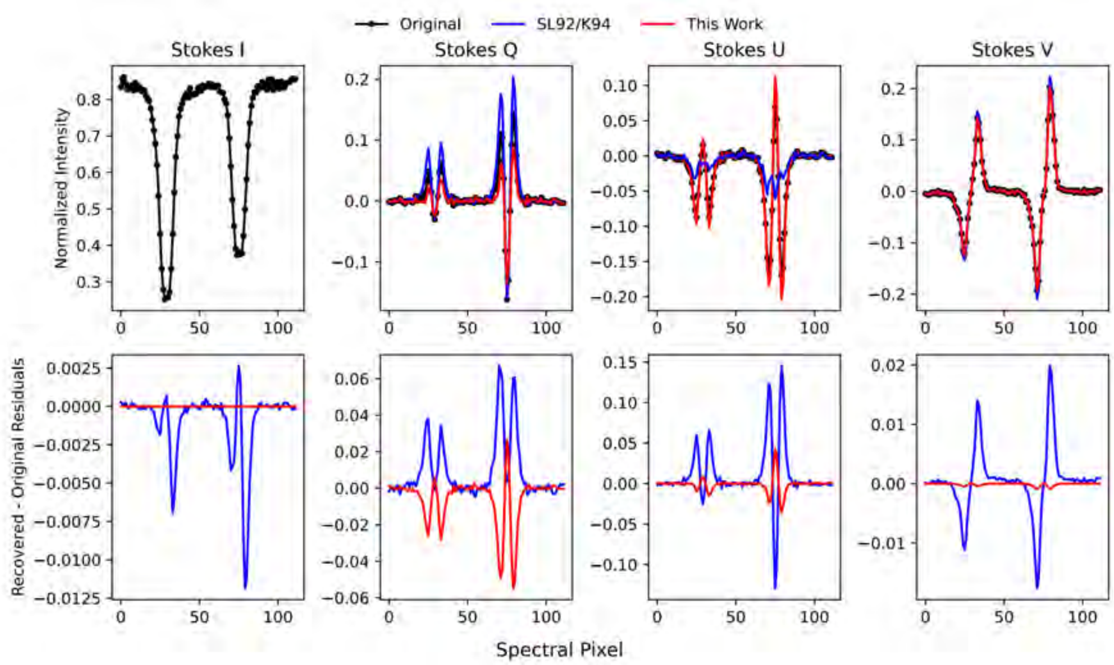


***Figure 2-1**: Example Stokes profiles extracted from a Hinode/SP sunspot observation to which known levels of crosstalk are applied and then ad hoc corrected. The top row shows the original and retrieved profiles from our method and the Kuhn et al. (1994) method. The bottom row shows the difference between the original and recovered profiles.*

S. Jaeggli et al. (ApJ, 930, 132, 2022) has developed a new ad hoc correction technique that takes advantage of the non-depolarizing character of many optical systems. In such cases, the polarized crosstalk can be modeled by two processes: diattenuation and retardance. Using the respective mathematical models and a simple minimization strategy, S. Jaeggli et al. find that large amounts of crosstalk can be accurately inferred and removed from spectropolarimetric observations. The new method is demonstrated using Hinode SP data of a sunspot as shown in Figure 2-1. As expected, it performs much better than previous methods when the levels of polarized crosstalk are large; therefore, it can be more generally applied.

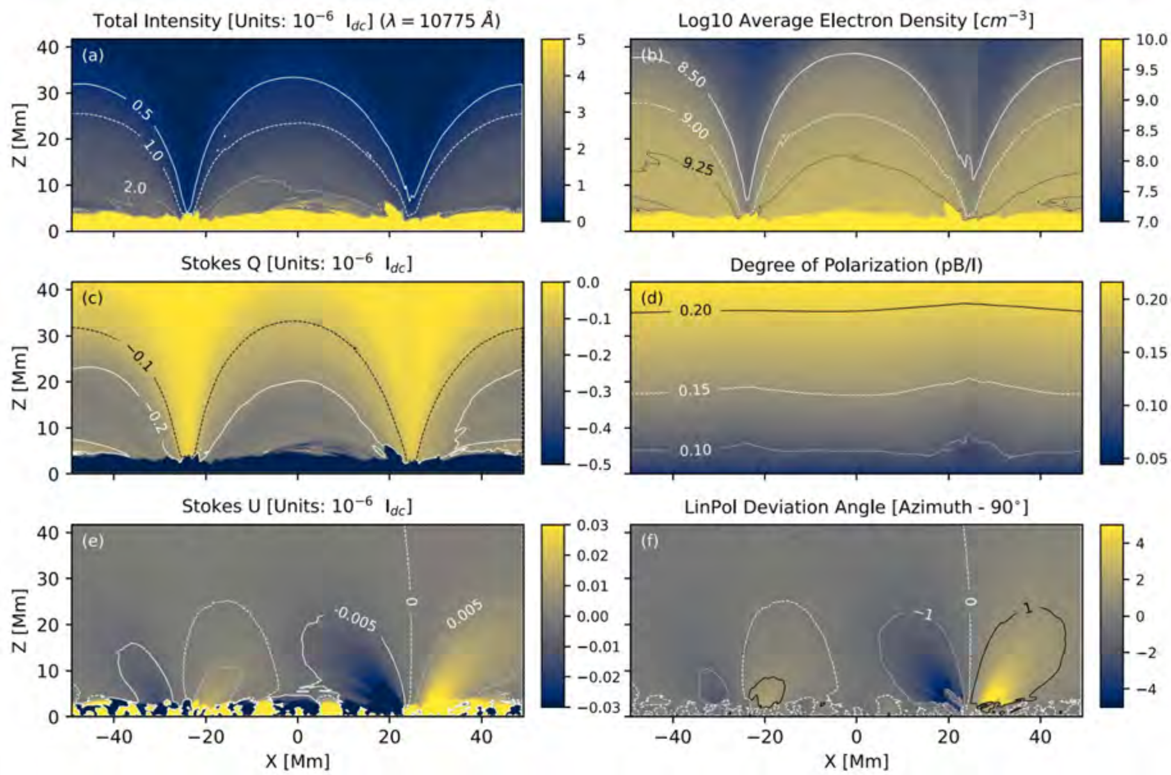


Figure 2-2: *Synthesized polarized Thomson-scattered continuum through a bipolar MHD coronal simulation. Panels (a), (c), and (e) show the total intensity, Stokes Q, and Stokes U intensities in units of millionths of the disk center's spectral radiance. Panel (b) is the LOS average electron density. Panel (d) shows the degree of polarization, while panel (f) shows the deviation angle of the linear polarization direction relative to the tangential direction.*

The approach of S. Jaeggli et al. can also be applied to polarized signals of the solar corona; however, in this case, different *a priori* assumptions regarding the true source signals are necessary for constraining the diattenuation and retardance terms. T. Schad et al. (*ApJ 933, 53, 2022*) proposes a combination of relevant constraints which are then tested using synthetically calculated signals emergent from an advanced radiative MHD simulation of the solar corona. One constraint relies on the polarized orientation of the Thomson scattered K-coronal continuum. Although generally assumed to be tangential to the solar limb, the K-corona polarization angle can deviate from this when the incident radiation field contains additional structure, *e.g.* due to the presence of sunspots. T. Schad et al. addresses this issue by deriving the Thomson scattered polarized emissivity's in a tensor basis, which facilitates the full treatment of the incident radiation field's structure. In Figure 2-2, panel f, one can see the rotation of the linear polarized angle near the sunspots in this bipolar region (*i.e.* near X ~ +/- 25 Mm). Although it is only a few degrees, this turns out to be the primary error source when adapting the Jaeggli et al. ad hoc correction approach for use in the solar corona at optical and infrared wavelengths. T. Schad et al. suggest strategies to mitigate this error source that can successfully recover the values of the polarization crosstalk matrix to an accuracy of ~ 0.02% for the simulation.

These new ad hoc techniques are generally robust and useful, particularly for initial characterization of instrument systems and/or the validation of a more complete system model.

2.2 Subsurface Meridional Flow at the Solar Equator

The amplitude and direction of the meridional flow at the solar equator is of interest in the context of cross-equatorial cancelation of magnetic flux and the formation of polar magnetic fields. The meridional flow is by now reasonably well established in near-surface layers (at depths shallower than about 20 Mm); the average flow is poleward in both hemispheres with a maximum amplitude of about 20 m s^{-1} at mid-latitudes near 40° latitude and varies with the solar cycle. The meridional flow at the equator is about one order of magnitude smaller and is expected to be close to zero.

Komm (SoPh, 297, 99, 2022) used meridional flows from the NSO/GONG ring-diagram pipeline derived from GONG Dopplergrams covering Solar Cycles 23–24 and the onset of Solar Cycle 25. SoHO/MDI flows were included to cover the beginning of Solar Cycle 23, while SDO/HMI data were used for comparison. Figure 2-3 shows that the meridional flow at the equator is small but non-zero at most times. At depths shallower than about 10 Mm, the cross-equatorial flow is mainly southward (negative) during Solar Cycle 23, except during 2000, while it is mainly northward (positive) during Solar Cycle 24, except during 2014. (The minimum of Solar Cycle 23 occurred near 2008 and that of Solar Cycle 24 occurred near 2019.) The temporal behavior of the cross-equatorial flow correlates well with that of the North-South asymmetry of the magnetic flux at low latitudes. During the declining phase of Solar Cycle 23, there was more activity in the southern hemisphere, while there was more activity in the northern hemisphere during Solar Cycle 24 except near 2014. The nonzero cross-equatorial flow is thus most likely a consequence of the inflows presents near active regions at these depths and the imbalance of magnetic activity between the hemispheres.

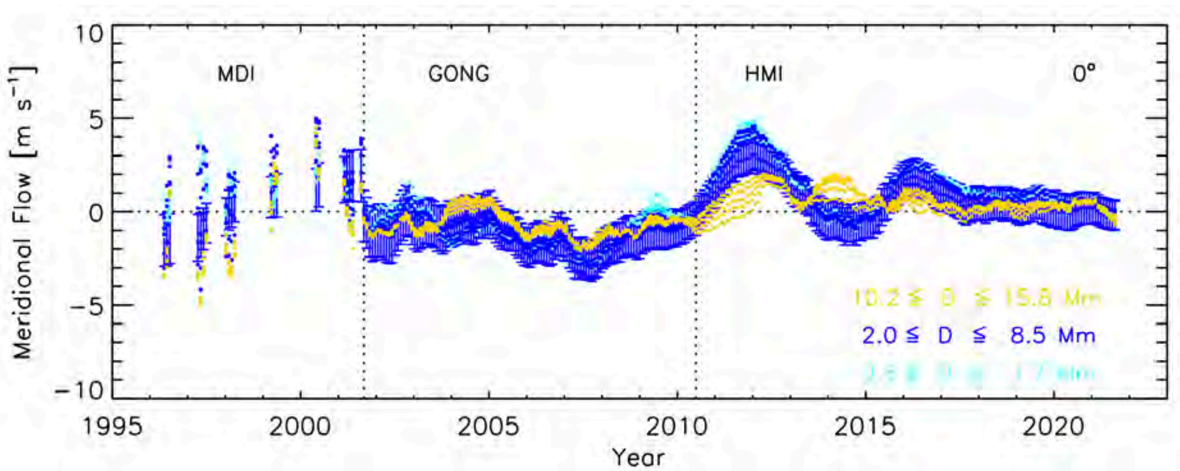


Figure 2-3: *The cross-equatorial meridional flow is small but non-zero at most times. The flow was derived from SoHO/MDI, GONG, and SDO/HMI observations (their beginning indicated by dotted lines) at depths from 0.6 to 15.8 Mm. At depths shallower than about 10 Mm, the flow is mainly southward (negative) during Solar Cycle 23 (minimum near 2008) and mainly northward (positive) during Solar Cycle 24 (minimum near 2019) except near 2014 where the flows are southward. Its temporal variation thus resembles that of the North-South difference of magnetic activity at low latitudes. The average flow errors at 2.0<D<8.5Mm are included for reference.*

2.3 Chromospheric Carbon Monoxide Formation around a Solar Pore

Atomic spectral lines represent the main diagnostics for our understanding of the solar atmosphere. In the lower and denser atmosphere – photosphere and chromosphere – we typically study lines emitted by neutral or singly ionized atoms, such as Fe I, Na I, or Ca II, which are mostly sensitive to temperatures of order 5-10,000 K due to their excitation processes. Yet, it is known that cooler temperatures (~4,000 K) not only exist in the so-called temperature minimum situated at some 500 km above the solar surface, but might extend to quite larger (chromospheric) heights, where the gas would be expected to be sensibly hotter, of order 10,000 K. Fortunately, several lines of the carbon monoxide (CO) molecule can be observed in the infrared portion of the solar spectrum; as this molecule can only form when the gas temperatures are less than about 4000 K, they represent a sensitive probe of these hard-to-sample physical conditions.

In a recent paper, Stauffer, Reardon, and Penn (*ApJ, 930, 87, 2022*) presented observations of a pore jointly observed at two NSO facilities, the McMath-Pierce Solar Telescope on Kitt Peak and the Dunn Solar Telescope at Sacramento Peak. For the first time, this campaign in February 2011 obtained observations of the fundamental ro-vibrational band of CO from the McMP simultaneously with high-spatial-resolution spectral imaging from the Interferometric Bidimensional Spectrometer (IBIS) from the DST. The spectral lines measured by IBIS sample the upper photosphere (Na D1 5896 Å) and chromosphere (Ca II 8542 Å). As shown in Figure 2-4, the CO lines clearly show the dark pore, as well as enhanced temperatures in the nearby magnetic plage. Temporal analysis highlights the presence of acoustic oscillations in the quiet Sun and, somewhat unexpectedly, the occurrence of several transient absorption events (termed by the authors "cold bubbles"), predominantly situated in a narrow annulus around the pore. One such bubble is shown at the center of the red box in Figure 2-4; note that no corresponding absorption features are seen in the simultaneous atomic-line spectral maps, observed by IBIS; these lines might simply be insensitive to the presence of cold gas.

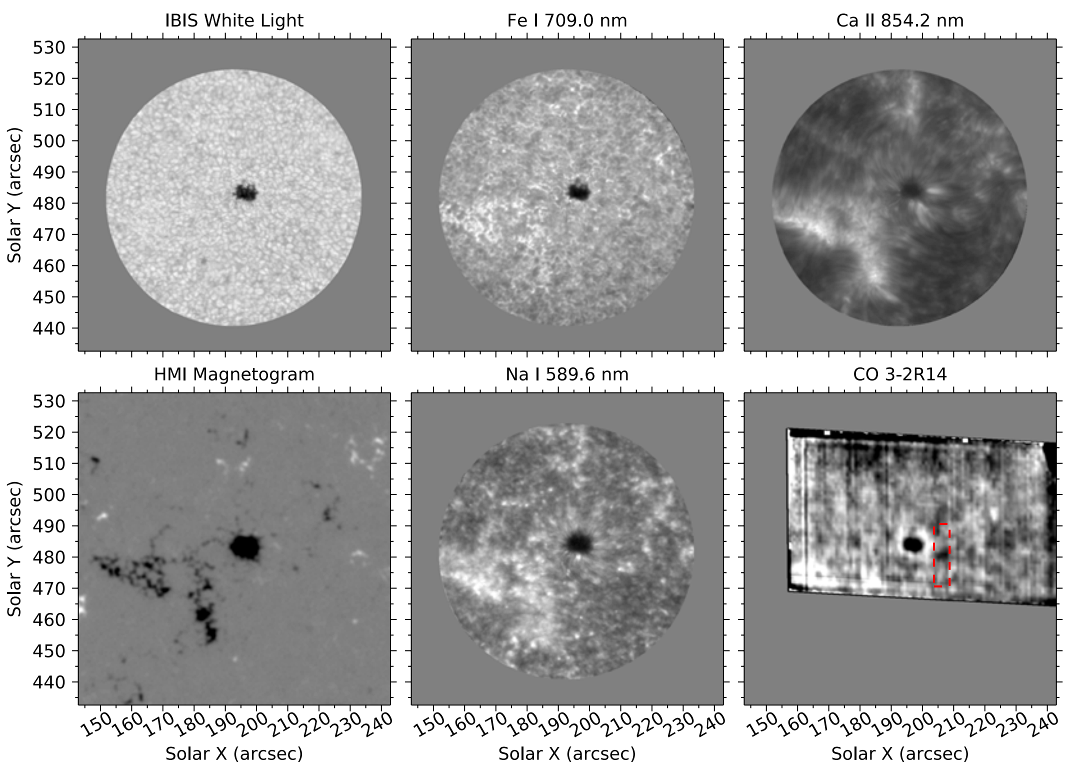


Figure 2-4. *Comparison of the line core intensities in the four observed spectral diagnostics. The left two panels show the IBIS white light reference (top) and HMI magnetogram (bottom). The line core intensities are shown for the photospheric Fe I and Na I lines (middle panels), and for the chromospheric Ca II line and the CO 3-2 R14 line (right panels). The IBIS scan shown here was captured between 17:35:46 UTC and 17:36:06 UTC, while the CO scan was captured between 17:34:54 UTC and 17:35:49 UTC. The red box marks a region surrounding one of seven "cold bubbles" observed in the CO spectrum during the two-hour observing sequence.*

The cold bubbles observed in the CO intensity maps show exponential growth and decay, with characteristic evolutionary timescales of 8 to 10 minutes. They can last up to 40 minutes, much longer than typical photospheric features, such as granular convection cells or p-mode (acoustic) oscillations. Instead, their longevity and self-similar evolution suggest that these features may be the result of "molecular cooling catastrophes" where intense radiative cooling by CO cools the solar atmosphere and catalyzes additional molecular formation. We estimate that the observed timescales are consistent with CO formation rates at chromospheric ($z \approx 1000$ km) heights, consistent with the observed above-limb emission in the CO spectrum. Combined with their location near the pore (whose inclined canopy field suppresses the transmission of acoustic energy into the chromosphere), we believe that these cold bubbles show pockets of cool chromospheric gas, which ordinarily only become visible above the limb.

Further observations of the CO lines will soon be possible with the Cryo-NIRSP instrument on the Daniel K. Inouye Solar Telescope. This will allow much higher spatial and temporal resolution of these features, as well as comparison with vector magnetic field maps of the photosphere and chromosphere to better understand the topology of the field at the site of these cold bubbles. The millimeter continuum is another independent and sensitive probe of the cool temperatures in the same regions of the solar atmosphere as sampled by the CO lines. To better understand the complex dynamics of the (relatively) cool solar plasma, a key goal is to combine observations of the CO lines with measurements of the millimeter continuum at comparable spatial resolution from the Atacama sub/Millimeter Array (ALMA).

2.4 Total Solar Irradiance during the Last Five Centuries

The solar power arriving to Earth from the Sun, the so called Total Solar Irradiance (TSI), has a significant impact on the terrestrial atmosphere on time scales ranging from days to millennia. While recent TSI variations have been monitored from space since the 1970s, TSI variations over several centuries or millennia can only be estimated using measurements of the cosmogenic isotope concentrations in tree rings and ice cores.

Using data from plage and sunspot areas starting from the late 19th century and the solar modulation potential derived from the analysis of 14C isotope over the last 500 years, Penza et al. (*ApJ, 937, 84, 2022*) have reconstructed the area coverage of faculae (plages) and sunspots from 1513 to 2001. Our planet is continuously hit by galactic cosmic rays (GCRs) which produce nucleon-muon-electromagnetic cascades in its atmosphere. Cosmogenic isotopes are a byproduct of this cascade. Among these, a particularly important cosmogenic isotope is 14C which has a half-life of 5,730 years. Measurements of the abundance of this long-lived cosmogenic radionuclide in terrestrial records (i.e., sediments or tree rings) constitute a very important tool for studying long-time-scale solar activity by means of the φ solar potential. This potential is a parameter typically used in modeling the modulation of the energy spectrum of GCR due to solar activity. It varies as a function of solar activity both due to a possible long-term trend and because it is modulated by the solar cycle, being high (low GCR flux) or low (higher GCR flux) around solar maxima and minima, respectively.

The reconstructed areas of sunspot and plage made it possible to estimate the Total Solar Irradiance during the same period. The ability to estimate the secular variations of TSI, especially if they include the solar minimum of Maunder, is extremely important to better understand the mechanisms of interaction between our star and the atmosphere of planet Earth.

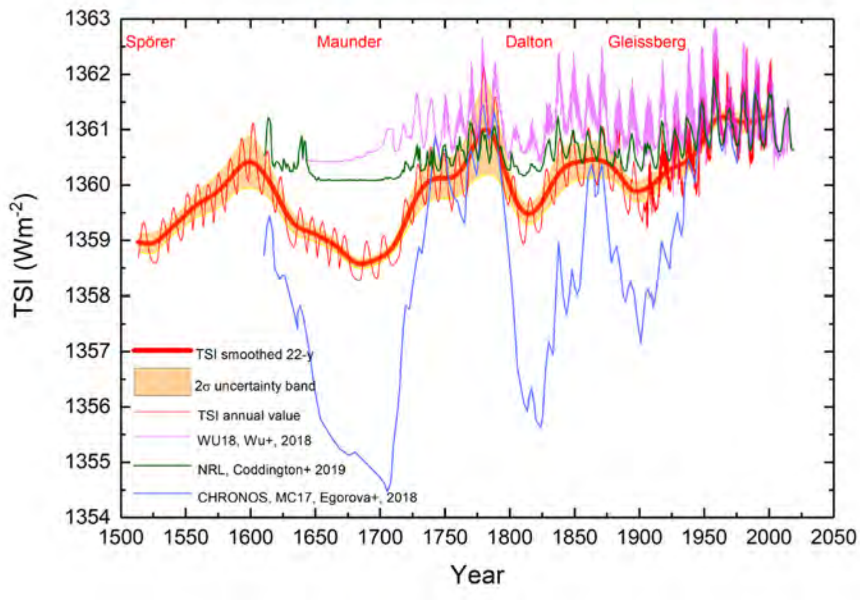


Figure 2-5. *The TSI reconstruction by Penza et al. 2022 is shown as a continuous red line; the red bold line is the TSI smoothed over a period of 22 yr with a 2σ uncertainty shown as the orange stripe. Other reconstructions of TSI are reported, obtained with different methods for comparison purposes only. The NRL-TSI data Climate Data Record (green line) is from Coddington et al. (2019). TSI values from Wu et al. (2018) are in magenta. CHRONOS, MC17 TSI values from Egorova et al. (2018) are in blue. The names refer to the grand minima that occurred in the analyzed period, i.e., Spörer, Maunder, Dalton, and Gleissberg.*

The reconstructed TSI variations are reported in Figure 2-5, which, for comparison, also shows reconstructions obtained with other methods. The result of this work plays a fundamental role in the study of the link between the Maunder minimum and a possible cold period, the so-called Little Ice Age, possibly forced by a variation of the TSI. This work estimated that the change in TSI levels between the Maunder minimum and the present epoch is approximately 2.5 W m^{-2}. This TSI variation would change the global temperatures by about 0.13ºC, an extremely small variation. The present work supports the idea that the Little Ice Age was not a global cooling phenomenon, but rather a regional moderate average cooling (which included European region).

2.5 Quantifying Properties of Photospheric Magnetic Cancellations in the Quiet Sun Internetwork

The study of small-scale cancellations is critically dependent on the quality of the observation. There had been some literature published before (Kaithakkal & Solanki 2019) that suggested magnetic cancellations were a mechanism for magnetic reconnection below the solar surface through "omega-loop submergence." In these cases of magnetic reconnection, you would expect to see transverse magnetic fields and enhanced downflows at the site of the magnetic cancellations. Furthermore, the concept of magnetic cancellations on small scales has been linked to heating in the chromosphere, a layer of the Sun's atmosphere above the photosphere. Lastly, small-scale magnetic cancellations are one of the primary mechanisms through which the total "flux budget" of the Sun's surface is maintained, and these cancellations act as a way the Sun can recycle energy (Schrijver et al. 1997; Lamb et al. 2013; Gošić et al. 2016).

The goal of the study was to test the hypothesis of the transverse magnetic field and downflows as well as obtain better statistics on extremely small-scale magnetic cancellations. Ledvina et al. (*ApJ, 934, 38, 2022*) had access to some extremely high-resolution data from the Swedish 1-m Solar Telescope (SST, La Palma) which could enable this research. The pixel scale was ≈0.059 arcsec/pixel with a field of view of 57.5 arcsec

× 57.3 arcsec. There's a good comparison of the resolution of SST to HMI here: https://svs.gsfc.nasa.gov/4715. The methodology used was fairly simple: 1. Identify cancellations in the field of view. 2. Track the magnetic elements in each cancellation event. 3. From 2), extract parameters like line-of-sight (LOS) magnetic field, LOS velocity, size, convergent velocity, etc.

In this way, the study *visually* identified the cancellations by simply playing the animation of the quiet Sun dataset from SST and finding where white (positive polarity) and black (negative polarity) magnetic features moved together and disappeared. This would signify a cancellation event. They found 38 cancellation events this way and assigned each of them a region of interest (ROI).

The study selected one exemplary cancellation event (ROI #03, Figure 2-6) and describe its behavior. The main takeaway is that as both polarities lose flux while canceling, the doppler velocity at the Polarity Inversion Line (PIL) increases and develops flows *into* the Sun (downflows). They noticed about a 1 km/s increase in the downflow for this event. For the other 37 events, they calculated mean statistics for all of them and found similar patterns. Some things to note were that the average lifetime of the cancellations was quite high at almost 40 minutes, but less than half the initial flux canceled, meaning that some events were still concluding in the available data.

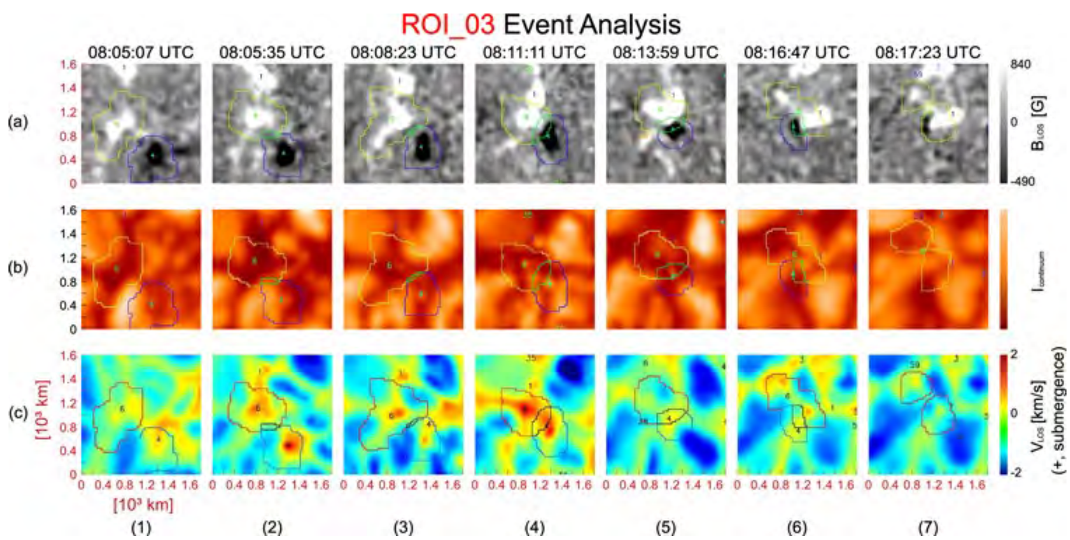


Figure 2-6. *Evolution of BLOS (top series), 630.1 nm intensity (middle series), and VLOS (bottom series). ROI_03 in the time series begins with panel (1) (time immediately before PIL is defined) and progresses to panel (7) (time immediately after PIL is no longer defined).*

Most notably, the study did not find any evidence of transverse magnetic fields during the cancellation. The data was just too noisy. Thus, it could not conclude whether the flux retracted below the surface forming the omega-loop reconnection event reported in other studies. The significance of this study is that it was able to provide robust statistics on magnetic cancellations which are important in global models of the Sun's photosphere and in understanding how flux is transported from the solar surface. Furthermore, having coincident chromospheric observations would have allowed us to examine u-loop emergence which has also been shown to lead to magnetic reconnection. In the future, this study must be repeated with more events and include chromospheric observations from DKIST. Its instrumentation will provide higher spectral sensitivity and spatial resolution which will allow observations of the transverse magnetic fields.

2.6 Evaluating Non-LTE Spectral Inversions with ALMA and IBIS

Understanding the temperature structure in the chromosphere is a key step in deciphering the heating in this complex region of the solar atmosphere. Spectral lines, with their various excitation states and heights of formation, carry information on these temperatures, which can be inferred through spectral inversions.

However, given the complexity of the solar chromosphere, (particularly the deviations from local thermal equilibrium, usually denoted as non-LTE conditions), there have been questions about the fidelity of these methods. One way to remedy this problem may be to include observations of the millimeter continuum, in principle simpler to interpret than a spectral profile, as an additional observational constraint in the inversions. With the advent of the Atacama Large sub/Millimeter Array (ALMA) we are now able to obtain observations at these wavelengths with sufficient resolution to make such comparisons viable.

Previous studies by da Silva Santos et al. (2020) compared spectral lines observed in the UV with the millimeter continuum and found there was an apparent improvement in the reliability of the recovered temperatures in the mid to low chromosphere. However, the lines and continuum diagnostics sample distinct regions of the solar atmosphere, which allowed the inversion procedure to treat them nearly separately. The recent work by Hofmann et al. (*ApJ, 933, 244, 2022*) instead performs inversions of Na I and Ca II spectral lines that form in a region that overlaps significantly with the one emitting the observed millimeter continuum. For the first time, these authors compare the temperature profiles recovered from these spectral lines using the inversion method, with the co-temporal and co-spatial ALMA measurements of the continuum brightness temperatures derived at wavelengths of 1.2 and 3.0 mm. They also took the additional step of performing inversions that directly include the ALMA continuum intensities in the inversion process to see if this additional information helps produce more representative temperature profiles of the atmosphere.

The authors found (Figure 2-7) that the temperatures determined from the spectral line inversions did not always seem to be consistent with the temperatures observed from the millimeter continuum, a puzzling result since these diagnostics should carry information about similar regions of the chromosphere. While the large-scale temperature structures were similar in all three diagnostics, showing the magnetic plage as a region of enhanced temperature with fibril-like extensions, the temperature variations at smaller scales are far less consistent. In particular, while the 1.2 mm brightness temperature values are on average very similar to those inferred with the Ca II line, there is very little spatial correlation between them. In contrast, while the 3.0 mm temperatures are on average ~2,000 K higher than what derived from Ca II, they still show a significant spatial correlation, similar to what Molnar *et al.* (2019) found for the 3.0 mm temperatures and H-alpha line width. Furthermore, when included in the inversions, the 1.2 mm continuum appears to confuse the inversion code, producing unusual atmospheric profiles with very cold temperatures above the hot chromospheric plage, whereas the inclusion of the 3.0 mm continuum, which is expected to form slightly higher in the atmosphere, mostly appears to enforce the expected steep temperature rise in the upper chromosphere.

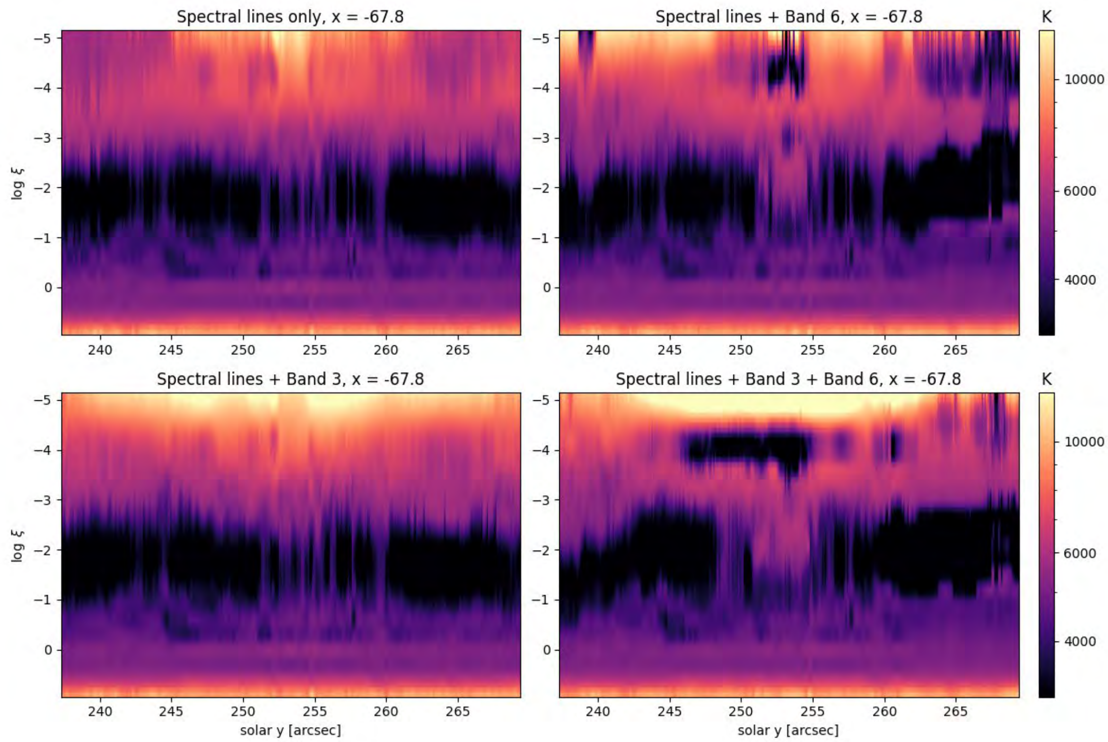


Figure 2-7. *Temperature stratifications along a slice through the plage, showing the effects of including different millimeter-continuum maps in the inversions: (top left) no millimeter inputs; (top right) Band 6 (1.2 mm) only; (lower left) Band 3 (3 mm) proxy only; (lower right) Band 6 and Band 3 proxy. The two inversions including Band 6 result in extended areas of low temperatures high in the chromosphere. Vertical axis is log column mass, effectively a pressure height scale.*

These discrepancies appear to originate because of a fundamental problem in determining the electron density in the tenuous upper layers of the solar atmosphere. The number of free electrons in the solar atmosphere is highly dependent on how many hydrogen atoms have been ionized, a highly non-linear process which is influenced by radiation propagating upward from the lower atmosphere. This process becomes critical in the rarefied plasma of the chromosphere, where radiation can more easily escape upward, leaving fewer energetic photons available for ionization at a given temperature. The electron density is important for defining the opacity and hence the height of formation of the millimeter continuum, but also for the temperatures indicated by the Ca II line used in this study, because it enables the coupling between the Ca II level populations and the local gas temperature. The difficulty in retrieving consistent temperatures for these two diagnostics is an indication that the inversion process does not fully constrain this key physical parameter in the chromosphere. The authors therefore conclude that, if inversions of chromospheric lines are to be quantitatively compared with ALMA brightness temperatures, it is essential to account for non-LTE hydrogen ionization in the inversion process. The authors also urge caution in the interpretation of millimeter-continuum observations as a local temperature diagnostic, owing to the spatial and temporal variations in their heights of formation. This may become especially important as chromosphere observations with DKIST and SOLIS will rely heavily on these inversion techniques for their interpretation.

2.7 GONG's Helioseismic Observations Reveal a Decrease in Strong Magnetic Fields at the Base of the Convection Zone

NSF's Global Oscillation Network Group (GONG) has been providing uninterrupted full-disk Dopplergrams spanning over more than two solar cycles since mid-1995. This period covers the last three solar activity minima, including the periods of two unusually deeper and wider minima in modern times. Since the active regions observed at the Sun's surface are manifestations of the magnetic field generated in the interior, GONG observations provide unique and consistent data sets for studying the structure and dynamics of the layers below the solar surface. In this context, Jain et al. (*ApJ, 924L,20, 2022*) studied the variability of solar interior using the techniques of helioseismology applied to GONG long-term helioseismic data. They investigated the timings of the solar minima in the interior to get an insight on the changes occurring in different layers.

As demonstrated in Figure 2-8, the evolution of the change in frequency, known as frequency shift, in all the panels are similar though the magnitudes are different. The amplitude of frequency shifts is higher in cycle 23 than in cycle 24 and the relative depths at all three minima are also different. The oscillation frequencies reveal that the frequency shifts during the minimum between cycles 22 and 23 were not as low as these were during other two minima, i.e., the minima between cycles 23 and 24, and cycles 24 and 25. However, depths of the seismic minimum during the last two minima were comparable. These inferences are supported by the solar activity indicator, e.g., 10.7 cm radio flux, measured above the surface. Moreover, the epochs of last minima in different layers deviated from the activity minima suggesting that the layers from which a propagating wave refracts towards the surface have significant influence on the timing of seismic minimum. To explore the origin of the different timings of seismic minimum, authors considered three major sources of magnetic fields inside the Sun: (i) a megagauss (strong) field located at tachocline that is primarily responsible for the dynamo mechanism and the 11-year cyclic variation in solar activity, (ii) a primodial weak field at the core that plays a crucial role in the generation of 22-year magnetic polarity cycle and is believed to have been present in the Sun since its formation, and (iii) another weak fields generated in near-surface shear layer, primarily due to small-scale dynamo action which are random and short-lived. All three fields can play important roles in contributing to the variation in oscillation frequencies and the multiple seismic minima -- the first two sources in a systematic way, and third in a random way.

Since the magnetic activity during the minimum between cycles 22 and 23 was not weak compared to the latter two minima, it was postulated that the earlier period was dominated by the strong fields generated in tachocline region while other two weak fields did not contribute significantly. As a result, both seismic and activity minima occurred around the same time irrespective of the regions where the modes travelled. However, the polar field strength decreased significantly in cycle 23 that led to a weak cycle 24. For the modes confined to outer 30% of the interior with no influence from the region below tachocline, near-surface shear layer remained magnetically strong during both minima between cycles 22 and 23, and cycles 23 and 24, and exhibited seismic activity minima around the same time. However, this scenario changed during the minimum between cycles 24 and 25 when the modes sampling the upper layers at depth approximately below 625 km showed disagreement with the surface activity. This must have contributed to an early seismic minimum and suggest a disparity between magnetic fields located in tachocline and the near-surface layers. Moreover, fields generated in the tachocline were not strong enough to reduce the influence of weak fields in the near-surface shear layers.

These findings demonstrate a decrease in strong magnetic fields at the base of the convection zone in last couple of decades, the primary driver of the surface magnetic activity. Since the continuous helioseismic observations sampling the entire interior are available only for the last two solar cycles including 3 minima, such studies cannot be carried out for other weaker cycles and deep minima at the beginning of the 20th century. Nevertheless, minima between cycles 23 and 24, and between cycles 24 and 25 are two consecutive minima that provide stronger evidence on the influence of relic magnetic field in the magnetism of deeper layers and finally on the solar oscillations. The continuation of the GONG project for another solar cycle will allow us to track the conditions in cycle 25 and the minimum thereafter for a better comprehension of dynamical changes occurring below the solar surface.

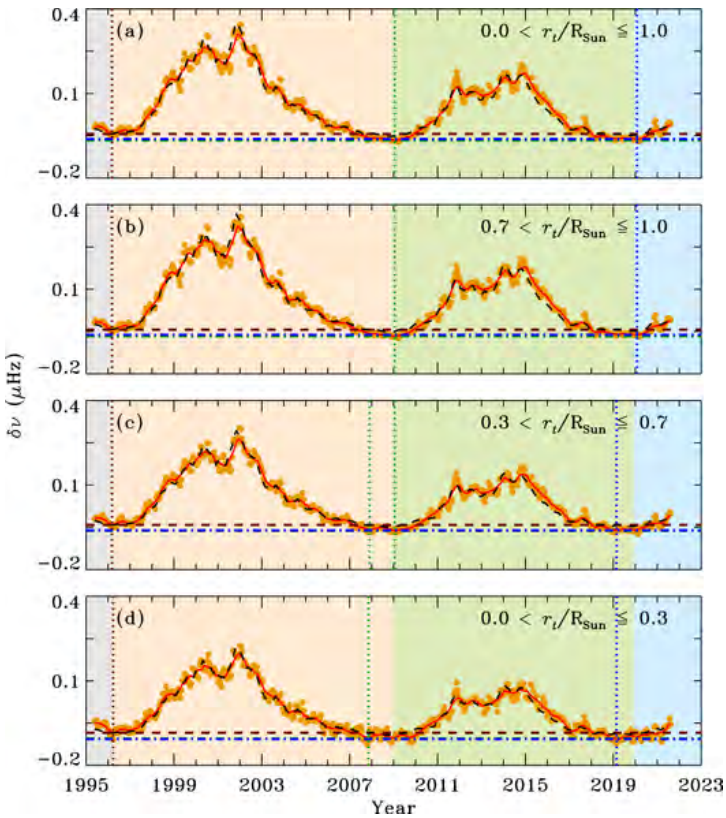


Figure 2-8. *Symbols represent the temporal evolution of frequency shifts (δυ) for (a) all modes, and the modes refracting back from (b) convection zone, (c) radiative zone, and (d) core. The errors in shifts are significantly smaller than the size of symbols. An 11-point running mean of the frequency shifts is shown by the solid red line. Vertical dotted lines show the epochs of minima in frequency shifts. The horizontal lines represent the lowest values of the running mean during minima between cycles 22 and 23 (brown), cycles 23 and 24 (green), and cycles 24 and 25 (blue). The variations in smoothed solar activity measure (10.7 cm radio flux) are shown by black dashed line. Background colors depict solar cycles (from left to right) 22 (partial), 23, 24, and 25 (partial) where the boundaries of different cycles are based on the activity minima.*

2.8 Compact Doppler Magnetograph: A miniaturized GONG for deep space missions

The Compact Doppler Magnetograph (CDM) is a space-qualified, miniaturized Doppler magnetograph, tailored to the requirements of deep space missions, and designed to provide photospheric line-of-sight magnetic field and Doppler velocity measurements of the solar surface. CDM (Hassler et al., *SPIE, 12180, 2022*) is derived from the proven GONG (Global Oscillations Network Group) instrument design (Harvey *et al*. 1988, 1996). Initial concept for compact GONG was demonstrated at NSO (Gosain *et al.* 2022), where a proof-of-concept was given for narrow band filter as a replacement for Lyot assembly, a key technology for miniaturization. Motivated by NSO concept of compact GONG, South West Research Institute (SWRI) and Laboratory for Atmospheric and Space Physics (LASP), partnered with NSO and evolved the CDM design for space operation and eventually proposed it as the Compact Doppler Magnetograph (Figure 2-9) instrument onboard *Solaris* solar polar MIDEX mission (Hassler *et al.,* 2020). During MIDEX Phase-A study of *Solaris* a space-qualified prototype was developed and brought to TRL 6 status (Hassler *et al.* 2022). NSO scientists, Sanjay Gosain, Jack Harvey and Han Uitenbroek actively participated in the CDM prototype development and GONG facility at Boulder was heavily used for the CDM tests. CDM has roughly 1/3 the mass of current state-of-the-art Doppler magnetographs (e.g., SOHO/MDI, SDO/HMI, SolO/PHI), with greatly increased sensitivity to the magnetic field (B) and Doppler velocity (v) and the capability to perform over an expanded spacecraft orbital velocity range, which is required to fit within the mission design constraints of currently feasible high latitude solar polar missions or Lagrange point (L4 and L5) orbits.

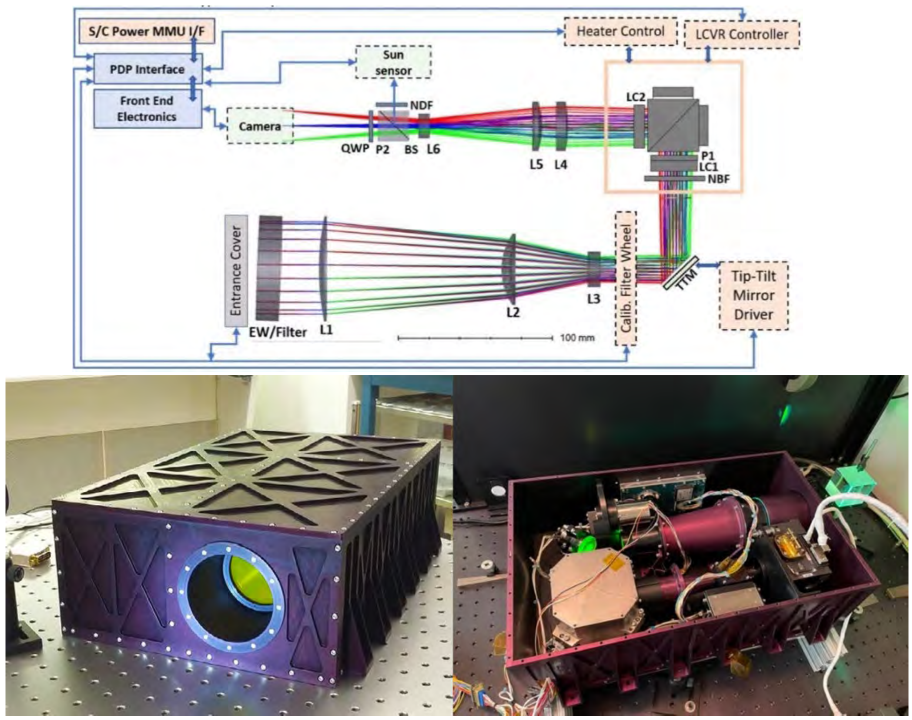


Figure 2-9*. Schematic of CDM instrument is shown in top panel. Photos in bottom panel show CDM prototype in the clean room (left), and during testing at the GONG test facility in Boulder (right).*

Measurement of the LOS magnetic (B) and velocity (v) fields is accomplished by recording the Zeeman and Doppler effects respectively of a group of three photospheric absorption lines near 547.6 nm (Fe I 547.628 nm, Fe I 547.656 nm, and Ni I 547.69 nm). All three lines have similar Lande g-factors (magnetic sensitivity) and are formed at similar heights and temperatures in the solar atmosphere. This “three-line approach” was developed specifically for the *Solaris* solar polar MIDEX mission and has several, key, enabling characteristics. First, observing 3 spectral lines simultaneously provides much higher sensitivity and SNR in B and v measurements compared to other single line measurements such as 676.8 nm (used by GONG) or 617.3 nm (used by SDO/HMI). Second it enhances the immunity from spacecraft Doppler shifts as a passband (0.2 nm) of 3-line pre-filter allows observations over greater spacecraft velocities relative to the Sun (+/- 20 km/s). This allows for elliptical orbits and eliminates the need to temperature tune the interference prefilter. Finally, the large acceptance angle of the narrowband prefilter allows for shorter optical system with lower mass.

The optical performance of the overall CDM system was demonstrated at the GONG facility with the acquisition of magnetograms and several multi-hour time series of Dopplergrams over a total of >100 hours total observing time. Long duration observations (>9 hr time series), demonstrating LCVR camera synchronization and stability, TTM tracking, and stability of the modulation amplitude over the entire time series. Figure 2-10 shows excellent agreement between the CDM prototype magnetograms and Dopplergrams compared with simultaneous magnetograms and Dopplergrams taken with GONG.

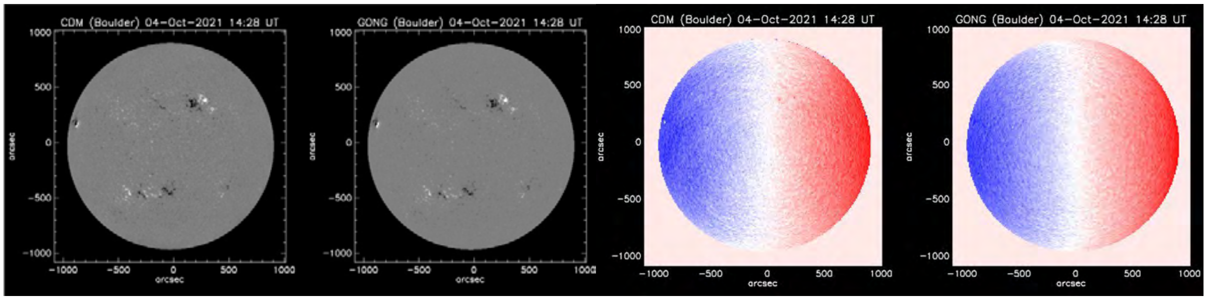


Figure 2-10. CDM-GONG Co-temporal Magnetogram and Dopplergram Comparison

Extensive work was carried out to bring CDM to Technology Readiness Level 6 (flight ready). Space qualified optical, mechanical and electronic materials and components were used in the design. CDM also leveraged previously flown systems such as the camera (Solar Orbiter heritage), sun sensor, tip-tilt image stabilization system and filter wheel system (LASP GOES heritage), entrance filter, narrowband filter, Michelson interferometer (SOHO/MDI and GONG heritage). Additional components that needed testing qualification were the liquid crystal variable retarders (LCVRs). Radiation and thermo-vac testing were carried out to qualify these. Finally, the entire CDM prototype was placed in thermos-vac chamber and cycled for survival and performance validation tests under vacuum and thermal conditions resembling space. Structural, vibration and thermal analysis was also done using finite element analysis to qualify the design.

2.9 The Atmospheric Response to High Nonthermal Electron-beam Fluxes in Solar Flares. II. Hydrogen-broadening Predictions for Solar Flare Observations with the Daniel K. Inouye Solar Telescope

In this study, Kowalski et al. (*ApJ, 928, 190, 2022*) updated the RADYN flare modeling code to include an accurate treatment of the pressure broadening of the hydrogen lines to study the conditions that are relevant to solar flare atmospheres. The inadequacy of the line broadening atomic physics traditionally used in solar (flare) models was first discussed in 1997 by Johns-Krull et al., and Kowalski et al. have finally implemented an accurate theory in time-dependent (radiative-hydrodynamic) models. As one of only two accurate treatments of hydrogen lines in the solar modeling community (and the only treatment with non-ideal opacities -- important for the interpretation of high-density flare plasmas), this update will be critical for proper interpretation of DKIST solar flare observations of the hydrogen lines that will be conducted by the community in the future.

In the *ApJ* paper, the authors determined the differences in the diagnostic potential of optically thick, Balmer lines of H-alpha/beta/gamma and optically thin hydrogen lines further in the blue for the first time. They fully described the roles of opacity broadening and Stark (pressure) broadening in flare atmospheres that are heated by high-energy particle beams. The time-evolution of an optically thick hydrogen line (H-gamma) over 10 seconds is shown in Figure 2.11 below. The prediction exhibits extreme wings and large intensities that can only be comprehensively tested with observations provided by the Visible Spectropolarimeter (ViSP) instrument on the DKIST. The related DKIST Cycle 1 proposal was successfully executed in Aug 2022, and a follow up Cycle 2 proposal (PI: PhD student Cole Tamburri) was awarded time to test these new models.

There are important broader astrophysical applications of this hydrogen broadening work. The RADYN flare models with accurate hydrogen broadening were recently extended to study an M dwarf superflare and constrain the dosages of germicidal NUV continuum radiation in the habitable zone of exoplanets (Kowalski 2022, *Frontiers*).

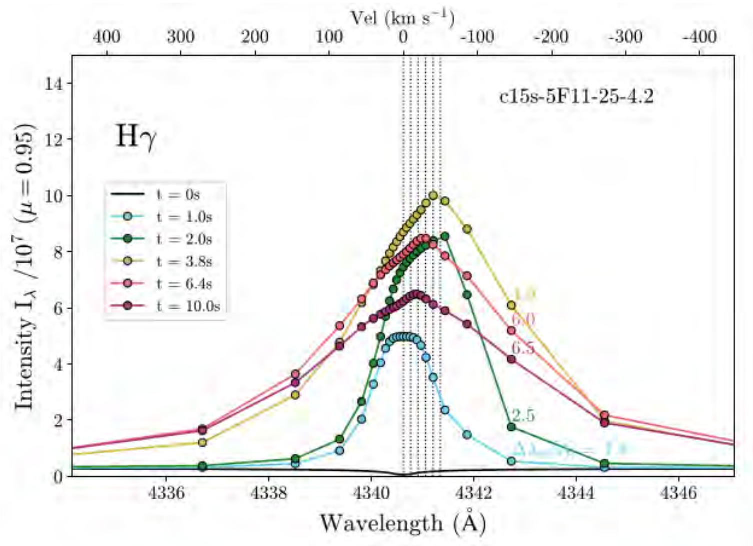


Figure 2.11 *-- The first accurate spectral prediction of the broadening evolution of the Hydrogen-gamma Balmer emission line in response to large flare heating rate. The wavelength range is shown for a possible ViSP observation window.*

3 DANIEL K. INOUYE SOLAR TELESCOPE (DKIST) THIS SECTION WAS NOT UPDATED FOR THE FY2022-FY2023 APRPP

3.1 DKIST Project

3.1.1 DKIST Construction Status

3.1.1.1 DKIST Development Timeline 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 (i.e., telescope, wavefront correction, instrumentation, high-level software and controls, enclosure, and buildings).

Key recent milestones over the past few years include:

- 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.
- 2021: ViSP Instrument successfully passed Science Verification (SV).

- 2021: Cryo-NIRSP Instrument successfully passed Site Acceptance Testing and Science Verification.
- 2021: DL-NIRSP Instrument successfully passed Site Acceptance Testing and Science Verification.
- 2021: Observatory Control System (OCS) successfully passed SAT.
- 2021: SIM #11, Observatory Validation successfully completed.
- 2021: Completion of Site Construction successfully completed
- 2021: Integration, Test, & Commissioning of the Observatory successfully completed.
- 2021: Handover to Operations successfully completed (Level-1 milestone).

The DKIST project is currently closing down, with planned close out activities (i.e., "punch list" work), purchase of critical spare parts, reconciliation of financials, and final reporting documents underway.

3.1.1.1.1 Telescope

During FY 2021, the final reflective heat stop and absorber system was fabricated, installed, and tested. Additionally, a new Lyot stop was installed and integrated into the system. The optic train underwent final adjustments and alignments. Finally, the telescope was rebalanced, and its control system parameters were retuned and optimized for the start of operations.

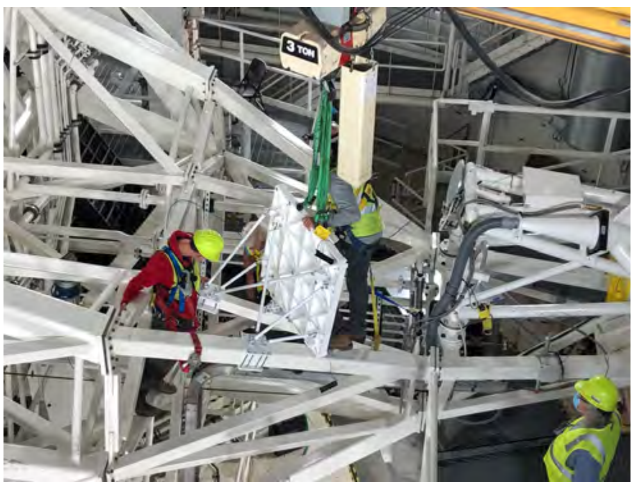


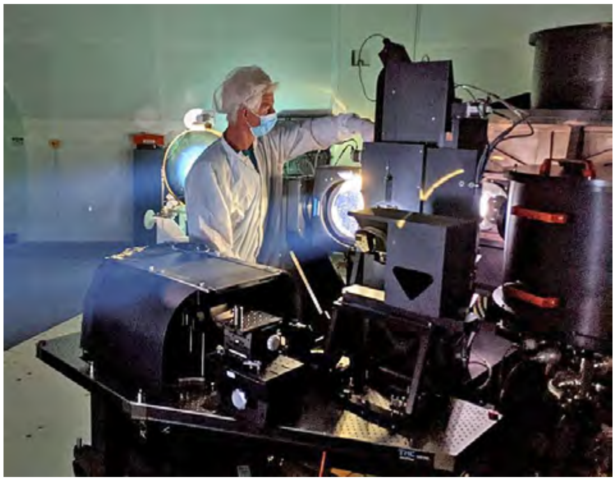

Figure 3-1. *Installation and testing of final heat stop and absorber plate.*

3.1.1.1.2 Wavefront Correction

The Wavefront Correction (WFC) system successfully underwent site acceptance testing on the summit in FY 2021. The system was then used to support the Integration, Test, and Commissioning (IT&C) on-Sun campaigns required for the instrument SATs and Science Verification work.

3.1.1.1.3 Instrumentation

The Visible Broadband Imager (VBI) instrument successfully underwent Site Acceptance Test (SAT) and successfully captured science-quality data with both the VBI Red and VBI Blue channels, thereby passing its Science Verification tests. The VBI was subsequently used in several other DKIST systems tests, including calibration polarizer alignment and occulter testing. The speckle image reconstruction pipeline was also fully tested.



The Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP) was fully integrated into the observatory this year. It then underwent successful Site Acceptance Testing, followed by Science Verification tests. The Diffraction-Limited Near-IR Spectro-polarimeter (DL-NIRSP) instrument also underwent full integration, SAT, and SV testing this year. And finally, the Visible Spectropolarimeter (ViSP) instrument completed its Science Verification testing this year as well.

Figure 3-2. *The Cryo-NIRSP Instrument Scientist during on-Sun testing in the Coudé lab.*

The Visible Tunable Filter (VTF) project with the Leibniz Institute for Solar Physics (KIS) in Freiburg, Germany continued integration in the lab. The instrument is expected to be delivered to the DKIST observatory in CY 2022.

Finally, the Polarization Analysis & Calibration (PA&C) team completed polarization measurements through the M9 mirror in the optic train; this was performed via the NSO Coudé Spectro-Polarimeter (NCSP), which was commissioned earlier this year. The Gregorian Optical System (GOS) successfully underwent SAT testing.

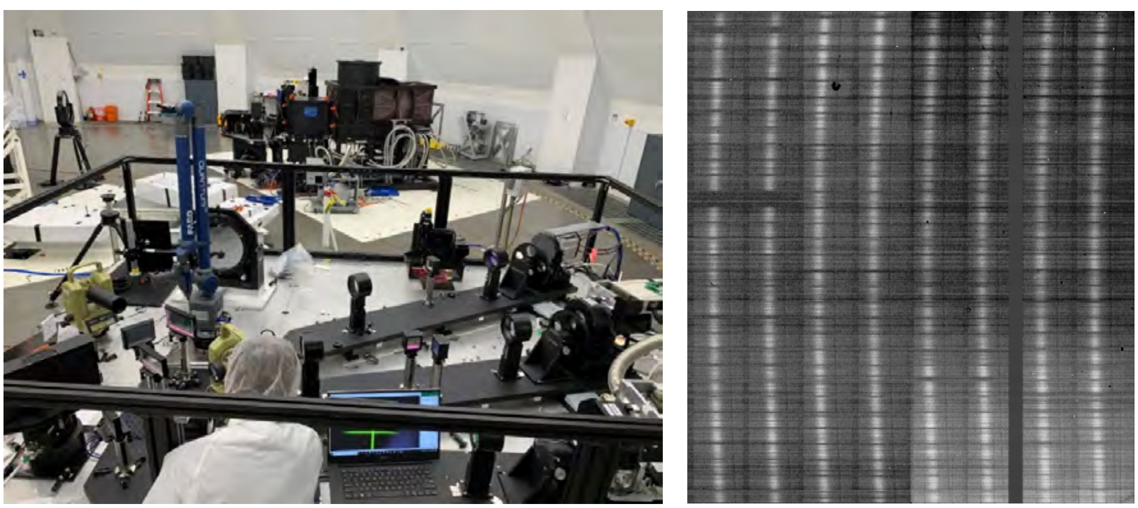


Figure 3-3. *Integration of the DL-NIRSP on the summit. Right: The DL-NIRSP Scientist is preparing for science verification observations. Left: First coronal emission line spectra of Fe XIII 10747 nm from DL-NIRSP obtained during science verification.*

3.1.1.1.4 High-Level Software

The DKIST High-Level Software (HLS) team completed all software Site Acceptance Testing (SAT) required to transition from Construction to Operations. The last of these SATs was for the Observatory Control System (OCS), which included integration with the telescope and instrument systems on site as well as the Observatory Tools system in Boulder. The OCS is now serving as the primary day-to-day interface for operating DKIST. The HLS team also rolled out ten major code releases this year, which included many critical features necessary to close out the Construction project. Major features implemented his year included integration with several thermal and weather systems, creation of an Engineering Data Store with an advanced user interface, automated power management of critical instruments, improved interface to low-level motion controllers, integration with remaining hardware systems, and integration of the data transfer system from the summit of Haleakalā on Maui to the Boulder Data Center in Colorado. This work was completed while maintaining the existing software systems and supporting all on-Sun commissioning campaigns. HLS has now transitioned successfully into Operations.

3.1.1.1.5 Site, Buildings and Enclosure

The support facilities were completed this year. Outside the buildings, this included completion of roadway repairs and recoating, roadway and parking lot striping, and completion of site demobilization and cleanup. The exterior was sealed and painted, and lightning protection improvements made. Inside the facility, the electrical lab loft was installed, an air knife fall protection system installed, and all building lighting and HVAC systems were completed. The fire alarm and elevator systems were approved and brought online. Seismic bracing of all equipment was installed. A set of interior monitoring cameras were also installed and brought online. Additionally, all flooring was completed, ceiling tiles put in place, and of texturing and painting of interior walls finished. Finally, all programmatic agreement and other environmental compliance obligations were completed this year, including the last item (artwork) that was installed in October 2021.

3.1.1.1.6 Facility Thermal Systems (FTS)

This year, the Facility Thermal System (FTS) was completed, and the system was brought online. This began with the completion of the primary loops, including refurbishment of one of the primary chillers. Per instructions from the thermal systems support contractor Johnson Controls (JCI), circuit setters were purchased and installed to provide more controllable output of the system. A fluid cooler bypass was also implemented this year. The secondary and tertiary loops were also completed. This included the TMW2 supplemental secondary loop that was installed and integrated into the telescope mount assembly. A number of other recommended modifications and minor changes from JCI to the system were implemented, including differential pressure transmitters that allowed better control of condenser water temperatures. Following these changes, the team worked with JCI to hydronic-balance and commission the overall system. This commissioning work then allowed the Facility Management.

3.1.2 Project Management

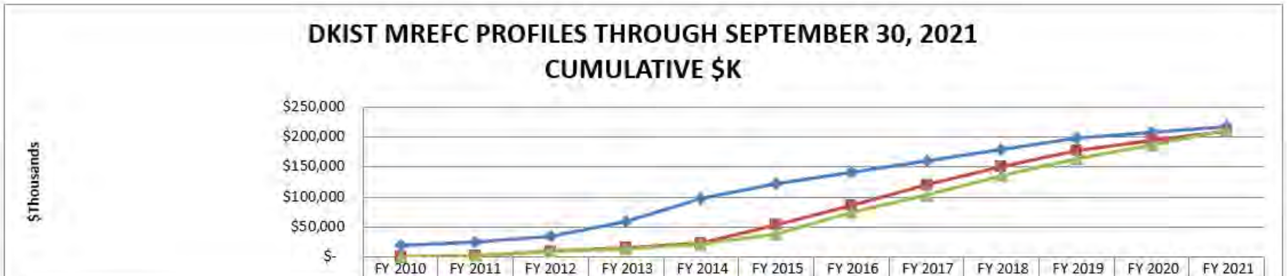
Completion of the project was delayed from the original plan approximately fourteen months due to the impact of the COVID-19 pandemic. All site construction was halted for 2.5 months (mid-March 2020 through May 2020) and then restarted, albeit in a very inefficient manner. The COVID-caused extension was funded via NSF-provided Management Reserve (MR) monies that were delivered via Supplemental Funding Requests (SFRs) submitted by the project. The MR was provided to the Project in discrete funding installments, thereby allowing the construction efforts to proceed per the revised plans.

The project financial status as of October 31, 2021 is shown in the table below.

EVM Status Report	**$M**	**Description**
EVM Reporting Date	Oct-21	Date of the report
Total Project Cost (TPC)	$362.5	Performance Baseline + Contingency
NSF Funding To-Date	$344.0	Amount of funding received to date
Budget at Completion (BAC)	$362.2	Approved Budget
Planned Value ($M)	$356.1	
Earned Value ($M)	$357.0	
Actual Costs ($M)	$354.0	
% Complete (Planned)	98%	PV/BAC*100%
% Complete (Actual)	99%	EV/BAC*100%
% Complete (Spent)	98%	AC/BAC*100%
Cost Variance (CV)	$3.0	EV-AC
Schedule Variance (SV)	$0.9	EV-PV
Forecast Estimate at Completion (EAC - $M)		
EAC_1: AC+(BAC-EV)	$359.2	
EAC_2: AC + Lagging invoices + (BAC – EV + Anticipated future negative cost variances that would increase the ETC for the work package)	$359.2	
Date of last EAC update	Oct-21	Date of last update of the EAC
Unencumbered Funds	$0.2	TPC-BAC
Liens	$0.8	Risks with probability >80% and pending change requests
Contingency Balance	$0.25	Contingency Log Value
Estimate to Complete (ETC)	5.2	EAC_1-AC
	5.2	EAC_2-AC
% Budget Contingency of ETC	4.8%	(BC/ETC_1)*100%
	4.8%	(BC/ETC_2)*100%
Risk Exposure		
Risk Confidence Level	80%	Confidence level of Risk Exposure
Project Baseline Completion	Feb-22	NSF funded and approved
Estimated Project Completion	Nov-21	Projected Construction Completion
Project Award Expiration Date	Feb-22	CSA expiration
Schedule Contingency	< 1 month	

In total, the project received $18.3M in MR funding, bringing the Total Project Cost (TPC) to $362.4M. The current NSF funding award profile is shown in Figure 3-4.

NSF Funding Award	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	Total Funding To
ARRA	$ 146,000													$ 146,000
MREFC	$ 20,000	$ 5,000	$ 10,000	$ 24,976	$ 36,880	$ 25,120	$ 20,000	$ 18,300	$ 18,180	$ 19,590	$ 9,388	$ 8,947	$ -	$ 216,381
Total Funding	$ 166,000	$ 5,000	$ 10,000	$ 24,976	$ 36,880	$ 25,120	$ 20,000	$ 18,300	$ 18,180	$ 19,590	$ 9,388	$ 8,947	$ -	$ 362,381



	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
NSF Funding	$20,000	$25,000	$35,000	$59,976	$96,856	$121,976	$141,976	$160,276	$178,456	$198,046	$207,434	$216,381
BAC Spend Profile (Budget + Contingency)	$195	$3,104	$9,693	$16,054	$23,189	$54,240	$85,914	$119,916	$149,731	$176,914	$194,170	$208,499
Actuals To Date (Sep 2021) + Encumbrances	$200	$3,192	$9,559	$13,998	$20,847	$39,296	$74,315	$103,868	$136,053	$163,670	$187,001	$211,245

Figure 3-4. *Cumulative Earned Value metrics for the project as of the end of FY 2021 (September 30, 2021).*

3.1.3 DKIST Project Closeout Process

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 (FCR). The FCR was successfully conducted in July 2021, and the two closeout reports are currently being drafted.

The latter (PMCS-0100) 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.

Handover to operations was attained on November 20, 2021. The schedule for completion of the closeout activities are as follows:

- December 2021–January 2022: Execution of technical closeout ("punch list") activities at the site, including rebalancing of primary mirror cell cooling fans.
- December 2021–February 2022 : Purchase of critical spare parts.
- December 2021–February 2022: Accounting financial closeout activities.
- December 2021–February 2022: Development of project closeout reports, lessons learned, and archiving of project documents and files.

Additionally, the project is required to document compliance with all environmental and site-related compliance obligations. These obligations are now complete and documented. They included:

- 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) – Dept. of Land & Natural Resources (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/ Hawai'i Dept. of Health.
- Project Labor Agreements (PLA) – Unions.
- Land Lease – University of Hawai'i.

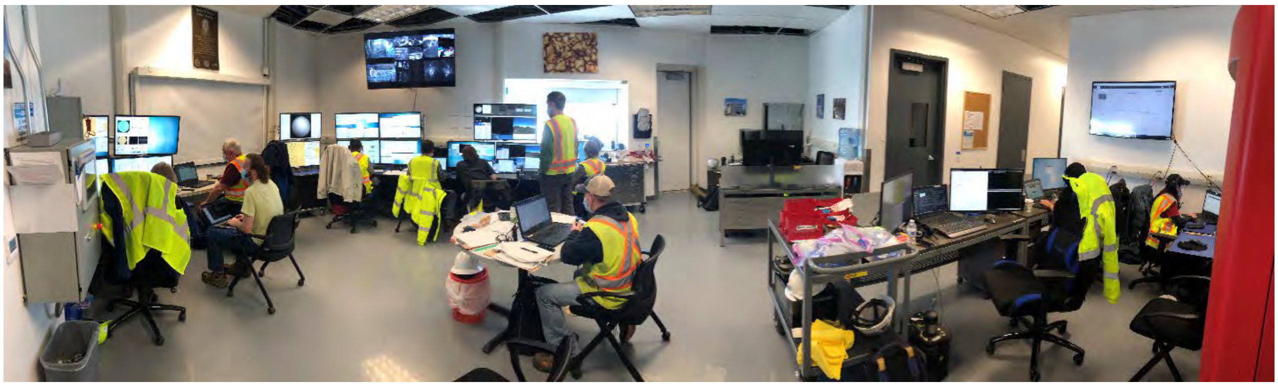


Figure 3-5. *Panorama view of the DKIST control room during an on-Sun campaign.*

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).

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 3-6) 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 described in the CSP document, but also are 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.

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 3-6. *The DKIST Critical Science Plan website with links to documentation and tools.*

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 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.

During the first year of operations, 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. Additional community workshops will be organized in FY 2022.

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 operated in PI mode. The PI was awarded a certain amount of observing time (typically 5-10 days) at the telescope and to a large extent was 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, were simply provided to the PI on hard disk or tape. It was the PI's responsibility to perform all necessary data processing, including calibrating the data. 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 was often the case at the Dunn Solar Telescope (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 can take many years of experience for a user to arrive at the necessary proficiency and, with limited support, build an individually owned toolbox for performing calibrations. Furthermore, the user-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 and broadly accessible 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 where 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, 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.

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, some operational concepts are similar and with some adaptation or modification can be transferred to some extent.

The previous NSO 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 and strategies to ensure sustainable operations over at least two magnetic solar cycles are being developed. At large nighttime observatories, technical work, including regular maintenance, is performed during the daytime by a technical team. The night observations are performed by a relatively small science operations team. The inverse for various reasons is not practical for DKIST operations. Consequently, most technical and science operations activities must be performed in parallel during the daytime.

The scope of DKIST Operations also 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.

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 phase, which includes the Operations Commissioning Phase (OCP), include the following major items:

- Development and implementation of Science Operations concepts and procedures, including service and access mode operations, TAC procedures, proposal and experiment cycle.
- 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.
- Development and operations of infrastructure, such as the DKIST Science Support Center (DSSC) on Maui, office, lab and shop space in Boulder.
- 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.

- The development and operations of the DKIST Data Center (DC), which will handle processing, archiving, and distribution to the community of calibrated DKIST data.
- 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.
- Support of the community in order to prepare for DKIST science by developing a Critical Science Plan (CSP).
- 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).
- For operations, the DKIST will adapt the safety program developed during DKIST construction.
- Development and implementation of an effective organizational structure, including staffing plans, schedules and budgets.

We emphasize that operations planning and ramp up to steady-state 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 Cooperative Agreement in 2015 and subsequent funding. During FY 2015 and FY 2021, significant progress has been made in all areas listed above, 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. Experiment generation and testing for accepted proposals was accomplished during FY 2021 and thus readiness for first OCP observations was achieved (see Section 3.5.9.1).

The team involved in the operations planning and ramp up consists of staff dedicated to the operations effort and 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. Due to the COVID impacts, the construction schedule slipped to November 2021. During FY 2021, the top priority remained the completion of DKIST construction on schedule. Hence, construction staff availability for operations planning remained very limited, which affects primarily the planning of technical operations on the summit. Nevertheless, substantial progress was made in this area as well.

During FY 2021, and in close collaboration with HR staff, transitions from construction to operations were completed. In this way, it is ensured that the required expertise and experience to operate and maintain DKIST systems is available for operations.

FY 2021 Milestone Summary and Status:

1. **Science Operations Concepts, Procedures and Supporting Tools:** Full implementation expected at the end of OCP.

   Concept development has been concluded. Procedures and supporting tools were developed and documented for the entire Proposal Cycle. The majority of procedures and supporting tools were implemented and tested during OCP1. First community proposal-based observations are expected to be conducted in early FY 2022.

2. **Help Desk:** Full implementation expected at the end of OCP).

   The DKIST Help Desk was released in conjunction with the Cycle 1 DKIST Call for Proposals. The Help Desk Working Group focused on the Data Center (DC) portion of the Help Desk for the majority of 2021 in order to compile all the infrastructure and DC Knowledgebase articles with respect to using the Data Center: the data search, data calibration and the analysis tools.

3. **Concepts, Plans, and Implementation of Technical Operations:** Sufficient progress to support OCP; full implementation expected at the end of OCP.

   Staffing plans for Technical Operations have been re-iterated and transition to staff to operations was concluded at the end of FY 2021. Improved start-up and shut-down procedures. Computerized Maintenance Management System (CMMS) was deployed.

4. **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 Cooperative Support Agreement (CSA).

   Testing of infrastructure performance is ongoing. Implementation and testing of science verification calibration pipelines for instruments commenced.

5. **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 4-km conjugate is nearing completion. Delivery of the device was expected in FY 2021 but continues to be delayed due to COVID impacts at the vendor. A final design and fabrication contract for the DM conjugate to 11 km has been prepared and iterated with the vendor. The award of a fabrication contract for DM11km has further slipped to FY 2022.

   Instrument upgrades: Development of the second etalon for the final dual-etalon VTF is progressing well at the Leibniz Institute, Germany. Polishing and coating of the two etalon plates to very stringent specifications has been concluded. A major contract to obtain advanced 4k x 4k infrared detectors for DKIST's infrared instruments has been led. Procurement of an image slicer upgrade to DL-NIRSP is ongoing. A contract is expected to be signed in early FY 2022.

6. **Community Support and Critical Science Plan:** Ongoing effort.

   A summary of the Critical Sscience Plan has been published in the DKIST Solar Physics Topical Collection. Training workshops were held. Support to individual PIs of observing proposals was provided via the help desk.

7. **Research**

   Despite significant service commitments, the DKIST science team continues to pursue research projects, including research in instrumentation development. The science team published 17 papers.

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

   The adaptation of construction safety procedures for operations is nearly completed.

9. **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 November 2021. The start of operations has slipped accordingly. The impact on operations staffing plans, schedules, and budgets has been considered in the development of the FY 2022–2024 budget.

3.4 Management Structure and Staffing

As a consequence of the COVID-related delays of the construction effort, staff transitions to operations had to be delayed. During FY 2021, construction staff received updated transfer letters with an anticipated transfer date of early FY 2022. Figure 3-7 shows the top-level organizational chart (org-chart) for the DKIST Program in operations.

DKIST is organized into functional areas including:

- Directorate (if funding permits, a Deputy Director position is envisioned to be implemented).
- 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.

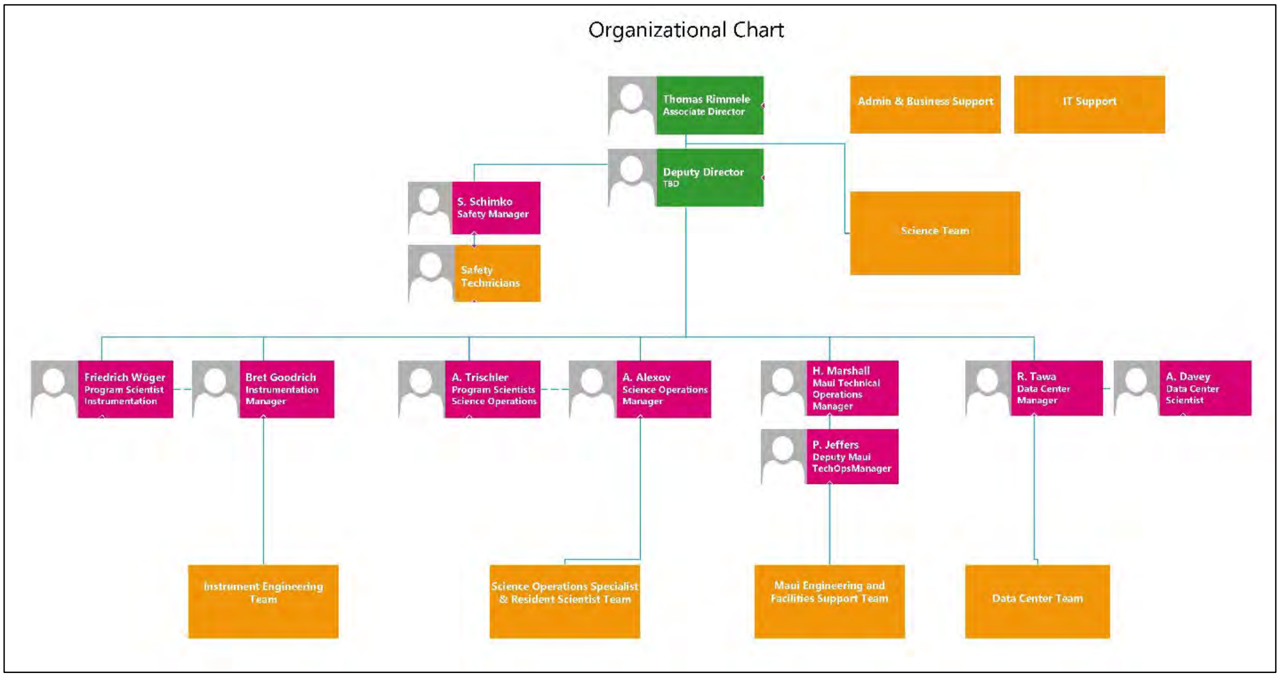


***Figure 3-7**. DKIST top-level organizational chart.*

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 in FY 2022 (contingent on funding).

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 report.

The Science Operations group participates and support observing proposal evaluation, planning and execution of daily observations. Resident Scientists are 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 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 participates in new developments and upgrades to existing instrument and telescope systems, including software. Similarly, the Boulder instrument engineering team contributes 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 have transitioned 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.

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 2022 – FY 2024

The staffing plan for FY 2022–2024 is summarized in Figure 3-8. The figure shows staffing numbers (FTEs) as a function of WBS element and fiscal year. Due to the COVID-related delay of construction completion, a significant fraction of the staff will transfer to operations later than previously anticipated. Some construction close-out activities continue into FY 2022 which results in slightly reduced FTE numbers for operations in FY22 as compared to FY23. The operations staffing plan for FY22 lists 98 FTE compared to 109 FTE projected for FY23, 106 FTE for FY24 and 101 FTE in FY25 (regular operations).

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 to run the proposal process and conduct the proposal driven observations at DKIST resulting in 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.

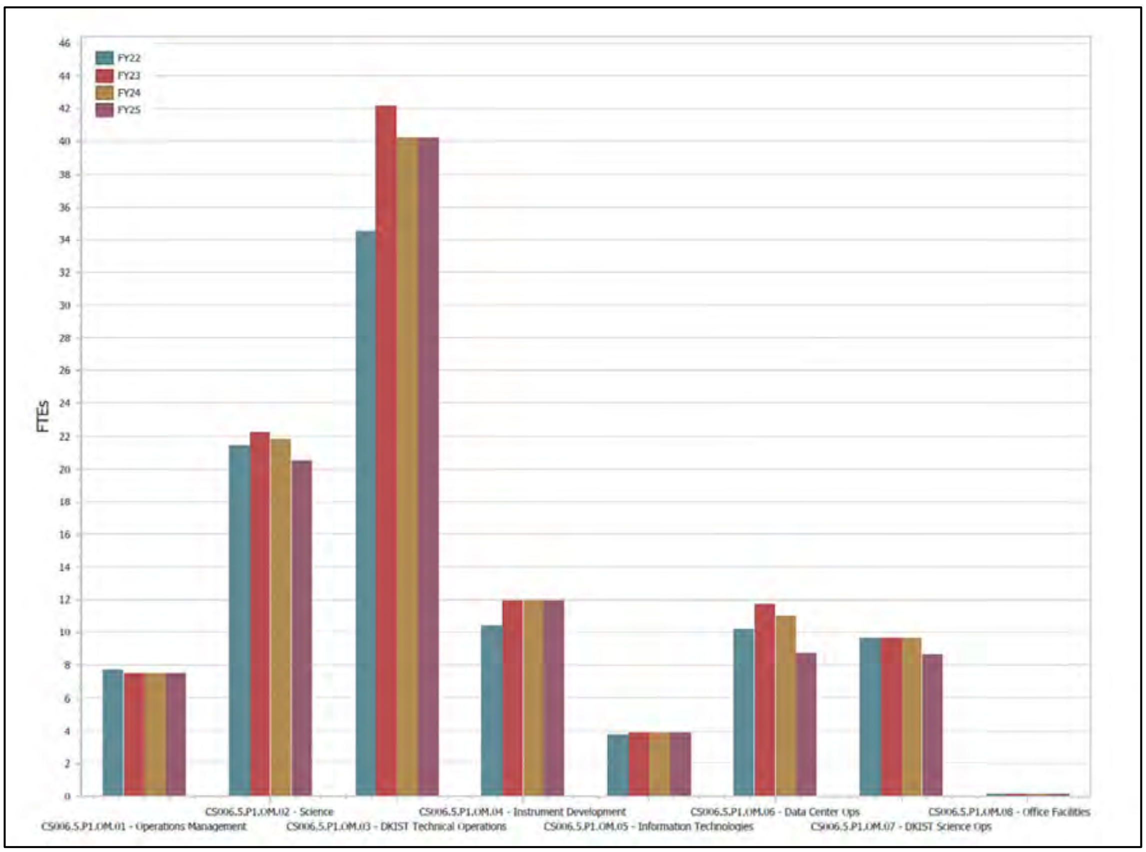


Figure 3-8. *DKIST Operations staffing plan for FY 2022 – FY 2024.*

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. While these requests still require the preparation and submission of a DKIST Proposal, the submission could be decoupled from the regular proposal cycle and instead be facilitated through Directors Discretionary Time (DDT) or e.g. a Supplemental Call.
- 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. 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 counter-part).

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 use in the 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 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 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 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).

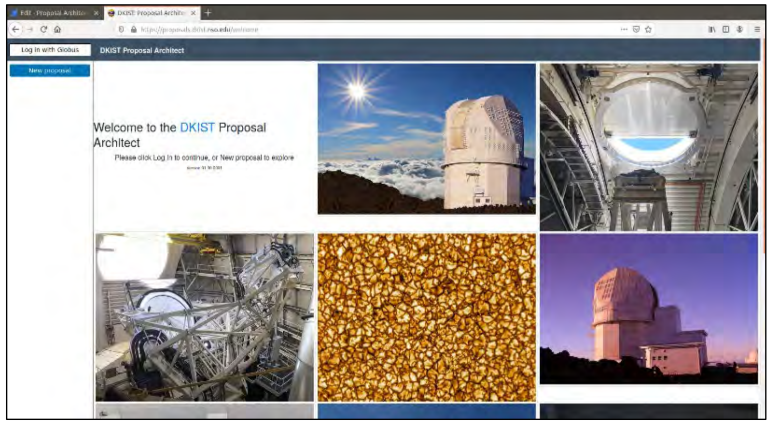


Figure 3-11. *Proposal Architect Portal.*

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 allows 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 supports 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. 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.

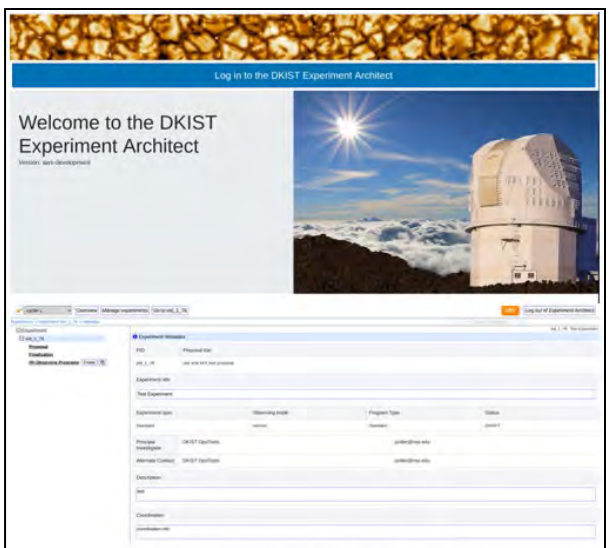


Figure 3-12. *Experiment Architect GUIs.*

Script generation has been and will continue to 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 allows planning and monitoring of the daily activities at the summit through communication with the OCS. The tool allows DKIST Scientists to generate Experiment Lists (aka priority lists) and potentially exact timelines (which is an eventual tool functionality goal) that are made available for ingestion by the OCS. The OCS sends status information and observing program execution reports back to the planning tool. This allows scientists to assess and flag the completion of Experiments and Observing Programs. Moreover, the tool facilitates 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 has started to 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 are 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 are 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 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.

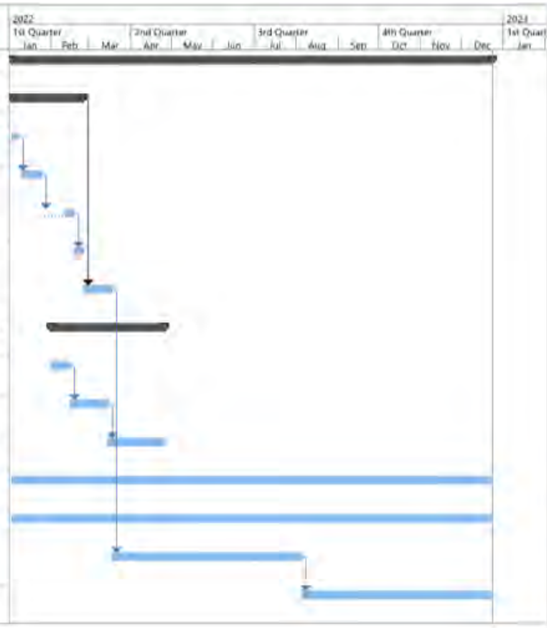
3.5.3.2 Operations Tools Development Status and 2022 Outlook

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 already 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 Cycle 1 proposal call will be worked on prior to the release of the PA for the second Call for Proposals in 2022. Furthermore, the PA will be enhanced to support the preparation and submission of technical proposals.

The Graphical User Interface for the Experiment Architect (EA) was copleted, tested and released for use by scientists to generate Experiments, Observing Pro-grams, and Instrument Observing Programs for all accepted and finalized Cycle 1 proposals. After demonstration of the tool and some initial procedural guidance the process of Cycle 1 Experiment Generation started in fall of 2021. During this first Experiment Generation Phase the EA was extensively used for two months to prepare for the first observing window of Cycle 1 in December 2021. No Help Desk tickets were filed, and no issues were reported; the EA tool withstood the initial usage ramp up without problems. The process of Cycle 1 Experiment Generation will continue into the first quarter of 2022.

Table 3-3. Operations Tools Development Schedule

ID	Task Name	Start	Finish
1	**Ops Tools**	**Mon 1/3/22**	**Fri 12/23/22**
2	**Proposal Architect Updates for OCP Cycle 2**	**Mon 1/3/22**	**Thu 2/24/22**
3	Display OPMT information/Status in PA	Mon 1/3/22	Fri 1/7/22
4	Technical Proposal	Mon 1/10/22	Mon 1/24/22
5	PA Bugs and enhancements	Tue 1/25/22	Thu 2/17/22
6	Proposal Finalize	Fri 2/18/22	Thu 2/24/22
7	Update OPMT Based on Cycle 1 Lessons	Fri 2/25/22	Thu 3/17/22
8	**EA**	**Tue 2/1/22**	**Mon 4/25/22**
9	Update Cryo-NIRSP DSPs	Tue 2/1/22	Mon 2/14/22
10	Create DL-NIRSP DSPs	Tue 2/15/22	Mon 3/14/22
11	Create VTF DSPs	Tue 3/15/22	Mon 4/25/22
12	UI Maintenenance and Updates	Mon 1/3/22	Fri 12/23/22
13	Backend Maintenenance and Updates	Mon 1/3/22	Fri 12/23/22
14	Develop TAC Tool	Fri 3/18/22	Thu 8/4/22
15	Develop KPI Tool	Fri 8/5/22	Thu 12/22/22



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The team also has tested and released the (Science) Operations Planning and Monitoring Tool's GUI inorder to support the Cycle 1 Experiment Quality Assurance phase and the Cycle 1 Experiment Execution phase starting with the December 2021 observing window. Testing as well as the official production usage of the Science Operations Planning and Monitoring Tool will continue and increase in 2022.

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, most aspects of the Proposal Review process are being done manually.

As the OT systems are used by scientists and the gathering of feedback is an ongoing process, an assessment of the OT suite will be conducted towards/at the end of the Operations Commissioning Phase. 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 (aka Service Management) software tool suite is specifically geared for Help Desk request tracking and is an expansion to the Jira product already used by most staff.

3.5.3.3.1 Help Desk Status

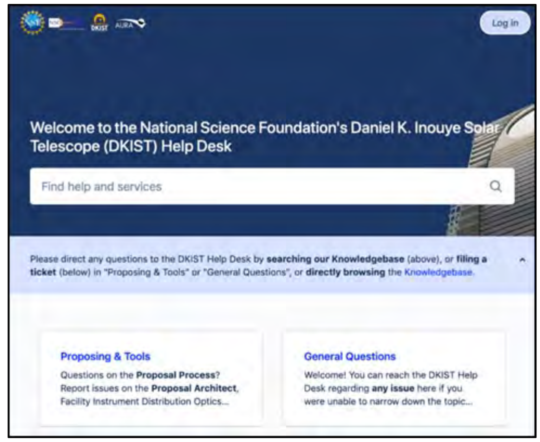


***Figure 3-13**. DKIST Help Desk screen.*

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, thus 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 was 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 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.

The Help Desk Working Group focused on the Data Center (DC) portion of the Help Desk for the majority of 2021, in order to put together all the infrastructure and DC Knowledgebase articles with the respect to using the Data Center: the data search, data calibration and the analysis tools. Extensive work was put into the content, organization, look and feel of the Help Desk articles and interface for the users. Testing took place between the Data Center and the Help Desk to make sure all the connections and backend were functioning as designed. The workflow for user requests for raw data via the DC were tested using the new interface and confirmed to be working as designed on the test systems. The Data Center manuals, links to all DC documentation & software as well as Help Desk web pages were reviewed and prepared for imminent release.

Another aspect of expanding the Help Desk was the design of the internal Science Operations Help Desk, the ticket workflow, the interface, and design of the umbrella architecture to support a broad subject of Science Operations tickets. The design was completed with the assistance of DKIST Systems Engineering; it was tested and released for use with the first observing run in December 2021.

Lastly, the DKIST Help Desk was used as the primary method of communication between the DKIST Scientist, working on the experiment design, and the PIs of the associated proposals. A ticket was created for each accepted proposal in Cycle 1; that ticket was used to address any questions the science staff had regarding the proposal with the PI, and to send a summary of the experiment design to the PI when all aspects regarding the experiment were addressed. This system of communication was designed, tested, and successfully put into play during the Cycle 1 Experiment Design phase.

3.5.3.1.2 Help Desk 2022 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. The Data Center Help Desk and all the documentation which has been worked will be released in 2022 along side of the release of the first DKIST data to PIs. There will be lessons learned from the DC release and usage of the Help Desk, which will then be prioritized and incorporated into future upgrades of the 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).

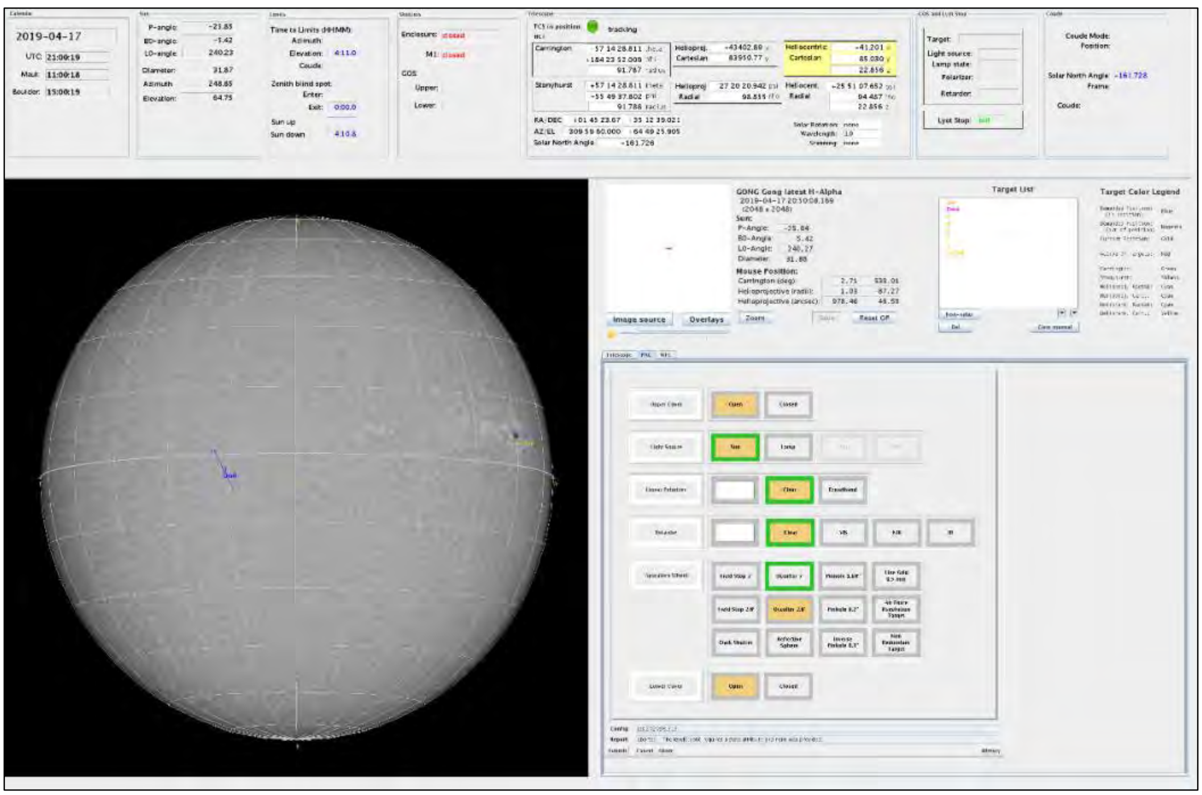


Figure 3-14. *OCS screen.*

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 (aka Loki) 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 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 updates 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.

During the Cycle 1 Experiment Quality Assurance phase the BE2E (Loki) played a crucial role as all Experiments and their components were extensively tested on that system by the Operations Scientist and the Science Operations Specialists (SOS's) offering a unique training opportunity for the real execution at the summit. The tool has clearly demonstrated its potency in preventing downtime at the summit and successfully passed its stress test during the first Cycle 1 Observing window in December 2021. It is worth to note that although the OCS is the tool used by SOS's, the key resident science staff was exposed to the system to prepare them for the first observing window.

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 during steady-state operations. 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 (aka master proposal list).

The DKIST Proposal Cycle during steady-state operations will be composed of the following timeline 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 timeline 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.

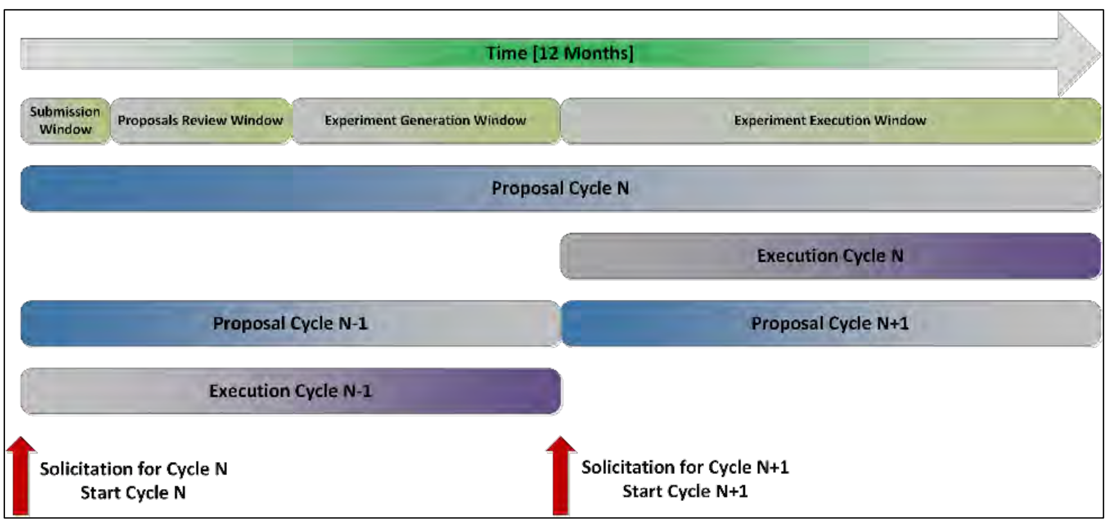


Figure 3-15. *The DKIST proposal cycle timeline during steady-state operations.*

3.5.5 Science Operations Planning Timeline

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-Is) 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 Night-time 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.

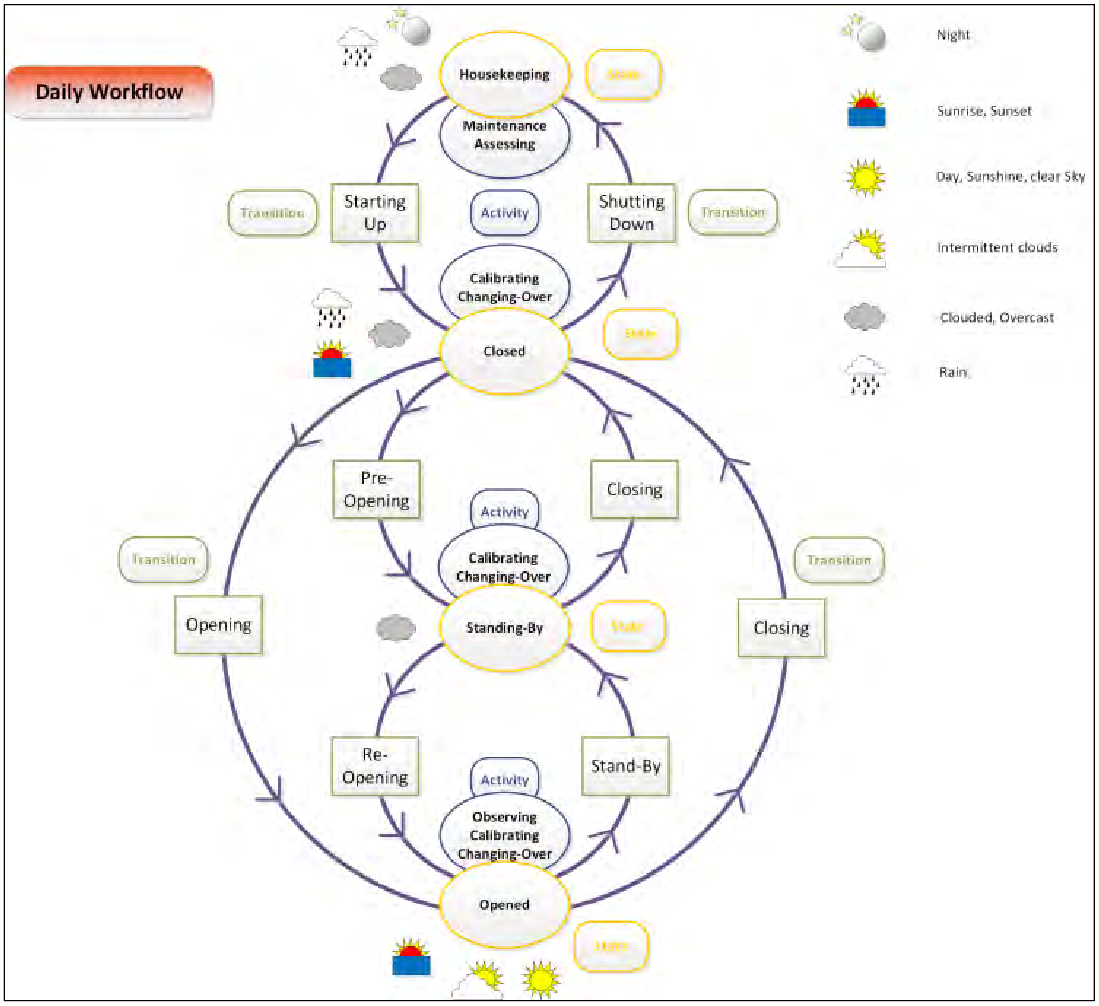


Figure 3-16. *DKIST Daily Workflow, depicting the observatory to transition from a high-level Housekeeping state into other high-level states like Open or Closed or possibly Standing-By.*

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 understand 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. The expected arrival time to the summit is defined by month-ranges grouped according to the sunrise times throughout the year. The summit arrival time is shown in the following table:

Months	Summit Arrival Time
November, December, January	07:00 am
February, March, April	06:00 am
May, June, July	05:30 am
August, September, October	06:00 am

A normal day supporting operations includes a total of 10 working hours for any given SciOps staff member.

Summit support for operations will be provided by two groups: a Technical Operations (TechOps) group and the Science Operations (SciOps) group.

The TechOps group includes technicians and engineers with different backgrounds who execute the tasks to prepare the facility for operations and provide technical support during observations. They are led by the Duty Engineer (assignee rotates based on a schedule).

The SciOps group includes Resident Scientists (RSs) and Science Operations Specialists (SOSs). The Science Operations Specialists participate in the preparation of the facility for observing and also execute the observations with guidance from the Resident Scientists.

The first activity of the day is the Plan of the Day (POD) meeting (led by TechOps and has SciOps participation) where the duty staff analyze the actual weather conditions and define the activities for the day. Then, if the weather conditions are not extremely poor for observing, the TechOps group starts the telescope inspections of the facility and removes the system's interlocks.

In parallel to the TechOps activities, the SOSs execute the procedures to startup the systems. Once the startup procedure is complete, all the observatory subsystems are be available and online ready for operations. The RSs review the Science Plan of the Day (SPOD) to be sure it is in line with the weather and availability of targets; they adjust the SPOD if needed. SciOps Management (in Boulder) is available for consultation remotely if needed during the observing day.

During a typical observing day, the RSs follow the SPOD to determine which experiments and their calibrations are executed by the SOSs. The SOSs log their activities in a Daily Report, which is ingested into a database and can be searched to create metrics. The RSs log their activities in a Daily Log of their own, indicating what was run w.r.t. SPOD, whether calibrations were taken, whether any problems arose, whether items have to be repeated, what the weather conditions were during the observations, as well as any items of note for the following day shift. Both sets of logs are kept on Confluene wiki pages and are also automatically emailed to all the SciOps staff, SciOps Management and the DKIST Director.

SOS Milestones FY 2021

The SOS Group fully participated in the IT&C on-Sun campaigns during the year. The SOSs' primary function was the High-Level Software (HLS) operations which controls the telescope and all it's subsystems during the campaigns. In addition, the SOS Group had some interaction with Instrument operations using the Engineering GUI, for testing. Checklists provided by IT&C were exercised by the SOSs in real-time, supporting on-Sun activities and observations. The SOSs used this experience to create operational procedures. Additionally, lessons learned while on the summit were added into the SOS knowledge base along with training material for the SOS group and future hires.

At the beginning of FY 2021, the SOS group documented in detail the first part of the SOS group Training Program. This first part of the training is called the Knowledge Training program and includes all the definitions and concepts needed to perform operations.

The new SOS hired in December 2020 completed this Knowledge Training program in three months. Additionally, the rest of the SOS group completed the same training, and therefore, the SOSs group has the same base knowledge to support operations in the future. This material can be used for future SOS hires.

In FY 2021, the SOS group completed additional Safety training activities: Portable Fire Extinguishers and Fire Prevention Training, and First Aid CPR training with certification for two years.

RS Milestones FY 2021

As part of the preparations for Science Operations start, a number of aspects were made ready to gear the Resident Scientist for their tasks in leading Science Operations at the summit. A dedicated web area, called a Confluence "Space", was created and populated with relevant science operations documentation, procedures, emergency contact information, schedules, and detailed plans for the December 2021 first science observing run in the OCP. Various tutorials were provided; hands-on training sessions took place with the Resident Scientists to familiarize the team with the operations tools as well as with the content of this Confluence Space.

The RSs were trained in how to use the SciOps Management tools: Confluence, Jira, and Help Desk. They were also trained on using the DKIST Operations Tools: the Experiment Architect (EA), the Operations Planning and Monitoring Tool (OPMT) and the Observatory Control System (OCS).

Dozens of scheduling options were laid out for Resident Scientist summit support, to better understand how many scientists and were needed for leading science operations for the durations of 6-month observing cycles. This was done to gauge the types of combinations options for coverage and backup coverage to understand how often staff from Boulder would need to travel to Maui to support operations. The initial schedule was conceived for RS summit coverage for the start of the OCP.

The RS Daily Log format was designed using two different tools sets: Confluence and Jira. The RSs were introduced to both options and their input was used to finalize the RS Daily Log for Science Operations.

SOS Milestones FY 2022

FY 2022 will be a critical year for the SOS group as the Construction phase will be completed in November 2021 and then DKIST will start the Operations Commissioning Phase (OCP).

The SOS Group will operate the systems to perform science observations for the first time, starting at the OCP. The experience performing observations will define several activities, procedures, and actions that the SOS group must document as part of the operations model. This new documentation will be the basis in the information needed to complete the second part of the training program, the SOS Group Skills Training program. The Skills Training program will include all the SOS-related actions/activities needed for operations. These activities will be documented as procedures with all the details required to learn and perform the actions.

The SOS group will complete the procedures that describe in detail the transitions indicated in Figure 3-16: starting up, shutting down, opening, preopening, closing, and standby. The SOS group will create the documentation that defines the constraints to change the observatory between the different states indicated in Figure 3-16: opened, standing-by, and closed (calibration/change over).

RS Milestones FY 2022

In FY 2022, the Resident Scientists will be leading science observing at the DKIST summit with the start of the OCP. Prior to the start, the first group of RSs in Maui will be trained on the type of information needed to report on the RS Daily Log. They will complete reviewing all the preparatory material for running science operations at the summit. Once the OCP is in process, additional RSs will be trained in Boulder on the material already in place to ramp up RS knowledge on Science Operations. RSs from Boulder will be flying to Maui to train and eventually lead Science Operations, just as the Maui RSs.

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 responsible for performing and executing all aspects of science operations at the summit under the direction of the Resident Scientists. The SOS works in conjunction with TechOps staff. In addition, the SOS is responsible for making sure that all observatory systems are functional for executing observations.

A day of operation will include three or four SOSs at the summit and one Resident Scientist. The SOSs will be distributed to work with different systems: Observatory Control System (OCS), Wavefront Control System (WFC) and the Quality Assurance System. The RS is in charge of leading Science Operations and tell the SOSs what to execute on the telescope.

The SOS Group created a Scheduling Tool used to create the support schedule and analyze the plan for the coming months based on metrics from the past schedules.

The SOS Group Scheduling Tool was developed in Google Sheets using Google Scripts. The tool also connects with Google Calendar to publish the official schedule for operations, as shown in Figure 3.17.

Figure 3-17. SOS Group Scheduling tool implementation.

The SOS Group schedule will be prepared by the Chief SOS (CSOS) using a template/form implemented in Google Sheets, as shown in Figure 3.18. The user can specify the specific assignment for each SOS in the tool, for instance, "Summit OBS" that describes a day supporting observations or "Summit NOBS" which means a day supporting operations for the execution of tests at the summit with the facility closed.

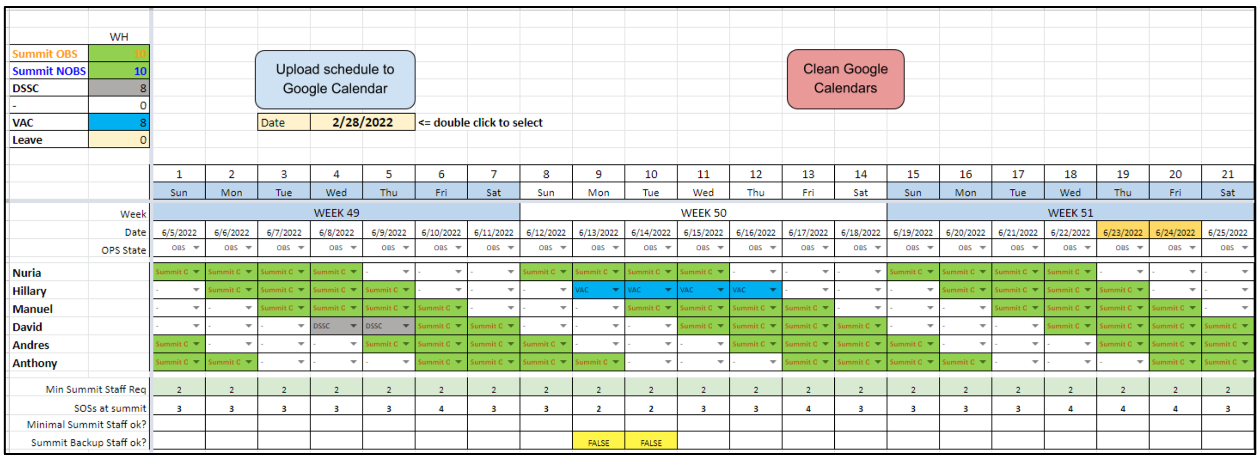


Figure 3-18. SOS Group Scheduling – Create Schedule Sheet.

Once the schedule to support operations is created, the information is published/updated to Google Calendar. The SOSs and SciOps Management can access the Google Calendar to get the information and prepare the support for the specific days assigned. An example of how the schedule is visible in Google Calendar can be seen in Figure 3-19.

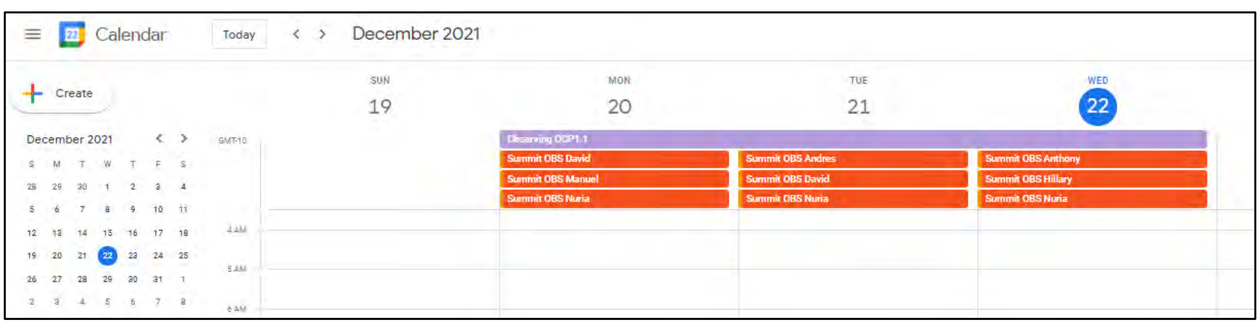


Figure 3-19. SOS Group Scheduling – Google Calendar.

The SOS Group Scheduling tool includes a dashboard shown in Figure 3-20. The dashboard displays the metrics of the schedule implemented and/or planned schedule in terms of days/hours/assignments, etc. The Chief SOS will use the dashboard to analyze the days supporting operations. In addition, the information will be used to plan the future support and present statistics of the SOS Group to SciOps Management.

The same set of tools were used to create the RS Scheduling Tool in FY 2021 and will be put into action in FY 2022. The project utilized the tool set and years of work put into the SOS Scheduling Tool to create the RS Schedule Tool, which was essentially a copy of the SOS software suite for a different group of SciOps staff. This cut down on duplication of effort in order to not reinvent the wheel for the RS Summit Schedules.

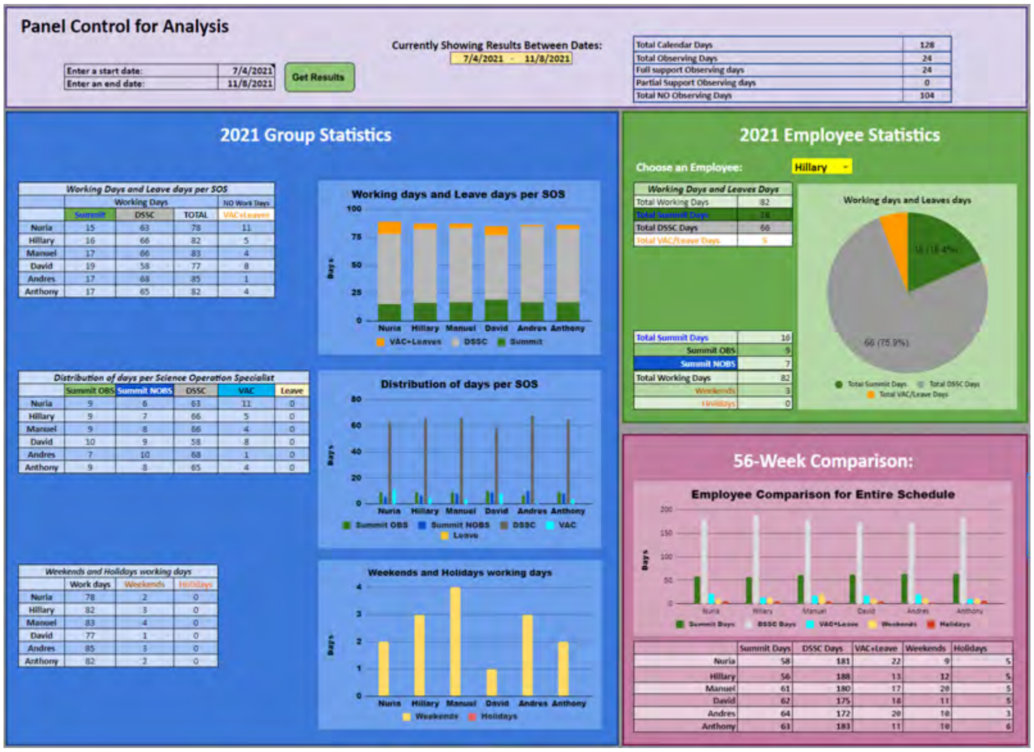


Figure 3-20. *SOS Group Scheduling – Dashboard.*

3.5.8.2 FY 2021 SOS Training Activities

The SOS group created and implemented a training program called Knowledge Training that includes the essential concepts and definitions that the SOS Group needs to learn and understand to ensure better support during science observations. Here are some of the topics documented in the training program:

1) DKIST Introductory Training
    a. Why, what, how DKIST
    b. Lightpath
    c. Facility Instrument Distribution Optics (FIDO)
2) DKIST Operations Concepts Training
    a. Operational Concept for SOSs
    b. Proposal call
    c. Introduction to BE2E
3) Observatory Site, Facility and Areas Training
    a. Site & Facility Overview
    b. Observatory Areas & Restricted Access Zones

4) Solar Essential Concepts Training
    a. Solar Structure
    b. Solar Rotation
    c. Solar Cycle
    d. Solar OCS Target Types
5) Solar Technical Concepts Training
    a. Solar Coordinate Angles
    b. Coordinate Systems for Solar Observations
    c. Reference Frames for Coudé Orientation
6) DKIST Instruments Training
    a. Visible Broadband Imager (VBI)
    b. Visible Spectropolarimeter (ViSP)
    c. Cryogenic Near-InfraRed Spectropolarimeter (Cryo-NIRSP)
7) GOS, MCS & ECS Training

The training activities regarding the full complement of DKIST instruments is not yet complete and is waiting for additional instrumentation to be integrated into DKIST.

The training knowledgebase includes extensive documentation on (wiki) Confluence pages, images, and video tutorials to explain the concepts and definitions.

All the training activities are included in quizzes which each SOS had to take and pass with a score of 85% or better to be certified with that training properly. A software product called ClassMarker was acquired and populated with more than 400 questions across all the different topics and used as the quiz platform.

The SOS Group completed the knowledge training program in FY 2021.

3.5.8.3 SOS Training during FY 2022

Extensive training with the BE2E is needed before starting the OCP. SOS training in FY 2022 will include a review of critical aspects of operations:

1) BE2E Introduction
    a. Open the OCS and GUIs
    b. Solar Monitor & Target Selection GUI
    c. Open/close the facility
2) Manual Pointing
    a. Point the telescope
    b. Offset telescope position
    c. Coude orientation and coordinate systems
3) Manual Targets
    a. Create/edit/delete manual targets
    b. Create some realistic targets for typical use cases (quiet sun, sunspot, filament, etc)

4) VBI and ViSP Blue Manual Control
    a. Execute an IP (align, dark focus, etc)
    b. DSPs parameter and queuing

Training in operations of the Wavefront Control System (WFC) will be needed to support observations. Procedures need to be created to specify operations with the WFC system and ensure the best image quality for the science.

The SOS group must participate in training sessions for all DKIST Instruments installed and made operational on the DKIST summit during FY 2021–FY 2022. Some of the topics to review during these sessions are as follows:

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

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.

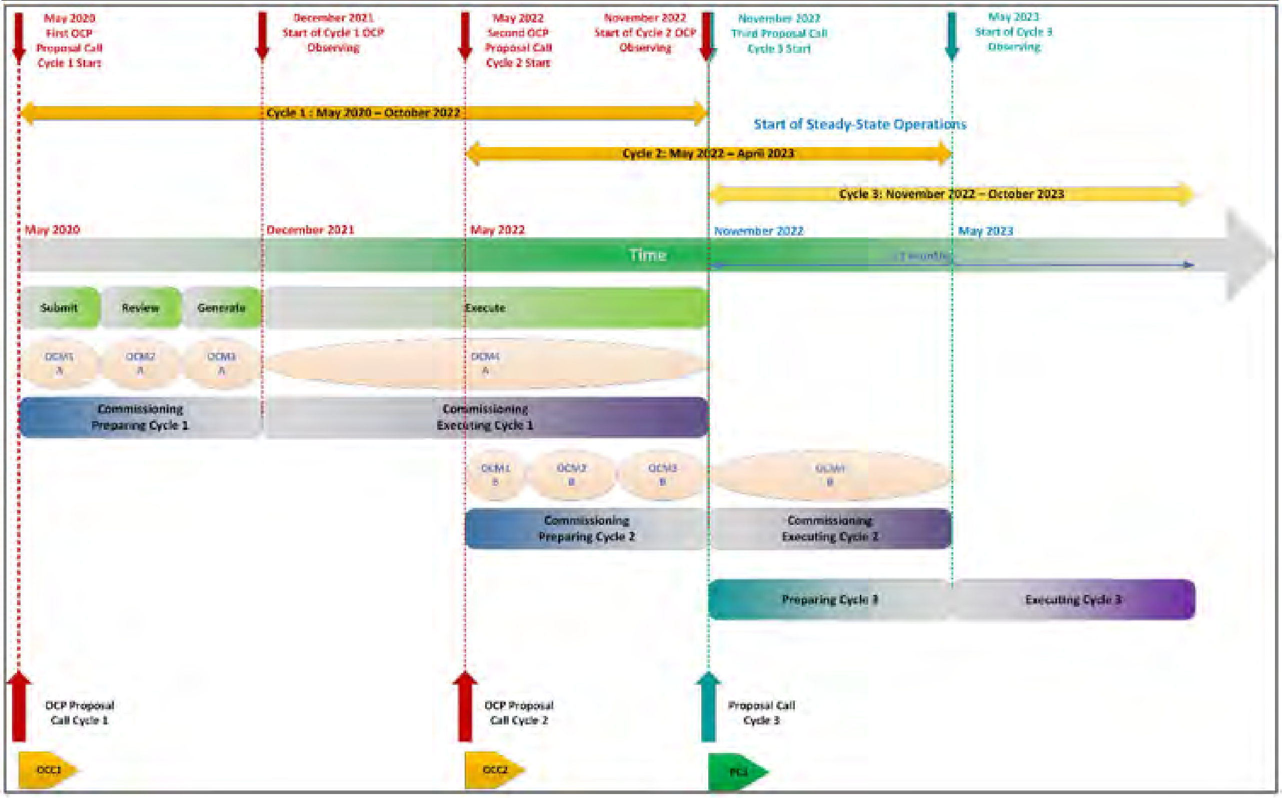
An important operational requirement for the DKIST is to regularly co-observe with other observatories and missions (aka coordinated observations). Hence, part of the OCP plans to allow for a limited amount of coordinated observations to test current baseline practices adopted by the DKIST. Proposal 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 have started 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, i.e., the design phase of Experiment Generation. The validated 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.

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.

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. 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 variable length to allow for enough flexibility during the OCP. In this way, we can iterate and exercise through each individual OCM (i.e., OCMx-A/B), gradually ramp up and implement lessons learned and improvements from one iteration to the next. 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.

Table 3-4. Operations Commissioning Phase Schedule Timeline



3.5.9.1 Operations Commissioning Activities in FY 2021 Included Major Achievements and Milestones

First, the completed proposal review process, i.e., OCM2-A, was successfully executed and concluded. 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 (already completed in FY 2020), 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 continue to be facilitated through manual procedures making extensive use of JIRA and Google Drive/Sheets.

Second, procedures and plans for the execution and development phase of OCM3 (Experiment Generation and Quality Assurance) were completed and following its procedures and plans, OCM3-A was executed. This execution essentially entails the generation of Cycle 1 Experiments, their validation on the Boulder End-to-End (BE2E) system (simulation for quality assurance) and testing at the summit. While the former two activities heavily involved internal scientists relying on the Experiment Architect, the (Science) Operations Planning and Monitoring Tool and the BE2E facility, the latter activity also involved SOSs using the OCS proper at the summit and the real hardware connected to it. Prior execution of OCM3-A, internal DKIST scientists were trained on the Experiment Architect, i.e., the tool was demonstrated, and supporting material (i.e., slides, Confluence pages) was prepared and made available, aiding the Experiment generation and communication process among team members. In addition, a kick-off meeting and experiment design meetings were held.

3.5.9.1.1 Cycle 1 Time Allocation

The 101 proposals submitted in response to the Cycle 1 Proposal Call first underwent a technical feasibility review by the Technical Review Committee (TRC) formed by internal DKIST scientific staff (completed and was part of FY 2020). The subsequent science review performed by the Science Review Committee (SRC) was held in November 2020 (i.e., FY 2021). Three thematic review panels of almost equal size in number of panel members and proposal load were formed, convening multiple times remotely due to COVID-19. After the science review concluded (including the preparation of result reports), the proposals were prioritized by a Time Allocation Committee (TAC) based on science merit, OCP objectives and policy guidance. The TAC accepted 50 proposals in total. All Proposers were notified of the results of the review in the first quarter of 2021 and the accepted Cycle 1 Proposals were published on the NSO webpages.

3.5.9.2 Operations Commissioning Milestones for FY 2022

The FY 2022 foresees the following major activities and milestones.

- Development and execution phase for OCM4 (Experiment Planning, Execution and Completion) which starts in December 2021, timed with the end of the construction IT&C project, and will continue well into 2022. This execution includes the medium- and short-term planning of summit science operations, conducting and monitoring of the observations, 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.

- Cycle 2 OCP Call (OCC2) will be prepared and announced (i.e., OCM1-B will be executed) and subsequently all submitted proposals will undergo the Cycle 2 proposal review (i.e., OCM2-B will be executed). It is planned to implement some of the lessons learned during the first execution of that module.

3.6 DKIST Technical Operations

3.6.1 Scope Summary

The DKIST Technical Operations team comprises Maui-based Technical Operations management and a team of engineers and technicians to maintain, repair, and upgrade the DKIST Observatory according to NSO overall priorities. In FY 2021, retained construction staff received and accepted offers and will, at the formal completion of construction, transition into operations positions. The delay of construction completion due to COVID-19 has in turn delayed the transition of construction staff into operations positions, with the incoming technical operations manager and deputy manager working on planning and organizational activities as IT&C construction priorities allowed.

The Maui-based Technical Operations team will be supported by Boulder-based colleagues, for example, specialists in wavefront correction or camera software, and with staff deployments when appropriate to support observing campaigns and collaborate on major upgrade and repair efforts.

3.6.2 Technical Operations Functions

From an engineering perspective, there are three functions in Technical Operations. The first is support of on-Sun observing and proactively minimizing the loss of Science Operations time. The second is maintenance, which can be subdivided into planned (preventive) and unplanned (repair) 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 maintenance and upgrade efforts, and to augment the on-Sun observing support teams as needed, additional staff would be deployed from NSO Boulder to work collaboratively with NSO Maui-based staff at the DKIST Observatory.

3.6.2.1 On-Sun Observing

During Operations Commissioning Phase planned on-Sun observing days, a core Technical Operations support team will accompany the Science Operations Specialist(s) and Resident Astronomer(s) to the Observatory. This team comprises a duty engineer, thermal systems operator, programmable logic controller (PLC) software engineer, high-level software engineer, optical engineer, electrical support, and mechanical support. The Technical Operations support team performs the startup of systems and handover to Science Operations for experiments. Then, during experiments, the technical operations team monitors performance of various subsystems, addresses urgent issues that may arise, and identifies non-urgent issues which are monitored or planned for repair or further investigation at a later time. The remainder of the technical operations team would be scheduled for concurrent maintenance and onsite support, or planning efforts and on-call support from the DSSC. At this stage, the vast majority of technical operations staff are onsite along with the dedicated observing support team, but as operations matures, onsite exigencies reduce, and pandemic impacts subside, work assignments and locations are expected to become dependent upon the observing conditions, maintenance or repair needs, resource availability and longer-term priorities.

During the closing phases of DKIST Construction IT&C, the incumbent Technical Operations Team has improved upon the observing campaign preparatory checkouts, daily on-Sun observing startup/shutdown processes and ongoing preventive maintenance inspections. Additional staff have been trained to serve in the various observing support roles. Finally, the duration to perform the startup/shutdown processes continues to reduce as more subsystems become automated, recurring issues are fixed or mitigated, and overall reliability increases.

3.6.2.2 Planned Maintenance and Repairs

As with the on-Sun observing support function, the incoming Technical Operations team has gained practical experience in performing urgent repairs (i.e., unplanned maintenance) during the IT&C observing campaigns and incorporating preventive and deferred maintenance into planned non-observing periods, or concurrently with observing activities when possible. This experience has informed the composition of the observing support team described in the previous section, as well as initial estimates and schedules for OCP.

Also, as part of the construction-to-operations handover and readiness for operations, the required utility, service agreements (i.e., key subsystem contractor hourly consulting support), and purchase order agreements with both local and mainland suppliers have been established. The team has sourced and ordered critical spares and made strides in organization of storage and inventory of spare parts, supplies, and consumables. The IT&C/Technical Operations team has also gained experience and developed or improved procedures for preventive maintenance such as optical cleaning (such as carbon dioxide "snow" cleaning and ultra-high purity nitrogen non-contact cleaning, contact and non-contact wet washing with isopropyl alcohol, ethanol, and other chemicals), and major mechanisms lubrication and balancing. The DKIST team has also continued collaborating with our AEOS (Boeing, US Air Force) neighbors regarding improvements and lessons learned on M1 strip and re-aluminization processes following on the successful DKIST M1 in fall 2020, and the AEOS M1 in summer 2021. Development and detailing of equipment, locations, service intervals, and records in computerized maintenance management system (CMMS) tool, called HIPPO, has progressed substantially this year. The mechanical and electrical technician leads, and machine shop supervisor have all become fluent in creating and tracking both Demand and Preventive Maintenance work orders; engineers on staff are learning and starting to utilize the tool.

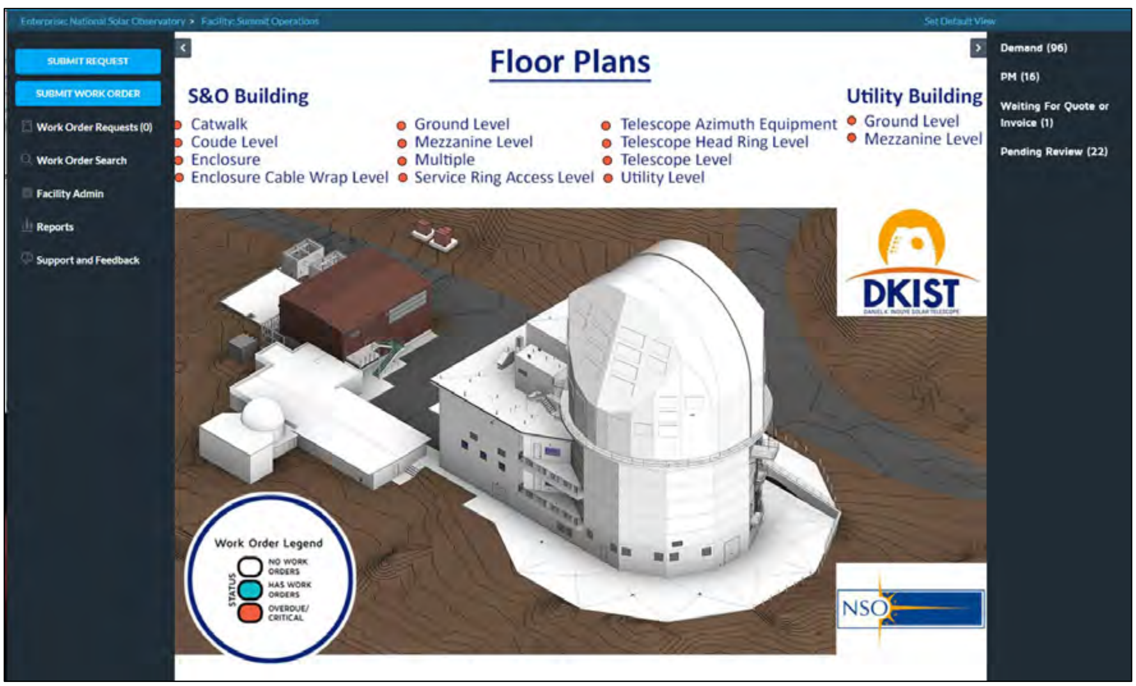


Figure 3-21. *Login screen for the DKIST Observatory Technical Operations HIPPO computerized maintenance management database.*

To ensure personnel and equipment safety and return to proper observing state following either unplanned or planned repairs, pre-move inspections of work observatory subsystems, with particular attention given to work areas, are required. This process has also been elaborated and enhanced during the last stages of construction and now incorporate checkouts of mount, Coudé, and enclosure mechanisms; primary, secondary, and tertiary thermal loops pumps and chillers; some instrument mechanisms, visible cameras data collection and pipeline; internal real-time network communications; and finally, proper configuration of the desired observing optical path.

3.6.2.3 Observatory and Instrument Upgrades

As time and resource limitations of the construction effort permitted during the past year, some technical efforts were dedicated to the highest priority operations needs for observatory and instrument upgrades. The site machine shop fabricated parts for the VTF instrument, the optical engineers performed measurements on MCAO triplet lenses, and a spare M3 optic was sourced and contract for machining, polishing, and bonding commenced. Members of the team have reviewed draft documents and plans for the incoming VTF instrument; more thorough review and planning for the site integration effort is expected in the coming year in accordance with the delivery timeline.

A number of activities anticipated to be ongoing long-term technical efforts are well underway as of the transition to operations. These include vibration mitigation, hazard mitigation and safety upgrades, optical alignment improvements, pointing model and control system accuracy, and thermal system automation and tuning.

Milestones FY 2021

- Transition-to-Operations offers were made for retained DKIST Construction Staff.
- Staffing plans and Summit Engineering and Facility Operations budgets were revised.
- Iteration and improvement of startup and shutdown procedures were made.
- Regular planning sessions were held.
- Critical spares sourced, prioritized, and procurement started.
- Computerized Maintenance Management System (CMMS) deployed.

Milestones FY 2022

- Start of operations and support of OCP.
- Full implementation of staffing.
- Continue internal cross training for observing support team roles
- Prepare for integration and commissioning of VTF.
- Develop process for technical proposal generation, review, and prioritization.
- Improve understanding of Observatory preventive maintenance needs.

3.7 DKIST Data Center

3.7.1 Introduction and Scope

The DKIST Data Center (DC) 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 Dunn Solar Telescope and elsewhere, users had to master the many intrinsic details ofinstrument 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 toolbox 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 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.
4. Roughly 6 PB of new science data every year.
5. Science data processing.
6. Search and discovery of DKIST produced data.
7. Data distribution.
8. Operations support.

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

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.

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 3-22 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.

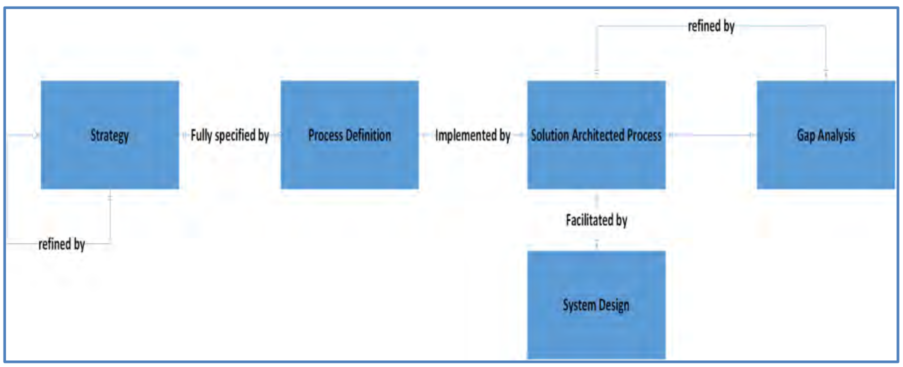


Figure 3-22. *Metahow Process.*

Table 3-5. Metahow Process Phases		
Phase	Activities	Produced Artifacts
Strategy	• Set Goals • Set Scope • Define Operational Approach	• Goals • Scope Diagram • Process Approaches
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 3-23).

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.

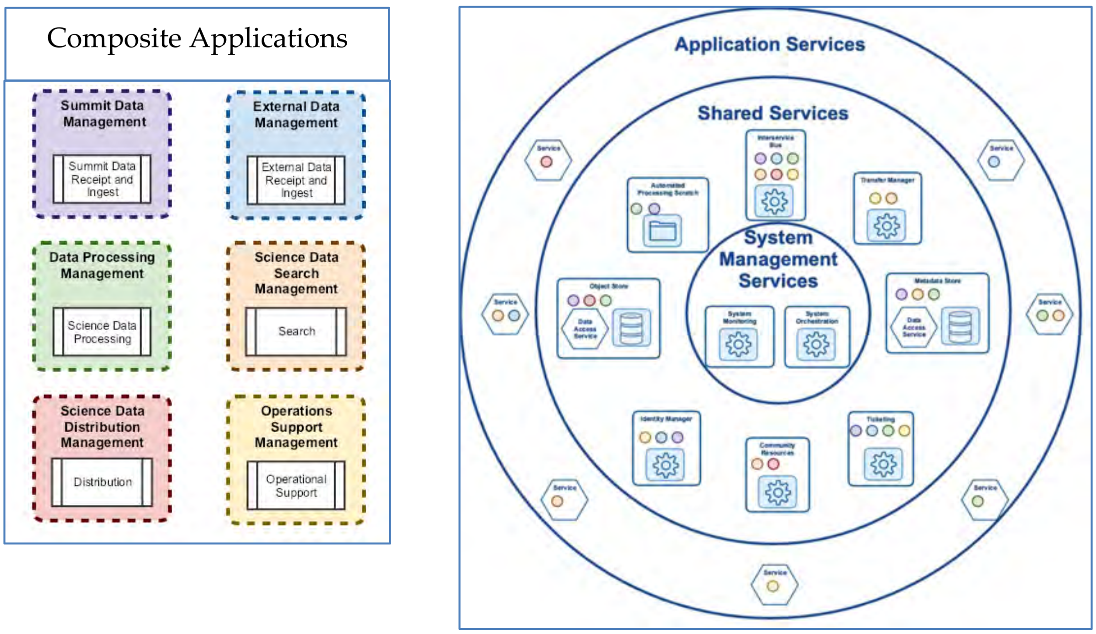


Figure 3-23. *DKIST Data Center Architecture.*

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 3-24). 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.

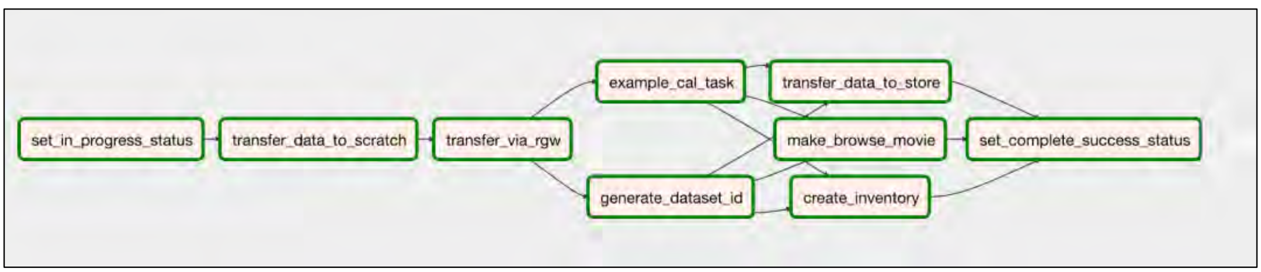


Figure 3-24. *Example Direct Acyclic Graph (DAG).*

3.7.4 Data Center Schedule and Current Status

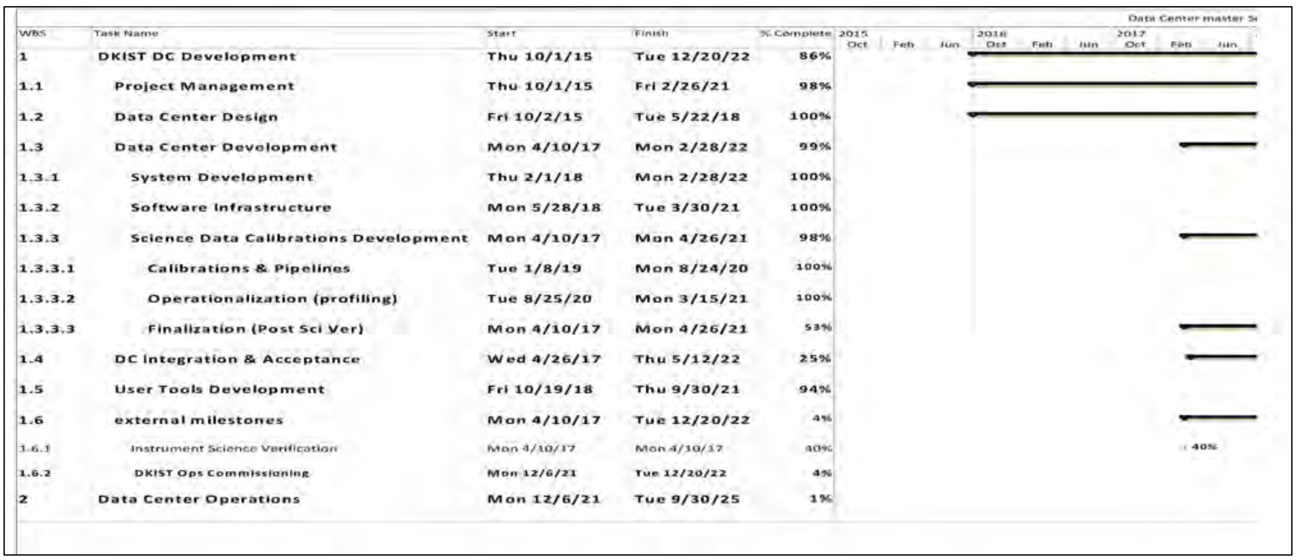
Given that the DKIST Data Center is being developed with an operations funding stream that extends to FY 2024, the DKIST DC schedule is broken up into a development phase and an operations phase. It should be noted that the passage from the development phase to the operations phase won’t be abrupt but 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 2022, the Data Center has completed all the requirements and is currently ingesting the first series of data sent from the summit as part of Operations Commissioning Phase. In addition, portions of the Data Center acceptance testing that required real data will be completed during the OCP. The Data Center has also developed and is ready to implement its Commissioning Plan with the rest of the Operations planning and scheduling.

3.7.4.1 Development Schedule

The development phase of the DKIST DC project is shown in Figure 3-25.

Development of the Data Center infrastructure, which includes all the hardware and software required to ingest, and disseminate data, has been completed. The remaining tasks, other than normal software maintenance, all relate to completing calibration software as the results of the instrument Science Verification are analyzed. Calibration code for two instruments (VBI, ViSP) is complete insofar as the final Science Verification codes have been implemented into functional pieplines to be used with the first sets of data streaming from the summit as part of OCP1. Cryo-NIRSP, DL-NIRSP, and VTF are expected to be completed by the end of FY 2022. During the 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.



WBS	Task Name	Start	Finish	% Complete
1	DKIST DC Development	Thu 10/1/15	Tue 12/20/22	86%
1.1	Project Management	Thu 10/1/15	Fri 2/26/21	98%
1.2	Data Center Design	Fri 10/2/15	Tue 5/22/18	100%
1.3	Data Center Development	Mon 4/10/17	Mon 2/28/22	99%
1.3.1	System Development	Thu 2/1/18	Mon 2/28/22	100%
1.3.2	Software Infrastructure	Mon 5/28/18	Tue 3/30/21	100%
1.3.3	Science Data Calibrations Development	Mon 4/10/17	Mon 4/26/21	98%
1.3.3.1	Calibrations & Pipelines	Tue 1/8/19	Mon 8/24/20	100%
1.3.3.2	Operationalization (profiling)	Tue 8/25/20	Mon 3/15/21	100%
1.3.3.3	Finalization (Post Sci Ver)	Mon 4/10/17	Mon 4/26/21	53%
1.4	DC Integration & Acceptance	Wed 4/26/17	Thu 5/12/22	25%
1.5	User Tools Development	Fri 10/19/18	Thu 9/30/21	94%
1.6	external milestones	Mon 4/10/17	Tue 12/20/22	4%
1.6.1	Instrument Science Verification	Mon 4/10/17	Mon 4/10/17	40%
1.6.2	DKIST Ops Commissioning	Mon 12/6/21	Tue 12/20/22	4%
2	Data Center Operations	Mon 12/6/21	Tue 9/30/25	1%

Figure 3-25. *DKIST Data Center development schedule.*

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	Complete
Integration, performance and acceptance Tests	Sept 2020 – Feb 2022	In Process
Ramp to Full Operations (OCP)/Commissioning	Dec 2021 – Nov 2022	Started
Begin Steady State Operations	Dec 2022	Not started

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

- Complete Acceptance testing.
    - Bug fixes and enhancements resulting from acceptance tests and beginning operations.
    - 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 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, updating, and implementing 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 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 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 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 Ongoing Programs

3.8.1.1 Multi-Conjugate Adaptive Optics (MCAO) for DKIST

The DKIST project intends to be at the forefront of scientific discoveries for the duration of its lifetime using state-of-the-art technology. An important requirement for meeting this goal is in facilitating data acquisition with the highest possible quality at all times given prevailing atmospheric conditions. While drafting the science requirements for the DKIST, the science working group recognized early on the importance of pursuing a promising technology called Multi-Conjugate Adaptive Optics (MCAO), which, in the early 2000s, was not demonstrated to work for the solar application. 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."

The initial High-Order Adaptive Optics (HOAO) system of DKIST, commissioned and verified in the summer of 2021, 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 Dunn Solar Telescope. 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 uni-directional 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. However, scientifically interesting regions can span dozens of arcseconds. Deployment of multiple deformable mirrors that are conjugate to different atmospheric altitudes in which strong turbulence occurs—the concept of a MCAO system—can widen the corrected field, providing a data set that is scientifically more useful.

3.8.1.1.1 Advances in MCAO for Solar Telescopes

To demonstrate the feasibility of MCAO, and in parallel with the construction of DKIST, NSO has supported the development of multi-conjugate adaptive optics for solar observations with the goal of demonstrating the technology on smaller telescopes and thus enable the MCAO-upgraded 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 3-26).

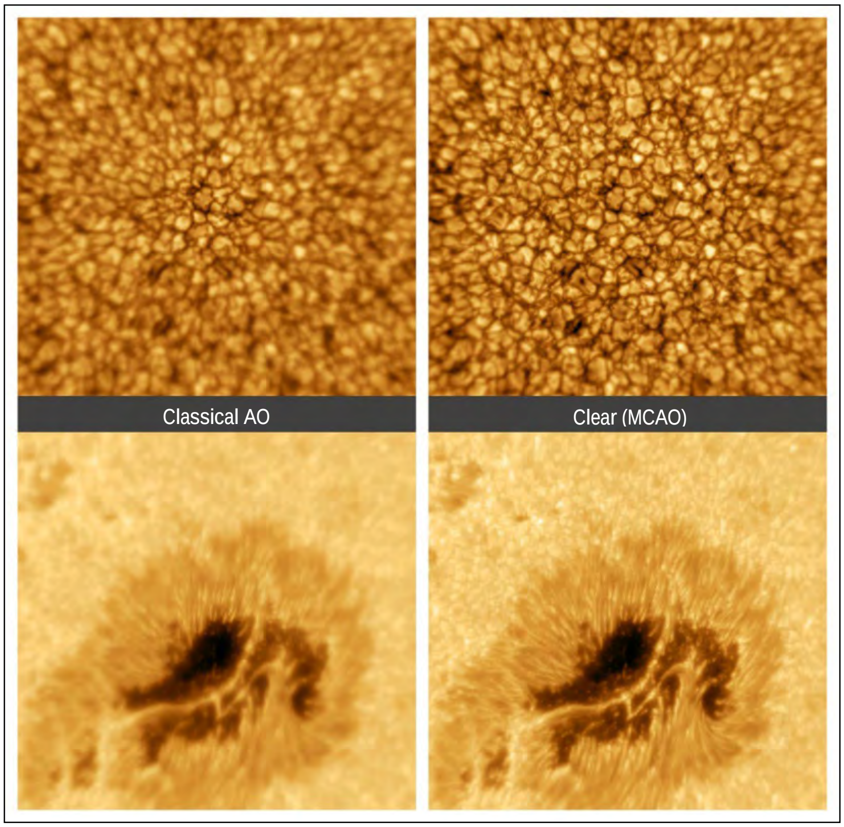


Figure 3-26. *Solar granulation and a sunspot corrected for atmospheric turbulence by the classical adaptive optics system (left) and the "Clear" adaptive optics system (right) on the Goode Solar Telescope.*

Clear features three deformable mirrors and it was designed to be ultra-flexible to enable experimental testing of various theoretical concepts. Simultaneously, DKIST developed the MCAO computer-simulation tool, called "Blur," which incorporates solar adaptive optics peculiarities, to predict the performance of MCAO for DKIST. In 2016, the Clear team, for the first time, was able 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 to accomplish corrections on-sky, i.e., for real-time observations. To our best knowledge, it 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. Given 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 up to 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 is currently available in fast and applicable image sensors. Furthermore, no current single computer is able to process the wavefront sensor data and compute in a timely manner the control commands for the deformable mirrors in a DKIST-sized MCAO system. Our concept therefore is to split up both the wavefront sensor and the computer system into a set of identical parallel subsystems. Some of the basic specifications are listed in Table 3-7 and compared against the Clear configuration.

Table 3-7. Design Parameters for Both the Clear System Installed at the Goode Solar Telescope and the DKIST MCAO System

	GST/Clear	DKIST (Preliminary)
Full telescope aperture diameter	1.6 m	4.0 m
Wavefront sensing diameter	1.42 m	3.81 m
Number of deformable mirrors	3	Same
Conjugate heights	0, 4, 8 km	0, 4.34, 11.2 km
Number of active actuators	241, 137, 177	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	9	1
Optical field of view per sensor	35×35 arcsec	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	ca. 0.6 arcsec/px	same
Correlation size	20×20 px	same
Number of correlation fields total	1872	11817
Number of correlation fields per sensor	1872	1313
Wavelength range	512 – 537 nm	similar
Image sensor read-out size	992×992 px	1000–1200 px square
Number of image sensors Frame	1	9
Rate	1568 fps	2000 fps
Control matrix size	4 MB	**≈380 MB**
CPUs	2× Intel Xeon Gold 6154	20 CPUs of same type
Number of computers	1	10
Cluster network	n/a	InfiniBand EDR (200 Gb/s)

3.8.1.1.2 MCAO Project Management

The MCAO team began to take shape in 2021 with resources becoming more available as the original DKIST construction activities were completed. With the core team organized, work was initiated to develop a set of high-level requirements for the MCAO project. These requirements will be used to further derive requirements for the different MCAO subsystems in the coming months. The project team also worked to develop a project plan consisting of a Work Breakdown Structure (WBS), schedule, budget, and risks. Being the first major upgrade project for DKIST, the MCAO effort is also helping to define processes and tools to be used for project management during DKIST operations. These efforts continued in parallel with long lead contract management for the DMs and early prototyping work on the wavefront sensor (WFS) and real-time control (RTC) (see sections below).

Milestones Achieved in 2021

- Develop high-level requirements for MCAO.
- Develop Work Breakdown Structure, schedule, budget, and risks.

Milestones for 2022

- Generate and hold Project Plan review.
- Develop deployment and integration plans.

3.8.1.1.3 Deformable Mirrors for MCAO

DKIST's MCAO will have three deformable mirrors, conjugate to 0, 4, and 11 km on the optical axis. The "M10" ("DM0") mirror is conjugate to the pupil and the deformable mirror in DKIST's initial HOAO. It will be reused for MCAO. The additional two deformable mirrors will 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 DM4 is under contract with Northrop Grumman Adaptive Optics Associates Xinetics (AOX). A fabrication review was completed successfully in November 2021, marking completion of assembly (Figure 3-27) except for bonding the facesheet, which is scheduled for early 2022. Its technology will be similar to the existing DM0 made by the same company. DM4 will only pass on DKIST's 2.8 arcmin field. Therefore, in order to be capable of passing on the 5-arcmin field to the Cryo-NIRSP that is downstream of M9, a mount design that enables exchange of the mirrors at the current location of M9 will be developed.

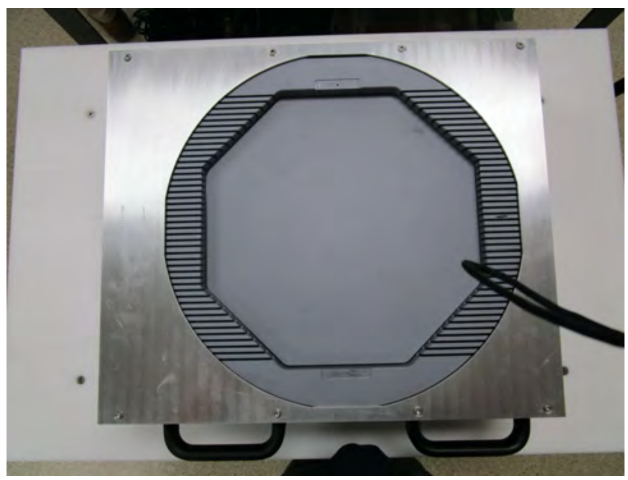


Figure 3-27. *DKIST MCAO DM4 has been fabricated and awaits binding of the reflective faceplate.*

Milestones Achieved in 2021

- Develop conceptual design for mounting DM4 in Coudé laboratory.
- Complete DM4 fabrication progress review.
- Set up contract for a preliminary design and fabrication of the 11-km mirror.

Milestones for 2022

- Complete factory acceptance testing and delivery of DM4 in summer 2022.
- Develop final design of DM4 mount to DKIST Coudé laboratory.
- Complete contract for preliminary design of DM11.
- Award contract for final design of DM11 and start final design phase.

3.8.1.1.4 Wavefront Sensors (WFS) and Real-Time Control (RTC) for MCAO

The wavefront sensor system in DKIST's MCAO will comprise nine separate sensors and will replace the sensor of the HOAO. Each sensor will be similar to the existing HOAO wavefront sensor but points in different directions in a 45-60-arcsec big field of view (Figure 3-28). Each sensor will carry its own CMOS camera.

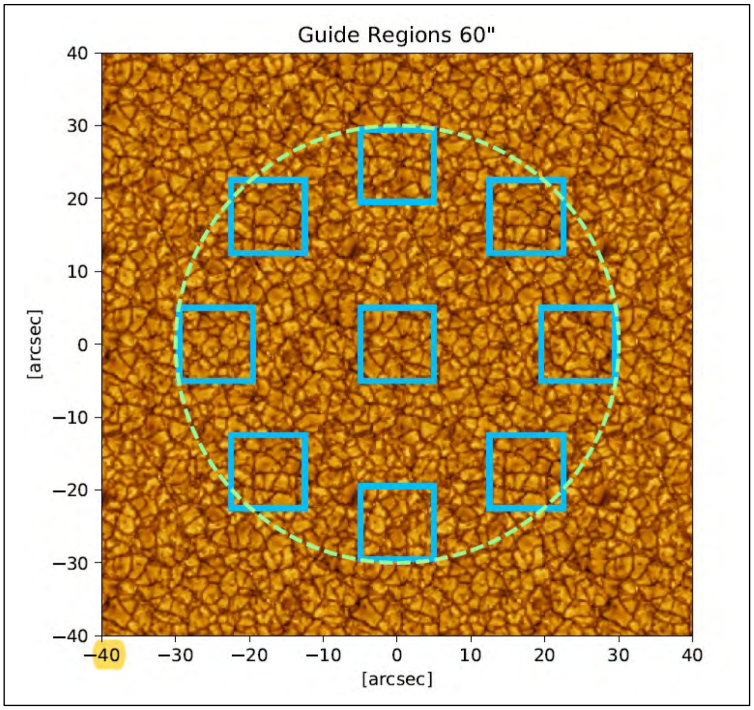


Figure 3-28. *DKIST MCAO will sample up to a 60" FOV with nine wavefront sensors in multiple directions of the field of view.*

Each of the nine wavefront sensor cameras will be connected to a dedicated computer. The full computer system will comprise 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 sub-apertures. The other CPU in each camera computer will 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.

In FY 2021, evaluation of the wavefront sensor system prototype was completed in the Boulder lab (Figure 3-29, top left). This system comprises nine separate wavefront sensors, involving nine cameras, optics and a mechanical structure. Test objectives were successfully completed for evaluating image quality, vignetting in sub-apertures, and alignment stability of the system. Evaluation and development of a concept (Figure 3-29, top right) to allow reconfiguration of the guide region FOV was also performed.

The real-time control system hardware and infrastructure has now been procured and fully assembled in the lab. The servers in the cluster are interconnected with 200 Gb/s InfiniBand. Characterization of latency and jitter through the cluster across this interconnect has been performed and shows a mean of about 8 μs (Figure 3-29, bottom left) which is adequate for this system.

A final design review of the high-speed cameras for the wavefront sensor system (Figure 3-29 bottom right) was held with our vendor (PCO) and successfully passed. Delivery of the cameras is expected by early summer 2022. The digital interface from the RTC to the deformable mirror systems is currently in fabrication and delivery is expected in spring 2022.

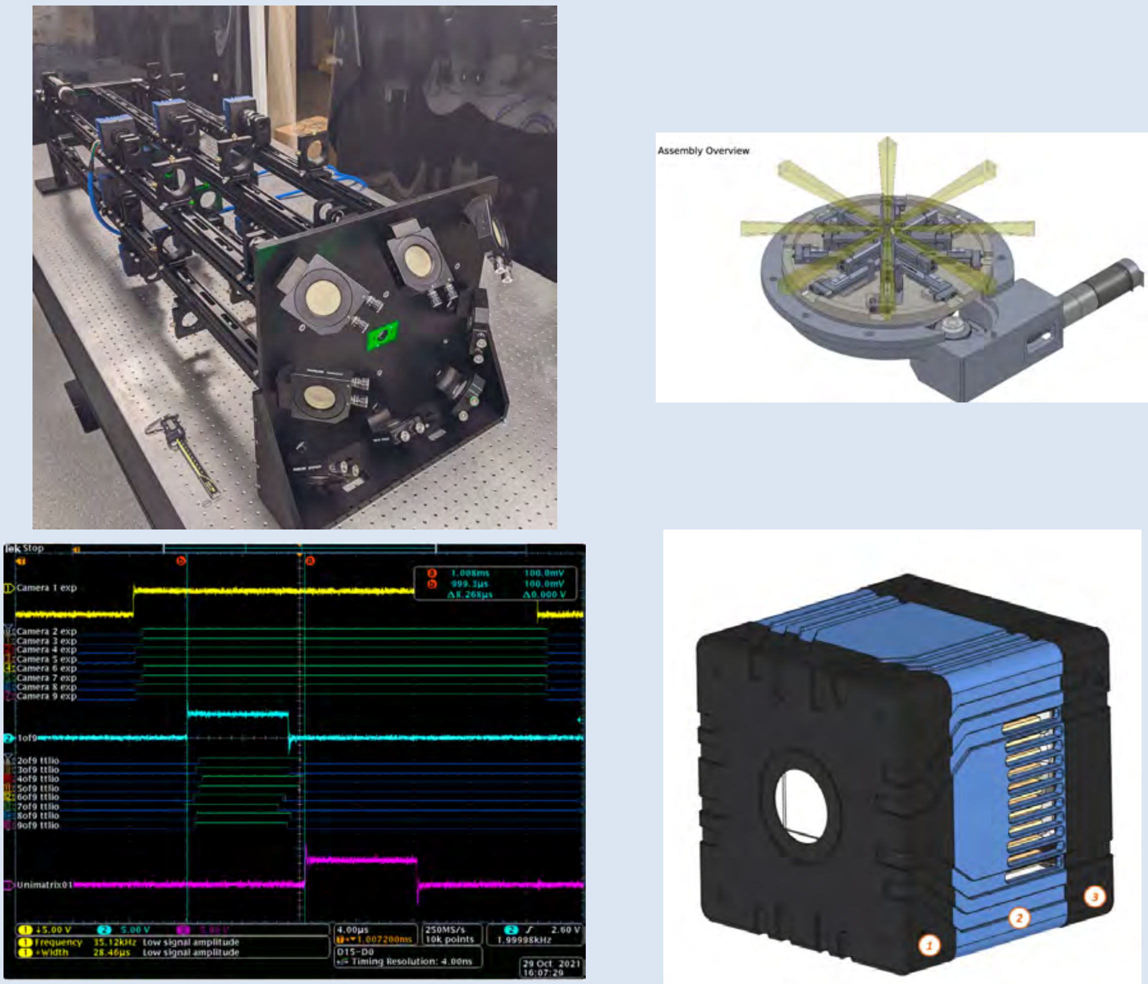


Figure 3-29. *<u>Top left</u>: MCAO prototype assembled in the Boulder optics lab. Nine separate wavefront sensor units in a 3×3 grid. <u>Top right</u>: Concept for the optical assembly that splits the incoming field into nine guide regions for the wavefront sensors. <u>Bottom left</u>: Oscilloscope screenshot demonstrating synchronization between the MCAO compute servers to within approximately 8 µs. <u>Bottom right</u>: Design drawing of the high-speed camera for the nine wavefront sensors.*

Milestones Achieved in 2021

- Selected and assembled all RTC hardware and completed inter-node communication latency testing.
- Completed test objectives associated with evaluating the MCAO WFS concept lab prototype.
- Finalized the MCAO WFS mechanical design concept.

Milestones for FY 2022

- Complete final design review for the MCAO wavefront sensor system.
- Begin fabrication and assembly of final MCAO wavefront sensor system.
- Complete development of RTC cluster inter-node communications.
- Lab integration and testing of high-speed WFS cameras.

3.8.1.1.5 Numerical Simulations of DKIST MCAO Performance

For the modeling of the DKIST MCAO system and to predict and 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 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.

Using "Blur", we performed numerical simulations of the DKIST MCAO system's performance as part of the design process currently underway in FY 2021. The performance of the DKIST MCAO system was measured with numerical simulations to explore the impacts of various design parameters, including degrees of correction based on the system's DMs potential designs.

The MCAO performance results have been used to determine further 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 further evaluate the AOA Xinetic proposed silicon carbide mirror with actuators mounted parallel to the surface of the mirror ("surface parallel actuator" (SPA)). This SPA mirror will 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 a SPA mirror in a solar MCAO system. Through numerical simulations, we have tested all the SPA mirror designs proposed by AOA Xinetics to date and determined which design is acceptable and best meets our correction requirements. The selected design will be the basis for the fabrication contract for DM11 to be awarded in FY 2022.

Milestones Achieved in FY 2021

- Fine tuned DKIST MCAO parameters based on available design concepts and available technology.
- Optimized correction strategies for the MCAO system.
- Explored the effects of a narrow FOV MCAO system configuration of around 30".
- Used numerical MCAO simulations to test a customized servo loop for mitigation of idiosyncrasies of SPA mirrors.

Milestones for FY 2022

- Update models of expected performance based on new information about wavefront sensor and deformable mirror performance.

3.8.1.2 Infrared Detectors for DKIST's Infrared Spectro-Polarimeters

The infrared detector technology used for the DL-NIRSP and Cryo-NIRSP instruments continues to be a great concern for the project. There are currently no spare devices or electronics for these custom-built detector systems. During 2021, an available science-grade H2RG detector was identified and purchased to replace the Cryo-NIRSP context imager's engineering-grade sensor; however, this upgrade was made only because of the immediate availability of the sensor. Also, during 2021, both DL-NIRSP IR cameras exhibited failures in their electronics during commissioning that required removal and rework. These types of failures during commissioning can be expected, but during operations these will result in significant down-time and costs.

To meet requirements of solar observations, the H2RG detectors need to be controlled in non-standard ways (e.g., at fast frame or even sub-frame rates). Many problems with the analog technology used to control these devices have been revealed during the development phase. These problems, such as bias flicker, frame synchronization, and pedestal subtraction, can be greatly reduced or eliminated completely with the new digital technology.

Through vendor interactions throughout FY 2021, the project has determined that new IR detector technology is now available that utilizes digital focal planes to meet the challenging requirements and provide additional capability and robustness. Off-the-shelf controllers (frame grabbers) are available for this technology. However, lead times for sensor acquisition are long (on the order of two years) and these devices are relatively expensive. To begin this process, DKIST issued a Request for Proposal for the fabrication of two short-wave and two mid-wave infrared sensors. Specifications for the sensors include features such as digital focal planes, 4K by 4K pixels, 60 frames per second with low read noise, high quantum efficiency, and non-destructive readout capability, among other capabilities.

At the conclusion of FY 2021, DKIST has received vendor responses to the IR Sensor solicitation and is in the process of selecting the best proposal.

DKIST expects to receive the new IR Sensors in early 2024. The project has also started planning for the integration of these sensors into the DL-NIRSP and Cryo-NIRSP. For both instruments, this will require significant changes for the camera electronics and software systems, along with detailed analysis of the optical and mechanical systems. During FY 2022, the project expects to analyze these impacts and begin planning the necessary instrument upgrades. By FY 2024, the project foresees the installation and testing of the new 4K digital detectors in these instruments, with the associated improvements in science capabilities.

Milestones Achieved in FY 2021

- Defined IR Sensor specification.
- Started request for proposals (RFP) process.

Milestones FY 2022

- Select the preferred IR Sensor proposal and present this choice to AURA.
- Sign contract to begin the sensor production.
- Hold kick-off meeting to discuss the project planning and upcoming work.
- Begin preparations for the upcoming Critical Design Review to discuss the final design and production schedule.
- Begin analysis and planning for necessary instrument upgrades to accommodate new sensors.

3.8.1.3 MiSi-36 – Image Slicer Upgrade for the Diffraction-Limited Near Infrared Spectro-Polarimeter

In order to increase throughput and performance of the Diffraction-Limited Near-IR Spectro-polarimeter (DL-NIRSP), the DKIST project plans to upgrade the Birefringent Fiber-Optic Image Slicer (BiFOIS) IFU-36 of the DL-NIRSP with a Machined Image Slicer Integral Field Unit, with 54 slits and 36 μm slit width (MISI-36) to replace the BiFOIS IFU-36. This will enable the DL-NIRSP to perform science above 1800 nm. DKIST is working in collaboration with the University of Hawaiʻi Institute for Astronomy (UH/IfA) to perform this upgrade.

MISI-36 is a drop-in replacement of the BiFOIS IFU-36 of DL-NIRSP. The optical system of MISI-36 is composed of two major subsystems, namely the 1:1 relay optics, and the Integral Field Unit (IFU), as shown in Figure 3-30. The telescope image is focused on the entrance field stop of the 1:1 relay optics system where the relay optics re-image the telescope image on the image slicer block of the IFU. The IFU decomposes the 2D telescope field into 112 narrow subfields and reformats these subfields into four segmented and staggered long exit slits. The exit slits of the IFU serve as the entrance slits of the multi-slit spectro-polarimeter of DL-NIRSP.

The MISI-36 IFU team has adopted a new two-segment slicer mirror design that allows it to fit into same location and volume of BiFOIS IFU-36. A prototype MISI-36-IFU was fabricated by Canon, Inc. and delivered to UH/IfA for evaluation on August 1, 2020. The UH/IfA team has evaluated the protype and has concluded that the system is acceptable with some minor modifications.

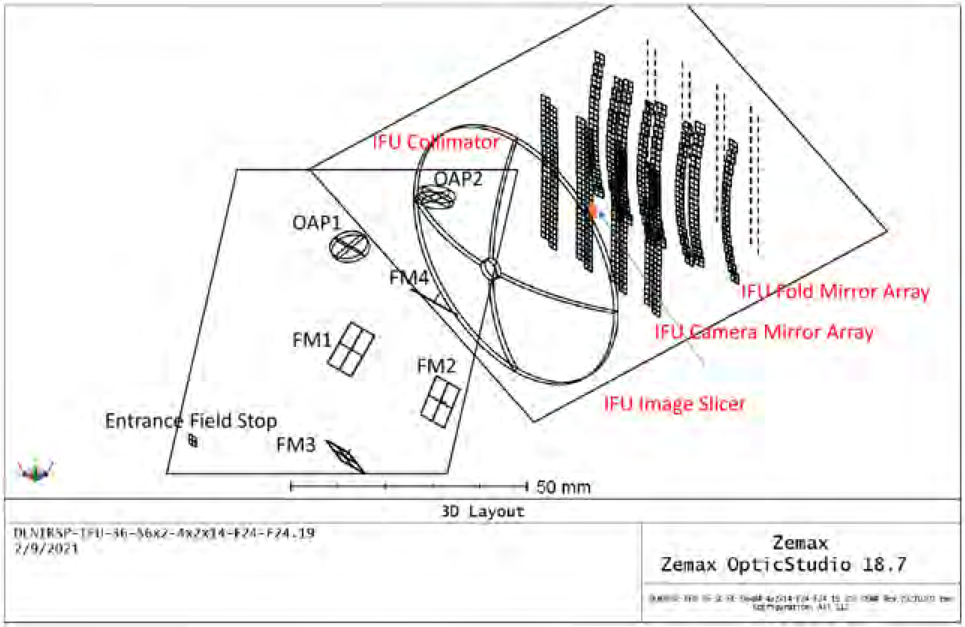


Figure 3-30. *Optical system of MISI-36 without ray trace to show the optical components. The relay optical system consists of six optical components: four-fold mirrors FM1, FM2, FM3, and FM4; and two off-axis parabola OAP1 and OAP2 (marked by parallelogram). The optics of the IFU can be divided into four major subcomponents: the image slicer, the collimator, the fold mirror array, and the camera mirror array. The beam enters at the entrance field stop, travels through the relay system (FM1-OAP1-FM2-FM3-OAP2) until FM4 redirects the beam to the IFU image slicer. The sliced images then travel to the collimator, the IFU fold mirror array, the IFU camera mirror array and finally exit through the exit slits (dashed).*

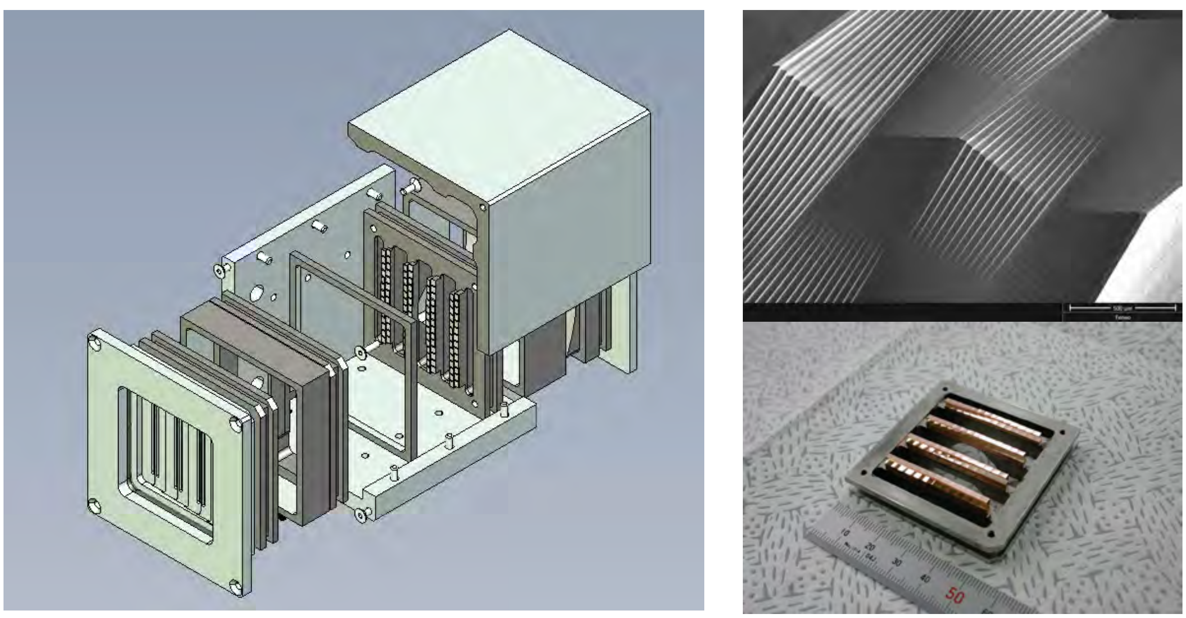


Figure 3-31. *Left: Exploded view of the design of the MISI assembly for drop-in replacement of DL-NIRSP's fiber-fed IFU (the exit slits are shown in the bottom left part of the image). Right top: close-up of the image slicer array (scale shown corresponds to 0.5 mm). Right bottom: Fabricated camera mirror array (as visible in the full assembly left).*

Milestones Achieved in FY 2021

- Defined the MISI-36 specification and statement of work.
- Started RFP process.

Milestones FY 2022

- Execute contract with UH/IfA.
- Kickoff sub-contract with Canon, Inc.
- Perform final design review.

3.8.1.4 Second Fabry-Perot Etalon for the Visible Tunable Filter

The Visible Tunable Filter (VTF) will be delivered to the summit initially in a single Fabry-Perot etalon configuration. While the VTF with only one Etalon meets the science requirements for all wavelengths above 550 nm, toward the blue end of the VTF wavelength range it becomes increasingly difficult to suppress the secondary Etalon transmission bands (Figure 3-32). This is due to the fact that the free spectral range (FSR) is only 0.24 nm at 525 nm, requiring a prefilter with a width of 0.06 nm. It will be challenging to reach a peak transmission of 0.6 for such a filter. In addition, the photon flux is lower than at 630 nm by a factor of 0.75, in part due to the higher spectral resolution of the VTF at shorter wavelengths. The polarimetric accuracy at 525 nm will therefore only meet the science requirement concerning SNR, when a longer integration time is used (10 accumulations instead of 8, leading to a reduced cadence).

In addition, the scan range around the central wavelength of each prefilter is reduced by a factor of two compared to the 2-Etalon configuration. The limitations are of no concern for spectro-polarimetry with photospheric line, but height-dependent Doppler and intensity measurements using chromospheric lines will be affected.

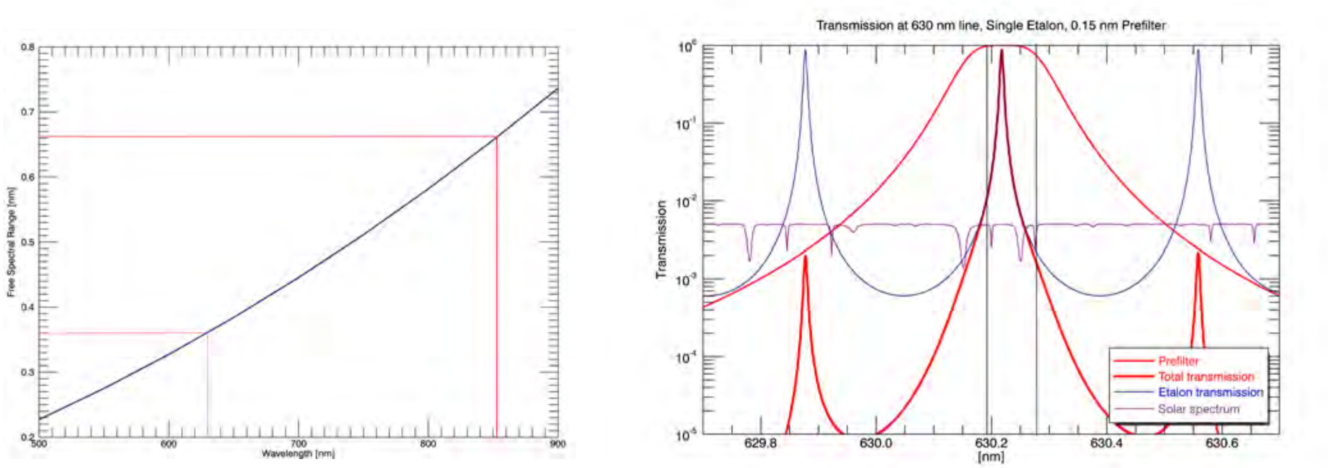


Figure 3-32. *Left: Free spectral range of the high-resolution Etalon of the VTF, red lines indicate the values for 630 nm and 854 nm. Right: Transmission curves for a single-Etalon configuration at 630 nm. Blue: Etalon transmission curve, Red: 0.15 nm 2-cavity prefilter, Thick red line: combined transmission curve. Purple: solar spectrum. The width of the Etalon transmission curve includes the broadening effects of the f:200 beam.*

For these reasons, the VTF will be upgraded to a 2-Etalon configuration based on a MOU with the Leibniz-Institut für Sonnenphysik (KIS) in Freiburg, Germany, after instrument commissioning and after the instrument has demonstrated its performance in single etalon configuration.

The second etalon is currently under fabrication by the VTF team. The substrates have been manufactured and have been handed off to the coating vendor for deposition of the reflective coatings on the surface of the plates. This process requires a very careful assessment of the etalon plate shape to a nanometer level. Figure 3-33 shows the interferograms of the lower etalon plate's upper and lower surface. These were measured by the substrate manufacturer before leaving their facility, and by the coating manufacturer upon reception at their facility to ensure agreement. Current status: once agreement has been reached on the shape for both plates of the second Fabry-Perot Etalon, both plates will be coated by the coating vendor.

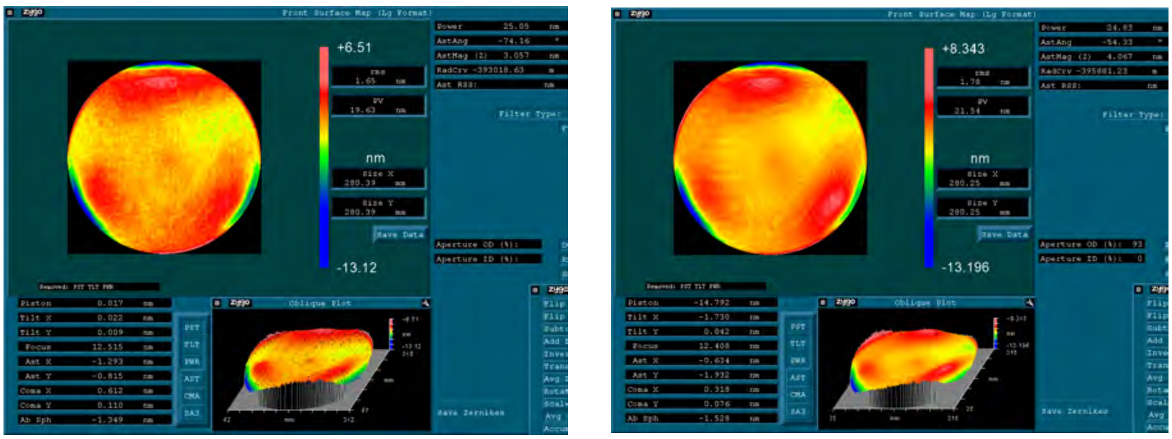


Figure 3-33. *Left: Shape of the second Fabry-Perot Etalon's lower plate (surface 1), prior to departure from substrate manufacturer. Right: Shape after arrival at coating vendor. Both measurements are in close agreement, a premise for beginning the coating process.*

Milestones Achieved in FY 2021

- Etalon substrates have been polished, measured, and delivered to coating vendor.
- Etalon mechanical and electrical assemblies have been designed and parts ordered.

Milestones for FY 2022

- Coating vendor receives the substrates, measures them and begins coating process.
- Final delivery of the coated plates.

3.8.1.5 Additional Optics for Dnhanced Flexibility for DKIST's Facility Instrument Distribution Optics (FIDO)

The DKIST Facility Instrument Distribution Optics (FIDO) allows the redistribution of chromatic light to DKIST facility instruments with an unprecedented built-in flexibility. The design of the subsystem allows substitution of dichroic beamsplitters at any of five locations in order to deliver a certain wavelength band to a particular instrument, based on the scientific needs as defined in a proposal. The reconfiguration can occur with little to no impact on the optical setup of the instrument itself.

The number of potential configurations is only limited by the number of available beamsplitter optics. During the design phase of DKIST, a limited initial set of optics were included based on the input of the DKIST Science Working Group. These optics are:

- C-BS465, reflecting wavelengths shorter than 465 nm, and transmitting the longer wavelengths;
- C-BS555, reflecting wavelengths shorter than 555 nm, and transmitting the longer wavelengths;
- C-BS643, reflecting wavelengths shorter than 643 nm, and transmitting the longer wavelengths;
- C-BS680, reflecting wavelengths shorter than 680 nm, and transmitting the longer wavelengths;
- C-BS950, reflecting wavelengths shorter than 950 nm, and transmitting the longer wavelengths,
- C-M1, a mirror reflecting all wavelength bands;
- C-W1 and C-W3, windows that transmit all wavelength bands and are anti-reflective coated;
- C-W2, a window that transmits all wavelength band with ~96%, and reflecting about ~4% from the uncoated front surface.

Additional optics will allow addressing more scientific use cases. Given the added experience gained with the Observatory Commissioning Phase proposals, specific additions to the FIDO beamsplitter suite were identified that are of particular interest for the solar physics community. In particular, a partially reflective ("gray") beamsplitter optic with 50% transmission and 50% reflection in the visible wavelength bands would enable addressing a variety of new use cases that allow combination of multiple instruments within the *same* wavelength band. Additional benefits come from using custom coating designs that allow for >95% transmission in the DL-NIRSP bandpass 1000 nm to 1800 nm.

For these reasons, in FY 2021, DKIST has begun the procurement of this "gray" beamsplitter optics with visible band transmission/reflection of 50:50 in FY 2021. A draft coating design that is suitable has been developed (Figure 3-34).

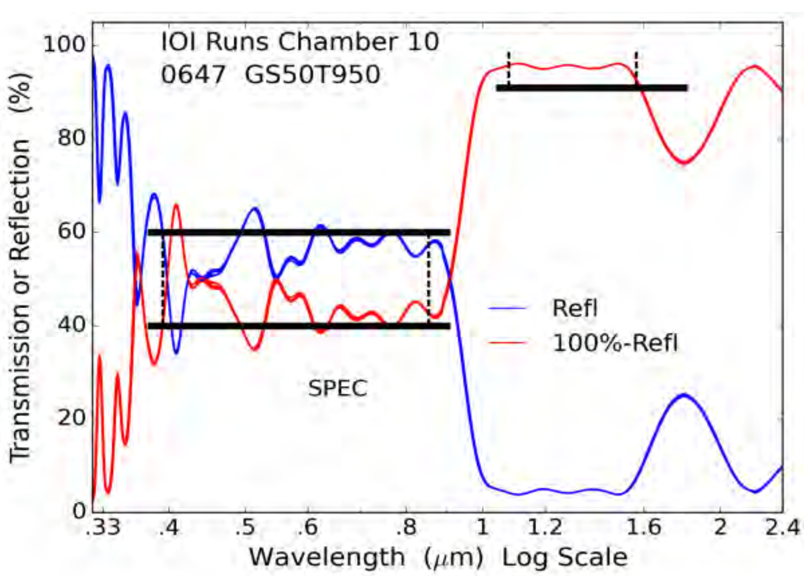


Figure 3-34. *Current draft design/performance of the coating of the additional FIDO "gray" beamsplitter.*

Milestones Achieved in FY 2021

- Initial coating design runs, coating thermal processing, and coating uniformity testing completed.
- The optical specification was finalized. Procurement of the substrate was initiated.

Milestones for FY 2022

- Finalization of the coating formula.
- Characterization of the coating stress for substrate conditioning.
- Fabrication of the substrate including coating stress compensation and wedge clocking.

3.8.1.6 Visible/Infrared Beamsplitter at Cryo-NIRSP Pickoff Coudé Location

Whenever necessary, the DKIST telescope beam can be fed into the Cryo-NIRSP by inserting a mirror at the Cryo-NIRSP pickoff Coudé location. The mirror (M9a) that is inserted into the science beam will be exchanged with a beamsplitter (hot mirror type), allowing the Cryo-NIRSP instrument to operate simultaneously with all other DKIST first-light instruments including adaptive optics. Alternatively, such a beamsplitter could become an additional option to the mirror. In either case, such a beamsplitter would enhance the ability to address more complex scientific use cases as well as streamline optical alignment for observatory efficiency.

A successful proposal for supplemental funding was submitted to the NSF Windows on the Universe Multi-Messenger Astrophysics (WoU-MMA) program. We proposed implementing a new air-spaced, two substrate design, short-pass beam splitter named M9b, interchangable with M9a, that enables simultaneous operation of CN with all other AO-assisted DKIST instruments (VBI+DL+ViSP+VTF). Current FIDO optics are sized to reflect the 2.8′ FOV, combined as wedge-compensated pairs to minimize ghosting and compensate spectral dispersion. We proposed a similar co-mounted wedge-matched pair of substrates for M9b with the option for an upstream substrate larger than current FIDO optics (i.e., matched to M9a) to reflect the full 5′ FOV to CN while transmitting the 2.8′ FOV to the AO-assisted downstream instruments.

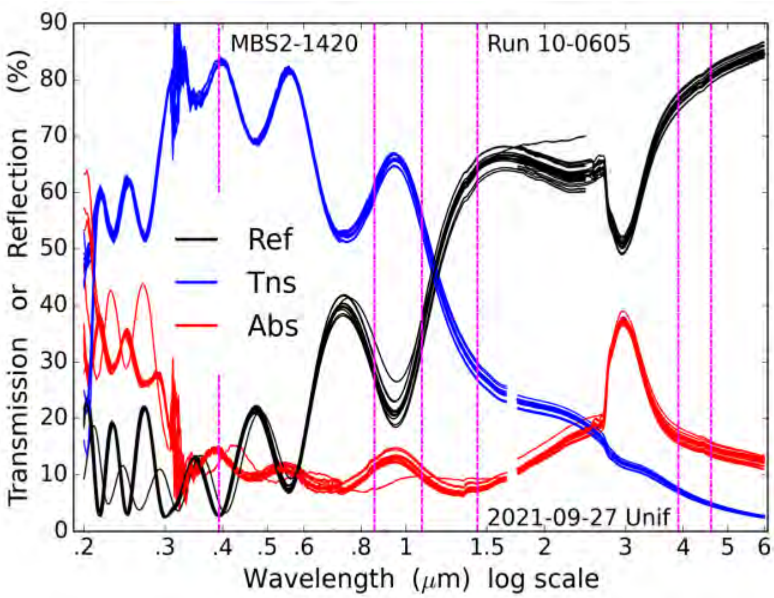


Figure 3-35. *Current draft design/performance of the coating of the M9b "hot mirror type" beamsplitter.*

This proposal will leverage the recent fabrication of the many FIDO optics and will re-use the DKIST-designed mounting strategy for the existing FIDO and M9a optics. Two common coatings had been identified from the FIDO coating vendor (Figure 3-35). In FY 2020, coatings were tested and optimized and assessed for durability, absorption, and uniformity over the >300 mm aperture.

DKIST staff, funded by the DKIST base budget, will perform optical analysis, coating tests, opto-mechanical designs, and thermal modeling required to enable the use of this optic for both off-limb and on-disk observations in the 80-Watt beam.

Supported science objectives:

- Sequential Cryo-NIRSP observations of Si+9 and Si+8 combined with simultaneous DL-NIRSP Fe+10 and Fe+12 observations, allowing broader coverage of transitional coronal magnetism and charge-state ratios otherwise unfeasible to achieve in a single experiment.
- [C1:] Cryo-NIRSP observations of Ar+12 (with task 2c filters) simultaneously with VISP and DL-NIRSP lines for FIP effect measurements off-limb.
- [C2:] All AO-instrument capabilities can be utilized alongside Cryo-NIRSP coronal long-wave observations and/or of the CO fundamental band for increased thermal coverage of corona and lower atmosphere.

Milestones Achieved in FY 2021

- Developed preliminary specifications for optical performance and coating performance. Optical tolerancing and alignment assessment is in progress.
- Performed coating development and uniformity testing.
- Validated coating as durable and deliverable.
- Preliminary design concepts developed for optic exchange mechanism.

Milestones for FY 2022

- Finalize optical specifications.
- Procure long-lead glass substrates and finalize optic purchase.
- Design and fabricate optical mounts.
- Design and fabricate optic exchange mechanism.
- Design and fabricate aperture stops and heat exchange mechanisms.

3.8.2 Future Programs and Enhancements for DKIST Instrumentation

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 the 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.

3.8.2.1 Visible Spectro-Polarimeter

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.

Near term: the instrument can be upgraded to ease any changes to the feed optics mirror that focuses DKIST's beam onto the entrance slit of the spectrograph. A motorized/automated procedure could be useful in order to ease a potential change in focus due to a FIDO exchange upstream of the instrument.

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 preliminary design has been developed for the mechanism 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.

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 of the camera arms and arm rail would be required to support the Andor Balor cameras.

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.

3.8.2.2 Visible Broadband Imager

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.

Near term: Commissioning images using the VBI red H-alpha showed a large photospheric contribution to the data that is undesirable for this chromospheric diagnostic. A new interference filter that is more homogenically centered on the H-alpha line core would allow accurate chromospheric imaging across the complete field of view of the VBI red.

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).

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.

3.8.2.3 Diffraction-Limited Near Infrared Spectro-Polarimeter

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.

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.

3.8.2.4 Cryogenic Near Infrared Spectro-Polarimeter

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.

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.
Potential additional filters 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).

Potential additional filters 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).

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.

Milestones Achieved in FY 2021

- Started initial concept studies for these upgrades.

Milestones for FY 2022

- Finalize initial concept studies for the instrument upgrades.
- Use Observatory commissioning phase to identify priorities of upgrades, and upgrade strategies.

3.9 Supporting Facilities

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 construc-tion effort but once DKIST is in operations will continue to support summit operations.

Figure 3-36. *DKIST Science Support Center at Pukalani, Maui.*

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 3-36). 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.

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. Remote operations 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 3-37).

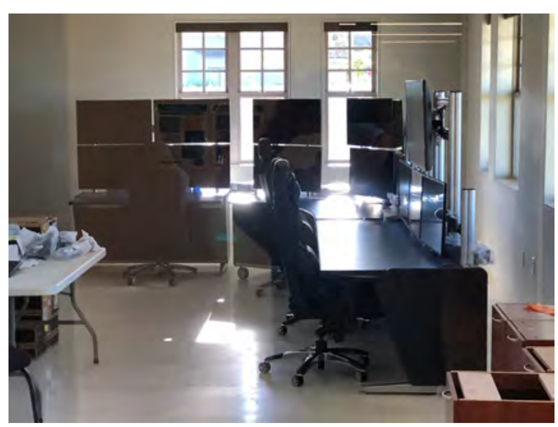


Figure 3-37. *Remote control room at the Maui DSSC implemented in FY20.*

Machine Shop: In FY 2017, NSO relocated the machine shop equipment from Sunspot to a Boulder off-campus leased space. NSO/AURA continues to lease 2,757 square feet of usable space at an industrial warehouse.

In FY 2022, DKIST Operations will utilize the machine shop to manufacture parts for new instrument developments, such as MCAO.

The NSO Headquarters building in Boulder provides leased office and common area space for DKIST staff and houses the instrument lab facility. DKIST uses the Boulder lab space to develop new instruments such as the multi-conjugate adaptive optics system, to implement and test upgrades to instruments (e.g., polarimetry optics) and to perform metrology and verification of opto-mechanical components (e.g., laser interferometer, fiber-spectrograph).

The DKIST construction project is renting warehouse space and lay-down area. During operations, we will continue to lease suitable storage space as needed. We note that given the lifetime of DKIST, long-term cost saving could be achieved by purchasing or building a suitable storage facility.

3.10 Safety Program

3.10.1 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 developed the detailed safety manual for the operations and maintenance phase while implementing sections incrementally as needed for the construction, IT&C, and technical operations 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, the night operations testing and technical operations checklists. 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.

DKIST safety staff participated in the development and subsequent revisions of the AURA NSF-Funded Centers COVID-19 Exposure Prevention Plan, and the NSO-COVID-19 Restart Procedure, and researched for AURA OSHA, CDC and various organizations' guidelines and process tools to reduce risk of corona virus infections. Safety staff supported the successful summit restart AURA Phase 1 Restart Readiness Review and prepared the site for restart with virus exposure prevention signage, safety emergency equipment inspections and COVID-19 supplies distribution. Also implemented was a contact tracing proximity card system to include the development of training materials, assigning unique QR codes to all staff and contractors, and performing hardware testing and the rollout of the system to all site staff. Ongoing NSO staff, partners and contractors COVID-19 virus-exposure prevention and site access training were also created and completed.

4 NSO INTEGRATED SYNOPTIC PROGRAM (NISP) THIS SECTION WAS NOT UPDATED FOR THE FY2022-FY2023 APRPP

4.1 Introduction

The Sun is our nearest and most important star. Its closeness enables the study of many important astrophysical and fundamental plasma physics processes in great detail—processes that also occur on other more distant stars. Solar activity also drives the geomagnetic activity on Earth, and the variable solar output is a driver of terrestrial climate. The Sun's magnetic field shapes the solar wind and powers explosive phenomena that result in space weather conditions impacting all bodies in the solar system within the heliosphere, including our home planet Earth, as well as the Moon and Mars—next stops in our space exploration quest (e.g., the NASA Artemis/Gateway program). To understand the complex physics behind solar activity and to develop realistic models for predicting space weather, we require essential and continuous observations of solar activity taken over large spatial scales (full disk) and over an extended period (several magnetic cycles or longer). Providing the background synoptic[3] observations to characterize the variable solar activity and operating/developing ground-based facilities to enable such long-term observations are two key aspects of NSO's mission, which are entrusted to the NSO Integrated Synoptic Program (NISP). The program was created in July 2011 by combining the Global Oscillation Network Group (GONG) and Synoptic Optical Long-term Investigations of the Sun (SOLIS) projects. In today's NSO, 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 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). The importance of NISP facilities (GONG and SOLIS) for solar and stellar research and their open access policies in significantly increasing the scientific output of research investments was recently recognized by the National Academy Decadal Survey on Astronomy and Astrophysics 2020 (Astro2020).

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[4]. The importance of ground-based observations in support of

[3] By synoptic, we mean large-scale (full disk), long-term (solar cycle and longer) observations.
[4] *https://trumpwhitehouse.archives.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf*

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[5]. Astro2020 (p. K-21) has identified the "greatly improved synoptic observations of the solar photosphere" as one of two critical measurement gaps that require investment in the coming decade. 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, Operations, and Community Support

Understanding the physics of solar activity and its impact on our home planet are the main intellectual drivers for NISP research activities. Currently, NISP operates GONG facilities. It manages the relocation of SOLIS to its permanent location at Big Bear Solar Observatory and operates the Data Center to disseminate solar synoptic observations to the research community. The NSF base funding to NSO/NISP partially supports research and service activities of seven (7) scientific, four (4) Data Center, and five (5) engineering staff. To a large extent, scientific research by NISP scientists is based on GONG, SOLIS and NSO historical data. External (NASA) grants support research based on non-NSO (mostly NASA) observations. NSF base funding also supports GONG refurbishment (see Section 4.3 The NISP GONG Component), SOLIS relocation/operations (Section 4.4 The NISP SOLIS Component) and NISP Data Center (Section 4.5 NISP Data Center). NOAA provides supplemental funding for GONG operations.

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 FY 2021, the NISP scientific staff continued to work on several research projects, including (only NSO authors are listed): a case study of acoustic halos in NOAA Active Region 12683 (Tripathy, S.C., Jain, K., Kholikov, S., Hill F. (NSO emeritus)); some exceptional activity in the early phase of Cycle 25 (Jain, K., Tripathy, S.C.); helioseismic investigations of the quasi-biennial oscillation (Jain, K., Tripathy, S.C.); prediction of solar Cycle 25 using spotless days and geomagnetic index (Tripathy, S.C.); the assessment of early performance of SONG spectrograph in measuring solar radial velocity (Hill, F., Jain, K., Tripathy, S. C.); the width and timing of last three solar minima at various depths in the solar interior (Jain, K., Tripathy, S. C., Hill, F.); a detailed analysis of the duty cycle using GONG observations spanning over 18 years (Jain, K., Tripathy, S.C., Hill, F., Pevtsov, A.A.); observations, identification, and diagnostics of solar inertial modes (Jain, K.); deciphering the deep origin of active regions (Jain, K.); solar magnetism and irradiance (Petrie, G., Bertello L., Criscuoli, S.); uncertainty estimates of solar wind prediction using photospheric vector and spatial standard deviation synoptic maps (Petrie, G., Bertello, L.); long-term studies of photospheric magnetic fields on the Sun (Pevtsov, A., Bertello, L.); a limitation of Zeeman polarimetry and imperfect instrumen-tation in representing solar magnetic fields with weaker polarization signal (Pevtsov, A., Bertello, L., Hughes, A.); analysis of the space radiation effects on liquid crystal variable retarders (Gosain, S.); subsurface horizontal flows during solar Cycles 24 and 25 with large-tile ring-diagram analysis (Komm, R.); divergence and vorticity of subsurface flows during solar Cycles 23 and 24 (Komm, R., Hill, F.); critical science plan for DKIST (Petrie, G. and 64 NSO coauthors);

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

the solar activity monitor network–SAMNet (Pevtsov, A.); far-side activity in surface flux transport simulations (Pevtsov, A.); tilt angle and lifetime of sunspot groups (Pevtsov, A.): the sunspot drawing collection of the National Solar Observatory at Sacramento (Pevtsov, A.); bi-lognormal distribution of sunspot group areas (Pevtsov, A.); the intensity and evolution of the extreme storms in January 1938 (Pevtsov, A.).

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 has been renewed for the next five years (FY 2022-FY 2026), with NOAA providing to SWPC for GONG operations about $1M annually. In FY 2021, NISP completed the migration of 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[6] that predicts the magnetic connectivity with the Sun of the Parker Solar Probe (PSP) 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[7].

During FY 2021, the Parker Solar Probe, launched by NASA on August 12, 2018, completed four closest approaches to the Sun: January 17, 2021 – Perihelion #7; April 29, 2021 – Perihelion #8; August 9, 2021 – Perihelion #9; and November 21, 2021 – Perihelion #10. The PSP perihelion passages #7, #8, and #10 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 4-1). 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. NISP/GONG support for PSP encounter #7 was featured at NASA's PSP mission website: (*https://www.nasa.gov/feature/goddard/2021/observations-around-the-solar-system-with-parker-solar-probe-s-seventh-solar-encounter).*

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

[6] *https://github.com/dstansby/publication-code/tree/master/2019-psp-connection*.
[7] *https://www.iswat-cospar.org/*

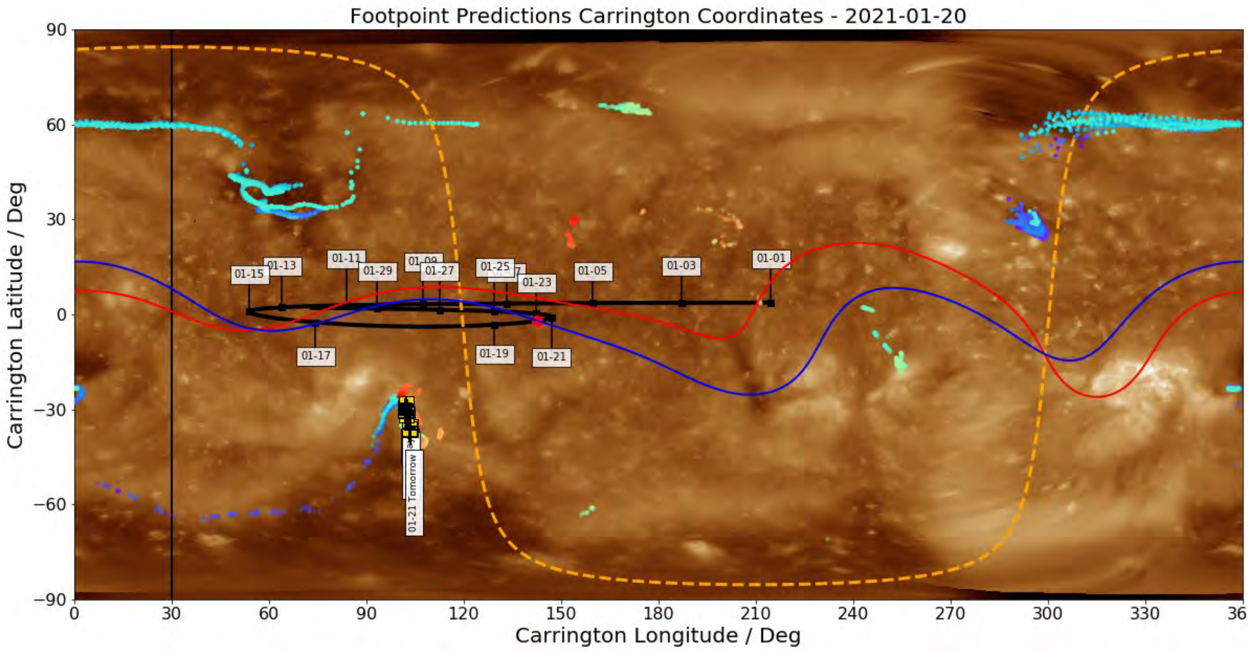


Figure 4-1. *Synoptic map of coronal image with magnetic field footpoints connecting to PSP location as predicted by a different model for PSP Encounter 7. The diamonds and squares show ADAPT HMI and ADAPT GONG predictions, respectively. Solid red (blue) lines show projection of the Heliospheric Current Sheet (HCS) derived using GONG (HMI) data. Solid black line with date (month/day) boxes shows the projection of PSP orbit on solar surface. Courtesy of Robert C. Allen (APL/JHU).*

Earth-facing side up to two weeks in advance, as demonstrated in the appearance of the first naked eye sunspot of Cycle 25.[8] 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 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.

4.3 The NISP GONG Component

This year (2021) was the 26th 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

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

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 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 4-2) are an increasingly popular data product and have been used to study filaments, flares, and the oscillations of the chromosphere.

Figure 4-2. Two ribbon flare and filament eruption associated with CME and X1.0 X-ray class flare as observed by GONG/CT on 28 October 2021. Black arrows mark approximate position of filament prior and during its eruption, bright flare ribbons, and a signature of the Moreton wave triggered by this major flare.

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. At any given time, however, 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 4-3 shows a cumulative histogram of the daily duty cycle of GONG from its deployment in 1995 through August 2020. 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. This duty cycles refer to the fully calibrated data. For quick-look observations used for the operational space weather forecast the duty cycle is higher at about 96%.

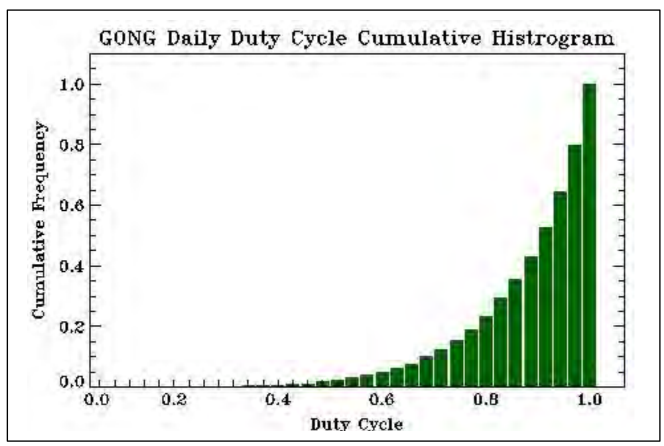


Figure 4-3. Cumulative histogram of the daily duty cycle of GONG from May 1995 through August 2020. The median daily duty cycle is 0.91. Courtesy of K. Jain (NSO/NISP).

In FY 2021, the Program experienced several emergencies, which required significant attention of the scientific, Data Center, and the engineering staff. In the aftermath of a cyclone, on 2 February 2021 several electronics components (including the Delta power supply) had failed. Sending the NSO team to Australia was not possible due to COVID pandemic travel restrictions, and the repairs were attempted remotely with the help of Learmonth (LE) site personnel. The repairs were successful, and GONG/LE was back online on 12 February 2021. On 28 February 2021, GONG at Mauna Loa (ML) experienced failure of multiple electronic boards caused by a lightning strike. Initial repairs with help of Mauna Loa Solar Observatory (MLSO) site personnel brought the instrument back online on 12 March 2021, but later, the observations were stopped, again due to development of a significant noise in one of the camera channels. In May 2021, the GONG/ML camera was replaced by the NSO team, who also conducted other repairs and replaced a failed lightning arrestor. In August 2021, the GONG camera at Big Bear (BB) was replaced due to an intermittent noise in one of its channels. In September 2021, the NISP team made a preventive maintenance (PM) trip to GONG at El Teide (TD), during which a rotating plate—a "heart" of every GONG instrument—had failed. The plate was replaced using the assembly taken out of the GONG engineering site in Boulder. In October 2021, the Ha filter at GONG/ML failed and was replaced by the MLSO site personnel. In early 2021, GONG at Cerro Tololo (CT) showed a significant increase in the number of magnetograms with instrumental artefacts. By November 2021, the number of such magnetograms was approaching a critical level, and at the end of November 2021, the NSO team was dispatched to CTIO for preventive maintenance. While this PM trip was cut short by an unexpected seven-day quarantine, the team was able to complete all the necessary repairs to address the issue with this instrument. Overall, the frequency of failures at different GONG sites may be indicative of aging of the GONG facilities. GONG shelter repairs and painting at Udaipur (UD) as well as replacement of the electric grounding network was attempted in early 2021. The work was postponed due to an acute COVID situation in India. The painting and grounding network replacement resumed in mid-December 2021 and were completed in the last week of December 2021.

The relocation of NISP from Tucson to Boulder included the GONG engineering sites. The engineering sites are now being used regularly for supporting remote site operations, new initiatives, and the GONG refurbishment project. During FY 2021, the engineering sites were used for testing the Compact Doppler Magnetograph (CDM), a compact, 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. The engineering sites were also used for observational tests of Camera 1 developed as part of GONG refurbishment (see below). Tests were also conducted in the framework of concept development of tunable Hα filter and zero-point monitoring approach.

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. Initially (e.g., APRPP 2016), GONG refurbishment included the following tasks: (1) camera replacements; (2) improving the polarization modulators; (3) tunable Hα filters; (4) Data Center upgrades; (5) refreshing the Hα workstations; and (6) additional improvements such as weather stations, replacement of aging optics, increasing network bandwidth, resupplying spare components. In CY 2016, improvements to the shelter cooling systems were also included among the refurbishment tasks but not mentioned in the APRPP 2016 document. The APRPP 2017 added magnetic zero-point improvements to the original list as an already completed item (improvements were achieved by excluding the initial integration frames following modulator transition). The following year, APRPP 2018 indicated that the original design for the pressure-tunable Hα filter was no longer a valuable option due to loss of interest from the vendor, and thus new approaches have been investigated. APRPP 2018 added a new item—hardware enhancements to allow remote characterization of residual magnetic bias. Between 2015 and 2018, several other items were added to the GONG refurbishment list including shelter cooling system improvements and UPS and GPS replacements. Thus, over the years, "GONG refurbishment" has seen a scope revision, without a realistic budget and timeline allocation. Unexpected pull-out of a sole-supply vendor for the pressure-tunable Hα filter (in 2017) forced the program to abandon its previous design and start investigating new design options. This had a negative impact on the overall project budget, which now requires re-visiting the scope of "GONG refurbishment". The scope of this project is now defined as the following: (1) replacing cameras; (2) improving polarization modulators; (3) upgrading Data Center hardware; (4) refreshing all GONG workstations, (5) making improvements to GONG shelter cooling systems; and (6) other improvements such as weather stations, and resupplying spare components at each GONG site. The progress on these tasks is discussed below. Two tasks: Hα tunable filter and hardware enhancements to allow remote characterization of residual magnetic bias have been re-scoped as explained later.

In FY 2021, progress was made on the following GONG refurbishment tasks:

1. <u>Replacement of 1K × 1K cameras (in progress)</u>. Twelve Emergent HB-1800-S were purchased. Based on the tests, which showed the antireflective (AR) coating on camera's protective windows reduces the amplitude of fringe pattern from 30% to about 5%, the protective windows in all camaras were replaced by windows with the AR coating. The cameras went through the acceptence testing in the optical lab (windows in two cameras failed, and later were replaced by the vendor). One camera was deployed to GONG/TC engineering station, and regular (engineering quality) data were taken for about one full month. The data were used to verify the scince quality of all data products, and to test the modifications to the pipeline codes, which were required for the new cameras. No issues were identified, which confirmed that the selected cameras meet requirements. The replacement of cameras also incudes the modifications of camera mounts, and the development of a new Data Aqusion System (DAS). These modifications went through the final technical reviews, and the contracts were placed for their manufactoring. All components required for the new camera mounts have been delivered, and the NISP engineering team is in the process of assembling these new mounts. DAS electronic boards will also be assembled "in house", and the electronic components have been ordered. The plan for FY 2022 is to assemble the camera mounts and DAS, mate them with individual cameras, and test each assembly as a complete system at GONG/TC. It is anticipated that the development and testing of new camera assemblies will be completed in FY 2022. The deployment of new cameras will be done during FY 2023, in part due to COVID and continuing restrictions on intetrnational travel. After the cameras are deployed and the post-deployment testing of network data products is performed, Task 1 would be completed in FY 2023.

2. <u>Improved polarization modulators (completed).</u> Replacement modulators were respectively deployed at five sites prior to FY 2020. The remaining modulator at the GONG Cerro Tololo site was replaced in December 2021.

3. <u>Data Center upgrades (completed).</u> Replacement data processing servers were acquired

and are now in use.

4. Refreshed workstations (in progress). Consolidated replacements for aging work-stations that currently handle Hα and 676.7 nm observations separately have been acquired, configured, and tested. New workstations have been delpoyed to GONG/ML, GONG/BB, and GONG/TD. Workstations were shipped to CTIO, but not installed due to a shortened PM trip duration (unforeseen quaranteen). For the remaining three GONG stations, the deployment will be completed during FY 2023. This delay is in large part due to current COVID restrictions on travel to India (GONG/UD) and Australia (GONG/LE).

5. Shelter cooling system upgrades (in progress). Replacing slide-in A/C units with split A/C units was completed at three GONG stations (UD, TE, LE). The remaining three stations (ML, BB, and CT) will be completed in FY 2022-23.

6. Additional improvements (completed). After shipping restrictions due to COVID were lifted, the replacement site-maintenance kits and restocked spare components have been shipped to all GONG sites.

Two tasks have been re-scoped.

7. Tunable Hα filters. This task has been re-scoped as development of a conceptual design only. *Historical background:* Initial work on developing Hα filters pursued a concept based on pressure-tunable filters. A source for these filters was identified, and a test unit was being prepared by the vendor (see NSO APRPP 2016-2017). The work was delayed due to temporary unavailability (as was indicated by the vendor) related to the 2017 total solar eclipse (NSO APRPP 2017-2018). After the eclipse, however, the vendor withdrew its interest in supplying low-cost pressure-tunable etalons (NSO APRPP 2018-2019). As an alternative solution, tuning the existing Hα mica etalons by tilting was explored and was found to be sufficient (NSO APRPP 2019-2020). In late CY 2021, a set of measurements was taken at GONG/TC to evaluate the sensitivity and the level of detection of Doppler velocities using this approach. The evaluation will continue in FY 2022. Upon completion of a conceptual design, NISP will identify a realistic cost and the options for manufacturing and deploying the Hα tunable filters to all GONG sites.
8. Magnetic zero-point improvements (or "remote characterization of residual magnetic bias" as listed earlier). This task has also been re-scoped as development of a conceptual design only. *Historical background:* Initially, magnetic zero-point improvements included improvements to the polarization modulators only (see Task 1). Later, this task was expanded to include hardware enhancements to allow remote characterization of residual magnetic bias (NSO APRPP 2018-2019). This addition was made without changing the funding profile for GONG refurbishment, and during FY 2021 it became clear that the remaining funding for the GONG refurbishment project was insufficient for manufactoring and deploying the devices to all six GONG sites. In CY 2021, the limited set of measurements with a half-wave retarder was taken at GONG/TC. Additional test data were taken at GONG/CT during the PM trip to that site. These data are now analyzed to evaluate the effectiveness of this approach and to develop a procedure for its application. Figure 4-4 shows an example of the application of this approach to a

single GONG magnetogram. These tests indicate that the approach could be used to further improve the zero-point correction for existing GONG magnetograms. Additional tests will be conducted during FY 2022 to investigate the stability of pattern, required cadence of auxiliary measurements, and their possible effect on other GONG observables. Upon completion of the conceptual design, NISP will explore options for funding the development and implementation of this GONG upgrade to all sites.

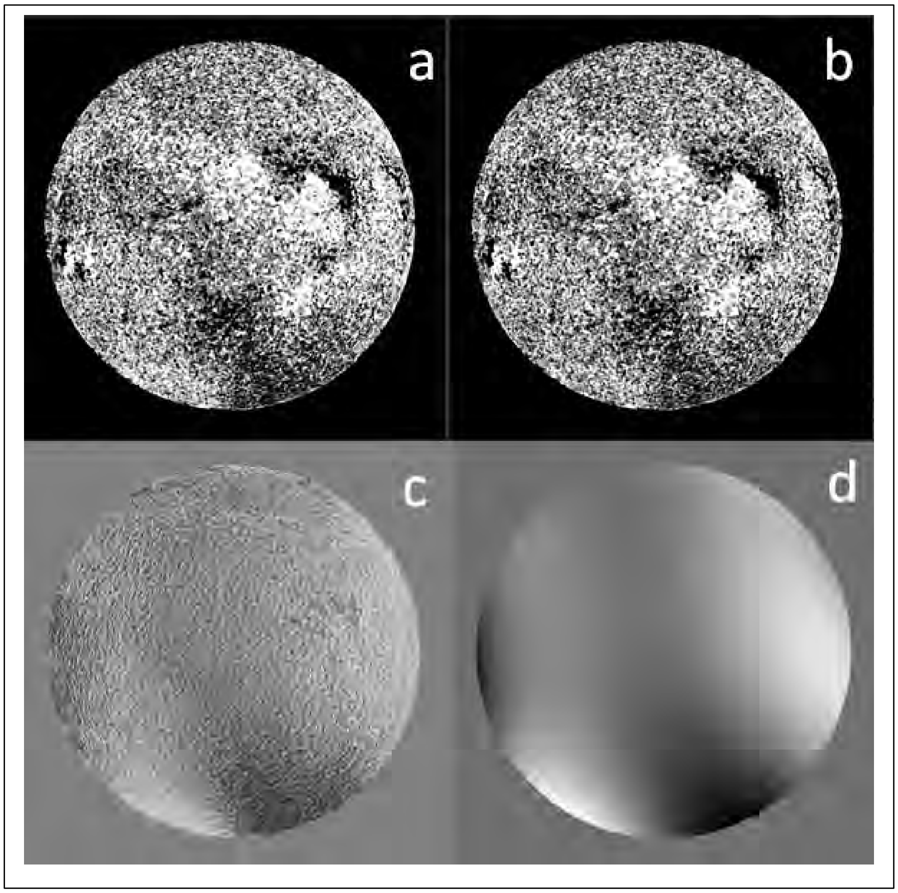


Figure 4-4. *GONG full disk magnetogram before (a) and after (b) correction for zero-point variations. Panel (c) shows zero-point offset derived by subtracting measurements with and without a half-wave retarder. Panel (d) is a polynomial fitting of panel (c) by fits fifteen Zernike polynomials. Panel (b) corresponds to panel (a) minus panel (d). Large-scale variations in zero point in panel (d) have amplitude of about 1.3 Gauss. Courtesy of Dr. Brian Harker.*

4.3.1 End-to-End GONG Calibration

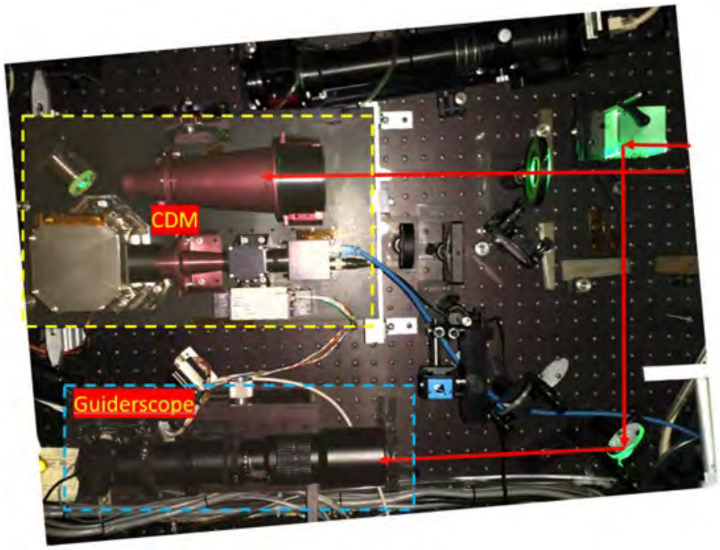
Space weather and operations projects such as the AFRL's Air Force Data Assimilative Photospheric Flux Transport (ADAPT) and Wang-Sheeley-Arge (WSA) models rely heavily on accurate, consistent magnetic field measurements from the solar surface. These projects are hindered by well-known but poorly understood 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. So far, we have a working model of a GONG magnetogram observation and are refining an example of a 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). During FY 2020-2021, 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). In FY 2021, NISP scientist Gordon Petrie applied the simulator to address the 12- and 24-hour variations in HMI magnetic and Doppler measurements. This work continues to completion into FY 2022.

4.3.2 Instrument and Software Development Activities Supported by External Non-NSF Grants

In addition to GONG refurbishment and other instrument/software development activities supported by NSF funding, the team leveraged external (non-NSF) funding for their work on several projects including the Compact Doppler Magnetograph (CDM), a compact instrument employing GONG concept, for measuring magnetic field and Doppler velocities planned as part of proposed NASA SOLARIS (over-the-pole) mission. A proof-of-concept for compact GONG was earlier demonstrated at NSO (Fig. 5.7-1 in APRPP 2018-2019), which was later adapted to the SOLARIS CDM instrument design in the Phase-A study. NSO scientists, Sanjay Gosain and Jack Harvey, provided key inputs to the current CDM design and were partially supported by NSO internal funding and by a contract with SouthWest Research Institute (SwRI). As part of the SOLARIS mission Phase A, for which SwRI activity was funded by NASA, the CDM underwent environmental testing, and NISP provided three multi-week observing periods to verify the instrument performance and produced data for comparison with GONG-network instruments. NISP personnel (Sanjay Gosain, Detrick Branston), funded by a combination of NSO internal funding and by a contract with SwRI, provided key support in these observing campaigns, instrument operation, data calibration and performance comparisons. These test observations were conducted at GONG/TC, one of two engineering sites in Boulder, Colorado. Figure 4-5 shows a top-view of the CDM on the optical table inside GONG/TC and an example of line-of-sight magnetograms taken on 17 November 2020. NSO participation in the SOLARIS proposal includes Drs. S. Gosain (Instrument Scientist for CDM), J. Harvey (Consultant), R. Komm (Science Co-I), and G. Petrie (Science Co-I).

Another instrument development project, the simplest magnetograph, is funded by a NASA grant. The instrument exploits the idea of creating full-disk magnetograms using the broadband polarization measurements. Application of this method to SOLIS



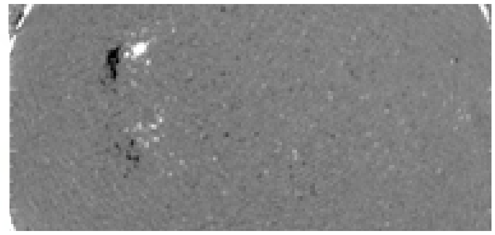


Figure 4-5. (left) Top view of the CDM on the optical table in GONG/TC and (right) a longitudinal magnetogram taken with the CDM on 17 Nov. 2020. The CDM footprint is shown by the yellow dashed line (approximately, 45 by 30 cm). Red lines show the light tracing to the instrument and the telescope guider. Courtesy of Dr. S. Gosain.

neric

line Fe I 6302.5 A uncovered the presence of a crosstalk between Stokes I and V. As a temporary solution, Dr. B. Harker developed a simplified correction, which after applying it, produced the full disk magnetogram as shown in Figure 4-6. Comparison with a regular photospheric VSM magnetogram confirms the validity of this method. Disagreements between the two magnetograms shown in Figure 4-6 are likely due to residual Stokes I and V crosstalk. This project is led by Dr. Luca Bertello and two instrument engineers, Mr. Austin Monaghan and Mr. Alexander Pevtsov.

Finally, in collaboration with the solar group at Kanzelhöhe Solar Observatory, Austria, a project was started on implementing machine-learning techniques for identification of solar flares using GONG Hα images. This project is conducted with limited funding via the SOLARNET project.

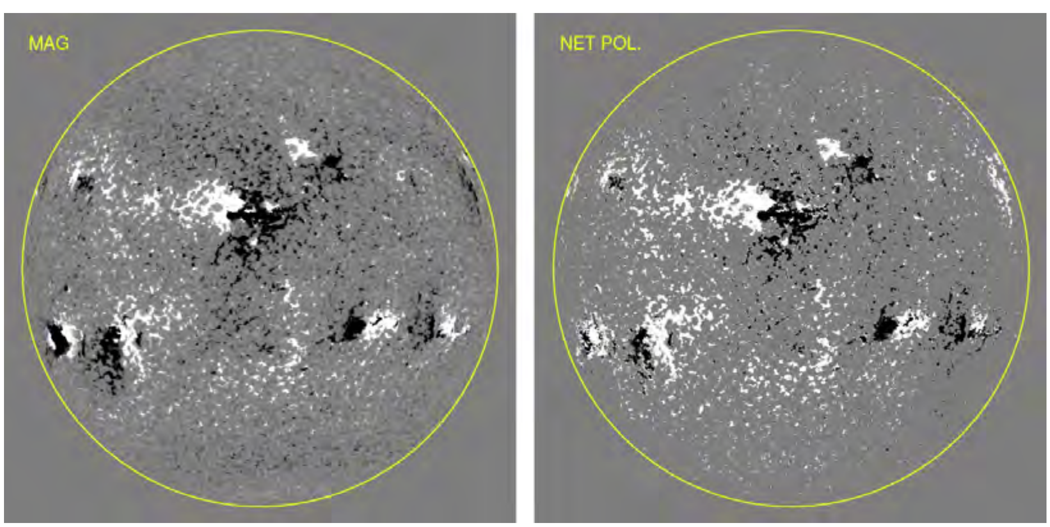


Figure 4-6. (left) Longitudinal magnetogram from VSM/SOLIS taken on 4/13/2013 at 14:31 UT, and (right) magnetogram derived from the broadband polarization averaged over 2A wavelength range after approximate correction for Stokes I-V crosstalk. Courtesy of Dr. L. Bertello.

NSO/NISP is a partner in this project funded by the European Union. Machine-learning codes are developed by Dr. Robert Jarolim (University of Graz, Austria) and his colleagues from Kanzelhöhe Solar Observatory. The codes are adopted by Mr. Alexander Pevtsov, under the supervision of Dr. Luca Bertello, to run on multi-core GPU desktop and full-disk Hα images from the GONG network. Initial test runs included 1000 epochs, with each epoch consisting of 500 training periods selected from one (2017) year of observations from a single GONG site (BBSO) at 15-minute cadence. The execution time for a training run on a high-end GPU desktop is about 2.5 days. The follow up tests demonstrated a significant improvement in identification of flares when using 5-minute cadence and 2000 training periods in each epoch. Figure 4-7 shows an example of successful flare identification by this machine-learning algorithm in one of the GONG Hα images. These initial tests indicated that while flares could be identified using 15-minute cadence, a much faster cadence is more desirable. The algorithm exhibits some predictive capabilities as it can identify flares in GONG Hα images about 30-40 minutes before flare onset. The tests will continue using higher (1-minute) cadence and the observations from other GONG sites.

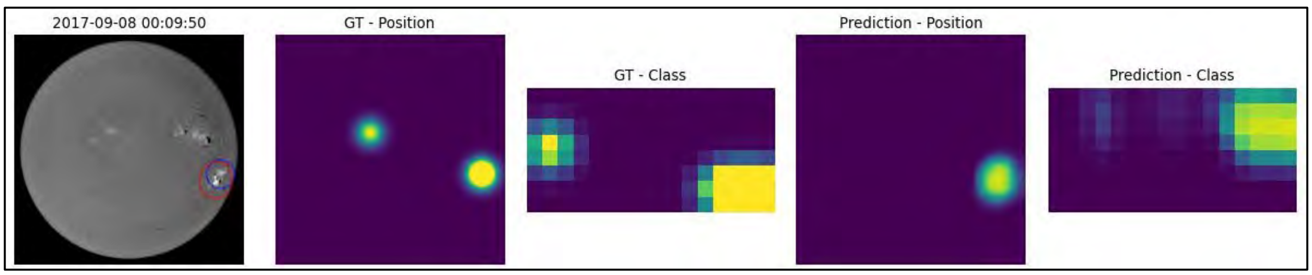


Figure 4-7. *Hα image with solar flare (blue contour) and its identification using neural networks (red contour). Panels to the right show "ground truth" flare positions and flare class. Two panels on the far right show predicted positions and flare class. Courtesy of Mr. Alexander Pevtsov.*

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.

When the FDP started its operations in June 2011, it operated with a temporary tunable Hα 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.

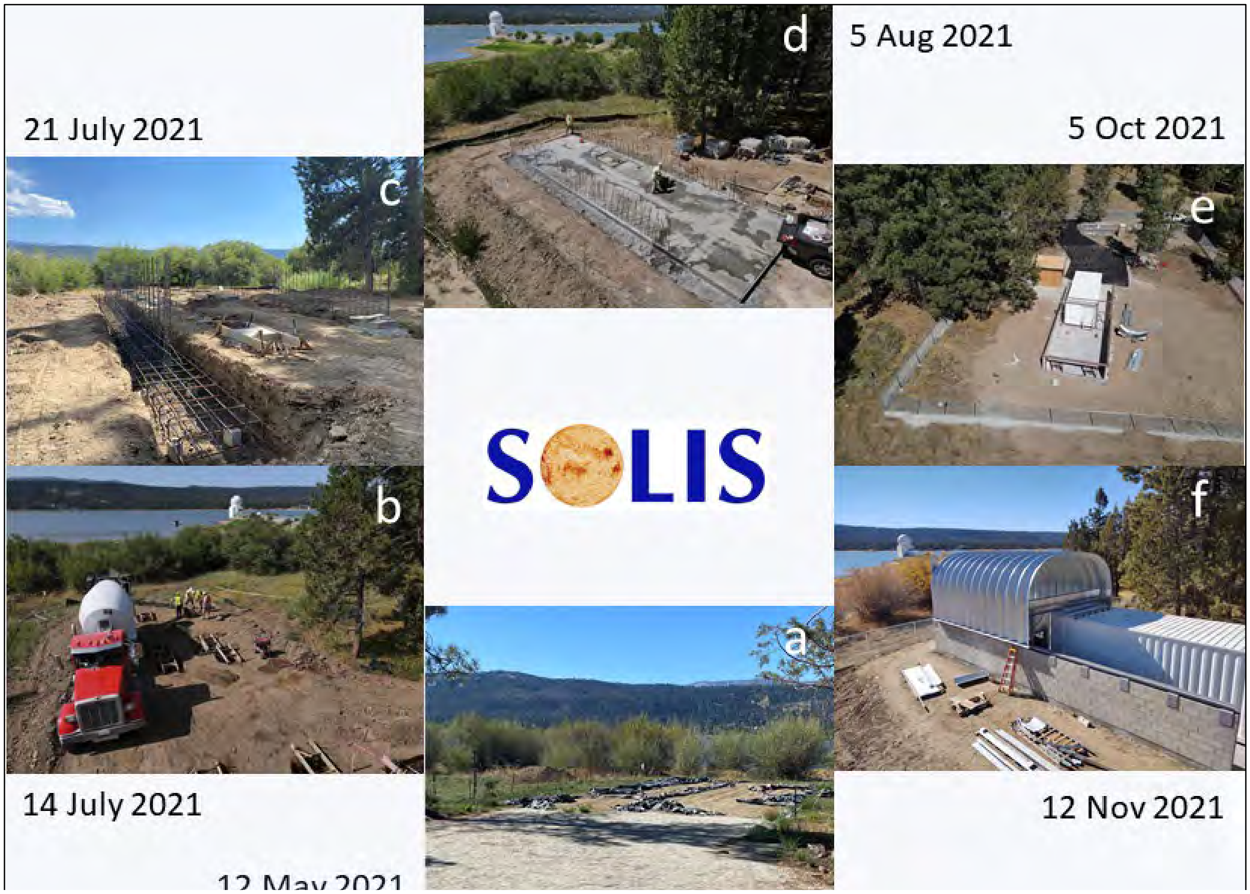


Figure 4-8. *Progress on SOLIS construction: (a) pre-construction site on 12 May 2021; (b) 14 July 2021, installation of concrete footing for the SOLIS telescope mount and ISS shelter; (c) 21 July 2021, construction of the foundation for the walls; (d) 5 Aug. 2021, completion of the main concrete pad; (e) 5 Oct. 2021, aerial view of the SOLIS construction site with ISS shelter installed; (f) 12 Nov. 2021, canopy installation. Photos are courtesy of S. Shumko (BBSL/NJIT) and G. Card.*

The relocation of SOLIS to the Big Bear Solar Observatory, which started in October 2017, 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. At that time, the SOLIS/VSM was made operational under an ambient-controlled tent after almost two years of no activity. Construction activities started in November 2019 with clearing the site of vegetation and foundation excavation (see, (NSO APRPP 2020-2021). 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 2020, 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. Due to significant cost increase, restarting the construction required NSF approval, which was received in early 2021. There were additional delays at the beginning of construction caused by the COVID pandemic and other contracting issues (e.g., delays in getting the permit extensions, availability of qualified subcontractors on the construction schedule, re-negotiation of final contract and applicability of US Government prevailing wages). Finally, the construction resumed in mid-May 2021. Most of the construction work was completed in CY 2021. Figure 4-8 shows a graphical summary of major milestones in SOLIS construction. In December 2021, the SOLIS main mount was installed inside the new SOLIS building. In January 2022, the Bear Valley Electric Company connected the SOLIS site to the electric grid, and NISP now works on submitting paperwork for the building occupancy permit, which is required for starting any activities in the new SOLIS facilities. Initial work on the VSM, which was conducted during the site visit by the NISP engineering group in October 2021 indicated that, in general, the instrument is in a good health. Due to cold weather, further work on SOLIS instruments is postponed until spring 2022. The current plans are to have the VSM operational and ready for first light on the SOLIS mount by October 2022.

4.5 NISP Data Center

Between SOLIS and GONG, NISP would acquire (depending on the observing cadence of the SOLIS/FDP) approximately 370-470K of full-disk observations in an average month. That corresponds to 900-990 K 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.

In addition to the direct observations, 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.

Figure 4-9. *(left) The 1.5PB primary data storage cluster, (middle) the tape robots and auxiliary data storage, and (right) a software engineer at the console in the pipeline processing rack. Courtesy of N. Oien.*

The migration of GONG's near real-time space weather data processing to NOAA/SWPC received significant emphasis during FY2021. Despite delays caused by the COVID-19 pandemic, in May 2021, NSO/NISP successfully transitioned the processing of observations of the Sun's magnetic field and lower atmosphere to the operational control of National Oceanic and Atmospheric Administration's, or NOAA's, Space Weather Prediction Center (SWPC), a move that will ensure reliable delivery of the data to the NOAA's space weather forecasters who are the nation's official civilian source for space weather watches, warnings, alerts, and forecasts.[9] The near real-time products are now automatically uploaded directly to NOAA/SWPC, and after the processing, the data products are disseminated to various agencies, including the US Air Force 557th Weather Wing, AFRL, the United Kingdom Meteorological Bureau, and Japan's Space Weather Forecast Center for space weather prediction applications. The data processed at SWPC are also transferred to NSO/NISP for dissemination to US and international researchers. Only quick-look pipelines were transferred to SWPC/NOAA. All helioseismology data continue to be processed by the NISP Data Center.

The zero-point pipeline has been made more accessible to maintenance efforts with a development environment, and portions 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

[9] *https://www.swpc.noaa.gov/news/gong-space-weather-data-processing-transitioned-swpc*

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.

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 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 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. So far, the DOIs were assigned to the following datasets: SOLIS VSM 8542L full-disk images (DOI: *10.25668/gq34-gx96*), GONG network full disk H-alpha images of the Sun (DOI: *10.25668/as28-7p13*), SOLIS/Integrated Sunlight Spectrometer (DOI: *10.25668/61pj-wh14*), the sunspot drawing collection of the National Solar Observatory at Sacramento Peak (1947–2004), DOI: *10.25668/9x5p-6d86*, and Dataset of Sunspot field strengths and polarities 1917-2015 (DOI: *10.25668/bkt9-4d24*).

The annual volume of HTTPS data distributed via the four primary NISP data service endpoints (NISP Data, GONG, GONG2, and SOLIS) is as follows: 50.61 GB (only a fraction of 2017), 191.44 GB (2018), 674.2 GB (2019), 1941 GB (2020), and 1007 GB (2021). Data volume for 2017 through 2019 does not include data served via FTP.

The holdings of the NISP Data Center are hosted on a storage system that, after the addition of two additional storage nodes in FY 2021, currently has about 1500 TB of on-line storage. These data are currently accessible via custom-tailored Web-based search interfaces to relational databases, FTP and Web browsing. To further improve the accessibility of NISP data, NSO participates in the development of the Virtual Solar Observatory. 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 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 several 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 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 25 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. NISP/NSO is a partner in an EU-funded project, SPRING, which includes concept development of a ground-based network of solar observing stations. In 2021, the NSO and the High-Altitude Observatory (HAO) submitted a joint proposal to the NSF to design the next generation ground-based network (ngGONG), which will replace GONG and SOLIS facilities. The research-driven scientific objectives of ngGONG are common to SPRING. This new network will enable new research opportunities that build on decades-long NSO observations of the global Sun and its magnetic environment.

ngGONG builds on existing operational networks: GONG, single-site observatories such as the HAO-operated Mauna Loa coronagraph; and the NSF's SOLIS instrument suite. While all these existing 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 instrument 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 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.[10] 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 the emission-line coronagraph. This approach has been adequately demonstrated to succeed with existing solar networks, both research and operational.

Once operational, ngGONG will (see Figure 4-10, graphical summary of ngGONG science objectives):

- 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.
- Enable discoveries by providing data to future generations of scientists.

The science case for a new synoptic network was described in a white paper submitted to the ASTRO2020 Decadal survey.[11] A white paper will also be submitted to the Solar and Space Physics (Heliophysics) Decadal Survey.

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

[10] *https://www.congress.gov/bill/116th-congress/senate-bill/881*
[11] *https://arxiv.org/ftp/arxiv/papers/1903/1903.06944.pdf*

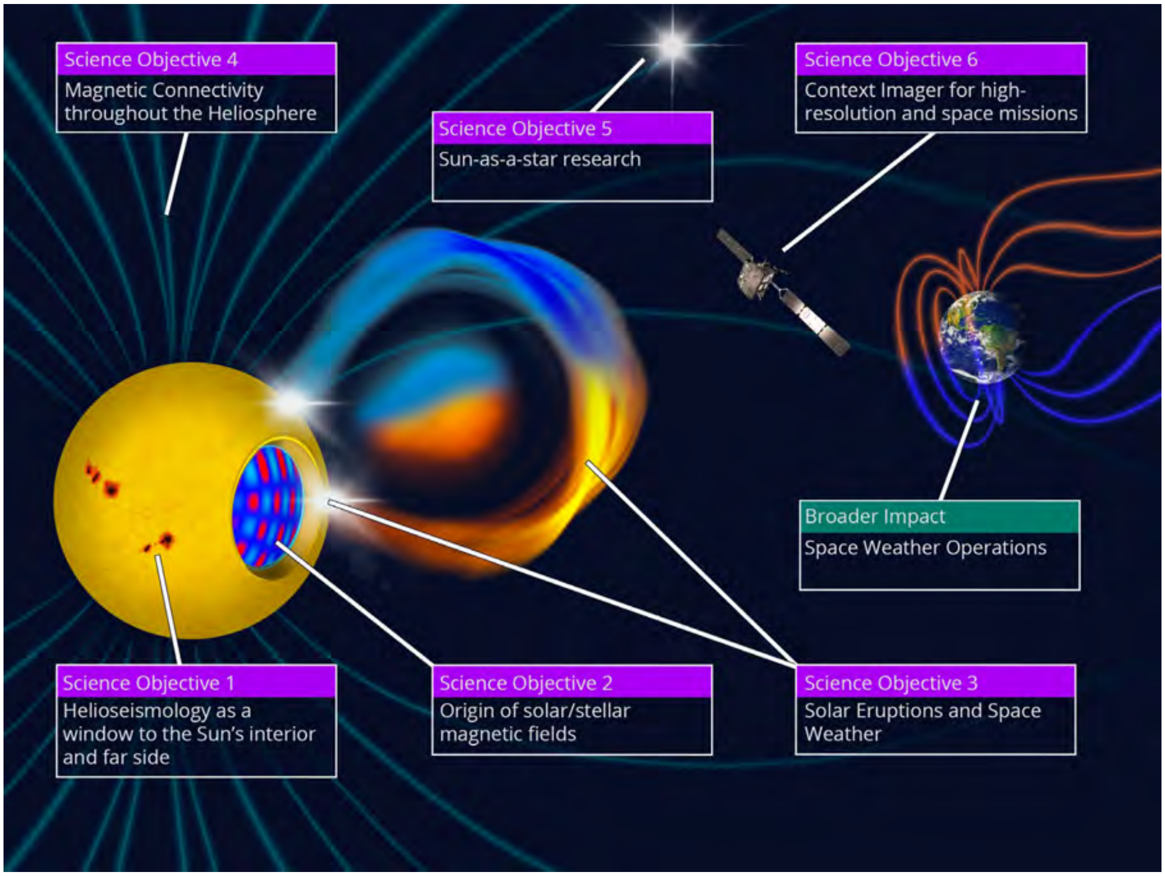


Figure 4-10. *Graphic summary of high-level science objectives. Courtesy of C. Raftery.*

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 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 Sun. The power of far-side imaging, first developed by NSO scientists (Lindsey and Braun, 2000), was demonstrated by NSO, predicting the emergence of a large active region about ten days before it rotated to the Earth-side view.[12] 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 sub-photospheric 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.

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.

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.

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

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, the 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.

Unfortunately, our proposal submitted in FY 2021 to NSF's Mid-Scale Research Infrastructure I program was not selected for funding. The NISP team, however, continues to work with our domestic and international partners to refine the scientific and operation space weather forecast requirements, and to identify the funding opportunities for this project. This work will continue in FY 2022.

While in FY 2021 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. The plans to hire additional engineering and Data Center personnel are put on hold, awaiting approval of the FY 2022 budget by the US Congress.

5 NSO COMMUNITY SCIENCE PROGRAM (NCSP) THIS SECTION WAS NOT UPDATED FOR THE FY2022-FY2023 APRPP

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 combines 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 includes 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 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. In addition, we will 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 line 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
5. 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) with their feasibility ascertained with forward modelled spetra obtained from realistic coronal MHD simulations.

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 are being 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. An additional rack housing and addition 36 nodes with 36 CPUs each was installed in early 2020.

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 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.

NCSP has hired Program Scientist Donald Schmidt for the Level-2 program to aid in the testing, installation and oversight of the four inversion pipelines described in Section 5.1.1, and to work with

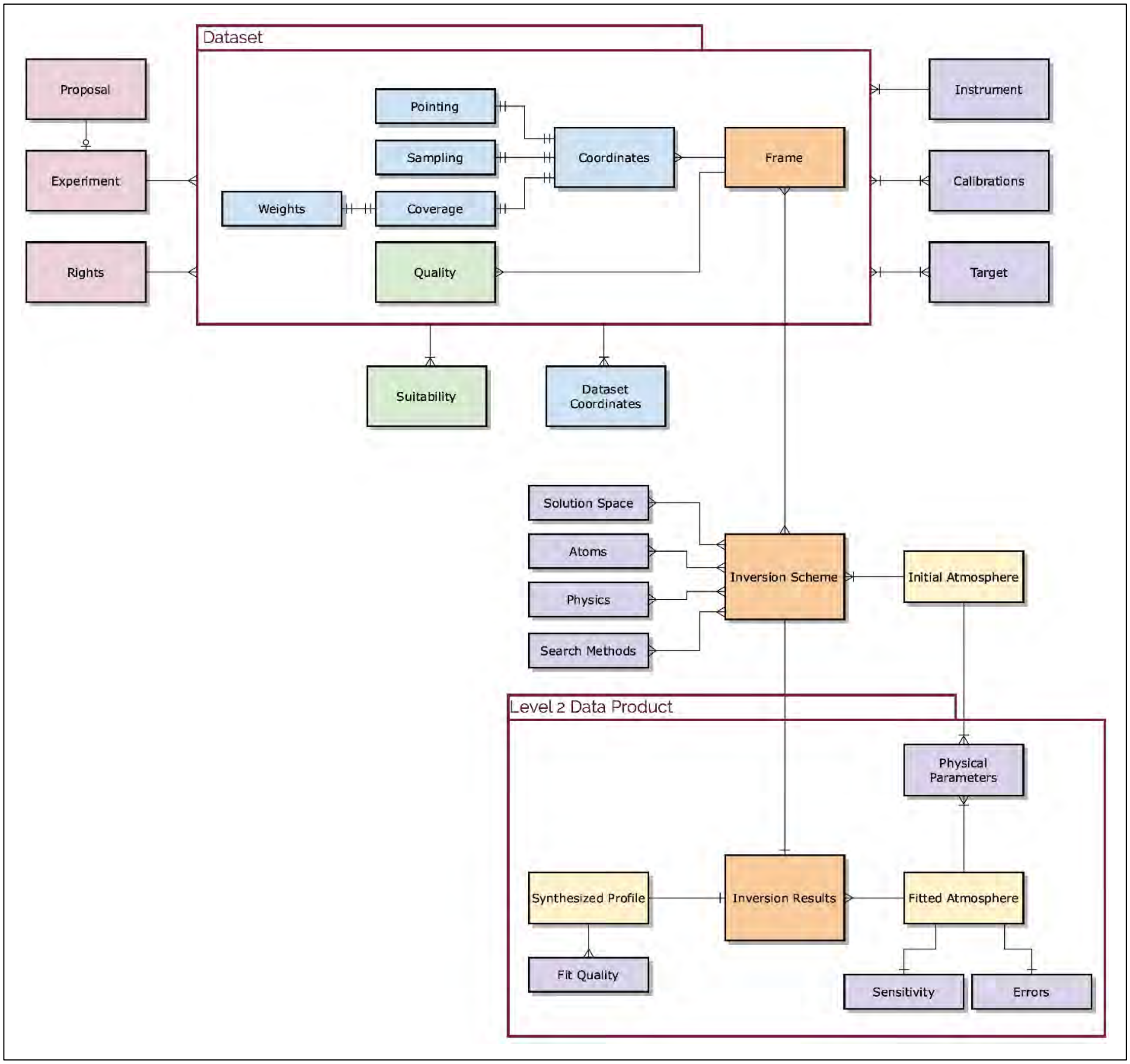


Figure 5-2. *Example of the data flow from DKIST proposal to Level-2 data, including meta-data, as outlined in the requirement document SPEC_0230.*

Steve Berukoff (hired 50-50% with the DKIST Data Center) on implementation of the pre- and post-processing of the pipelines and integration of ingestion of appropriate Level-1 data sets for inversion and integration of the Level-2 inversion results back into the DKIST Data Center, so that they can be retrieved by the community and found in data searches together with the Level-1 data from which they originated.

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 working with 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 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 has identified 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 provides 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
Aparna V.	Georgia State University	Piet Martens
Eleni Nikou	George Mason University	Jie Zhang
Suman Dhakal	George Mason University	Jie Zhang
Shuo Wang	New Mexico State University	James McAteer
Wen He	University of Alabama Huntsville	Qiang Hu
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
Bryan Yamashiro	University of Hawaiʻi	Xudong Sun
Yingjie Zhu	University of Michigan	Enrico Landi

The recipients of the matching-fund subcontracts are 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. Eleven of the twelve originally selected students/postdocs to become Ambassadors, together with their home institutions and supervisors, are listed in Table 5-1, as one has since dropped out of the program at their home institution. All DKIST Ambassadors are always 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 four 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 original 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 reorganized the workshop to be completely virtual including hands-on exercises employing Python Notebooks (*https://nso.edu/blog/virtual-dkist-data-workshop/).* Interest in the workshop was so high that participation had to be split between two sessions, July 20–24 and August 3–5, 2020, with 59 parti-cipants in total, including all twelve DKIST Ambassadors. A fourth Data Training workshop on Chromo-spheric Diagnostics, was organized from July 19–23 2021, again virtually. This workshop was again very well attended with 80 partici-pants, divided equally between the US and the rest of the world, including 35 US students and early career scientists, and 10 Ambassadors. Similar to the third workshop, about half of the time was devoted to hands-on exercises utilizing interactive Python Notebooks. A snapshot of on-line attendants of the fourth workshop is shown in Figure 5-3.

A fifth DKIST Data-Training Workshop was planned for January 31 – February 4, 2022, again virtually, with the topic "Planning for DKIST: He I Diagnostics in the Solar Atmosphere".

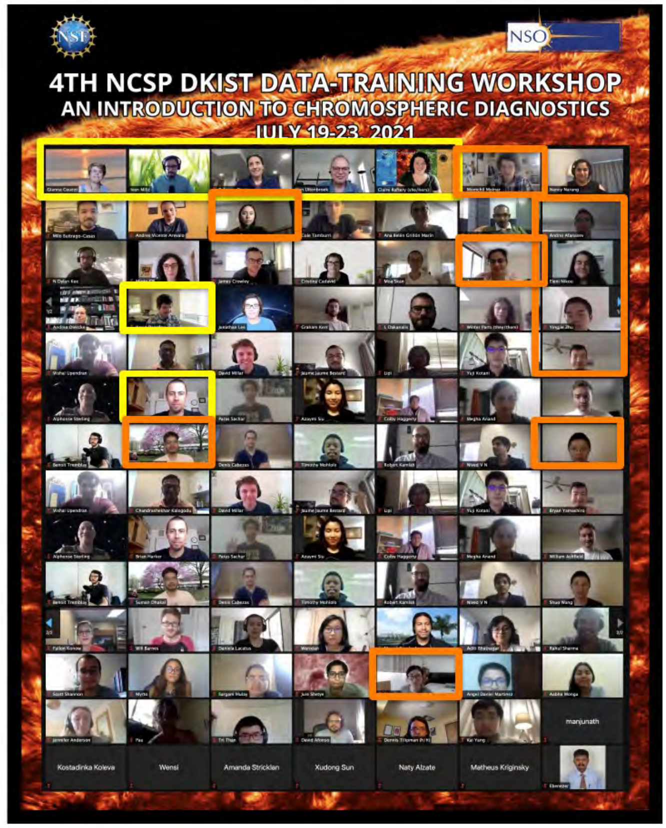


Figure 5-3. *Screenshot of participants in the fourth (virtual) DKIST Data-Training Workshop***.**

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). Two recent papers (Arevalo, Asensio Ramos & Esteban Pozuelo 2021 and Chappell & Pereira 2021) have shown that forward modeling of Non-LTE radiative transfer with Neural Networks is possible, in principle.

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 must 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) THIS SECTION WAS NOT UPDATED FOR THE FY2022-FY2023 APRPP

6.1 New Employees for EPO

In November 2021, NSO recruited a Communications Specialist to join the Education and Outreach team. The Communications Specialist will be responsible for developing and implementing the media engagement strategy for NSO and projects therein as directed by the NSO's Head of Education, Outreach and Communications. This position will include writing media releases that will be disseminated through the print and broadcast media, and also working with new-media strategies such as online blogging and social media. It will also include internally-focused communications efforts in support of the NSO Director and the Directorate as needed. The Communications Specialist will be responsible for sourcing stories from within NSO and the NSO user community, with the support of the education and outreach team.

6.2 Communications

6.2.1 Press Engagement

FY 2021 included preparations for the Inouye Solar Telescope end of construction/beginning of operations announcements. After consulta-tion with AURA and NSF, it was decided to make the announcement as a press release, developed by NSO in collaboration with AURA and NSF, with possibly a follow-on press briefing, which would be led by NSF. The press release includes a quote from the NSF Director, Dr. Sethuraman Panchanathan, and will include a quote from the PI (or team member) of the experiment that will be run first at the telescope. Early development of materials began in FY 2021, though at the time of this report, the first science has not yet been conducted.

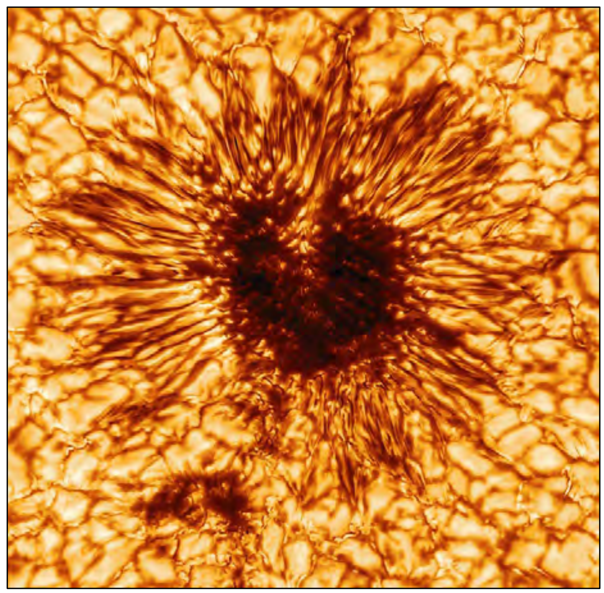


Figure 6-1. *The first sunspot image taken by the Inouye Solar Telescope (2020).*

During FY 2021, NSO published 16 blog posts and seven press releases. Interactions of each are listed below, as of January 2022. As the page views indicate, the release of the Inouye Solar Telescope First Image was the most popular event of the year, followed by the prediction of a far side sunspot by the NISP GONG team. Notably, the first sunspot image taken by the Inouye Solar Telescope was also featured in the *2020 Astronomy Decadal Survey*.

Press Releases			
Date	**Post Title**	**Project**	**Page Views**
12/03/20	*Inouye Solar Telescope Releases First Image of a Sunspot*	DKIST	17,176

11/23/20	*NSF's National Solar Observatory Predicts a Large Sunspot for Thanksgiving*	NISP	2,158

Press Releases

Date	Post Title	Project	Page Views
05/24/21	*Critical solar observations from NSF's GONG network now maintained by NOAA's Space Weather Prediction Center*	NISP	2,097
04/01/21	*NSF donates 21 housing units to White Sands Habitat for Humanity*	General	750
07/22/21	*NSF's National Solar Observatory breaks ground on new telescope site in California*	NISP	454
02/03/21	*NSO's Dr. Thomas Rimmele wins SPIE's Goddard Award in Space and Airborne Optics*	DKIST	279

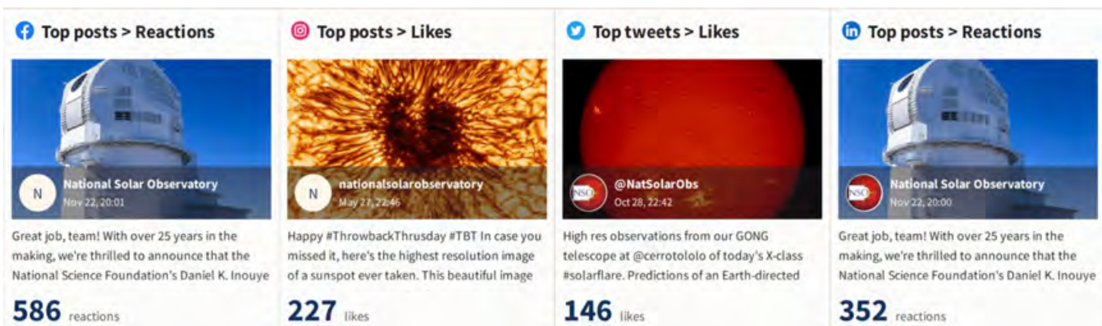
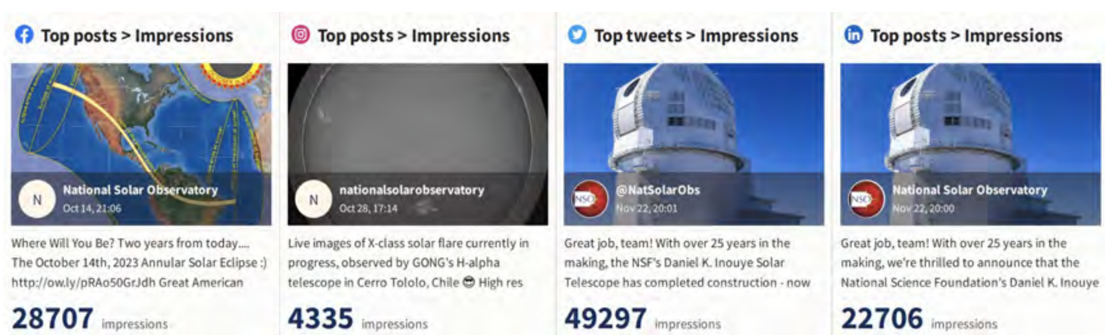
Blog Posts

Date	Post Title	Project	Page Views
11/18/20	*NSF's National Solar Observatory Predicts a Large Sunspot for Thanksgiving*	NISP	*2,158*
03/09/21	*Former director of NSO Dr. Jacques Beckers has passed away*	General	*630*
12/16/20	*Inouye Solar Telescope Ambassador unveils how tiny, cool magnetic loops make the Sun's atmosphere so hot*	DKIST	*572*
11/09/20	*How the NSO predicted a new sunspot group before it rotated into view*	NISP	*507*
09/08/21	*Inouye Telescope project passes final construction review*	DKIST	*477*
04/27/21	*Inouye Solar Telescope's Critical Science Plan released*	DKIST	*407*
06/22/21	*Exploring the Sources of the Solar Wind with Parker Solar Probe and NSO/GONG*	NISP	342
04/23/21	*Humongous flare from Sun's nearest neighbor breaks records*	General	322
02/10/21	*Inouye Solar Telescope Data Handling System performs first end-to-end data transfer*	DKIST	270
10/30/20	*Community Response to the DKIST Cycle 1 Call for Proposals*	DKIST	220
08/27/21	*NSF's GONG Observations of Long-period Oscillations of the Sun*	NISP	189
10/22/20	*"Becoming a Super Solar Scientist!" – NSO WISER Live Stream for Planets Foundation's AstroFest*	Outreach	167
07/13/21	*My Experience as an Undergraduate Researcher Preparing Calibrations for DKIST Observations*	Outreach	153

03/04/21	*[NSF's GONG program aids NASA's Parker Solar Probe during its latest close encounter with the Sun]*	NISP	141

6.2.2 Social Media

NSO manages social media through the four major platforms: Facebook, Instagram, Twitter, and LinkedIn. Social media channels support NSO's communication goals by disseminating news, updates, and engaging directly to its target audiences. Awareness and engagement are key metrics and focus of NSO's social media activity.

<table>
<tr><th colspan="5">Social Media Metrics</th></tr>
<tr><td></td><td>Facebook</td><td>Instagram</td><td>Twitter</td><td>LinkedIn</td></tr>
<tr><td>Followers</td><td>9.5K</td><td>2.5K</td><td>5K</td><td>1.3K</td></tr>
<tr><td colspan="5">
</td></tr>
<tr><td>Post Impressions</td><td>212K</td><td>39K</td><td>202K</td><td>59K</td></tr>
<tr><td colspan="5">
</td></tr>
<tr><td>Post Engagement Rate</td><td>5.68%</td><td>9.73%</td><td>2.4%</td><td>6.73%</td></tr>
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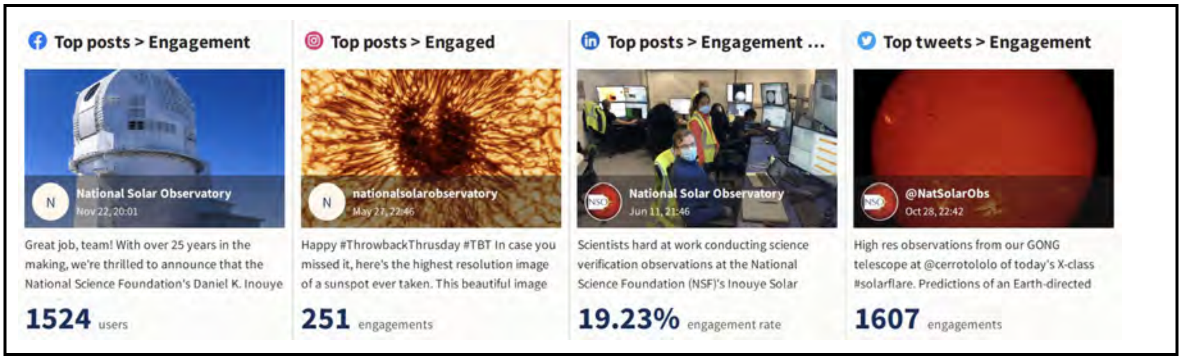


6.2.3 FY 2022 Plans for Communications

Anticipation of the Inouye Solar Telescope's construction completion continues to be eagerly anticipated, and it is expected that stories relating to Telescope progress will continue to be high performing, both in social media and in traditional media. Social media will play a cornerstone role in carrying the momentum of the observatory's completion through 2022 by focusing on its first year of operation commission phase, featuring the research, people, behind-the-scenes updates, and potential findings of the solar observations taken. Images of the Sun's surface captured by the Inouye Solar Telescope performed well in 2021—similar success is expected in 2022 as the observatory begins to conduct its first scientific observations.

The Inouye Solar Telescope's first science experiments will also be conducted in FY 2022 and are expected to draw significant attention, both on social and in the traditional media. The continued planning and development for ngGONG will also provide new direction for the communications efforts at NSO, redirecting messaging to be aligned with space weather efforts in order to drive support for ngGONG development. A targeted undertaking is the redevelopment of the NISP portion of the NSO website, as preparations for ngGONG continue.

Additional efforts with the NSO website will continue to position the NSO as an authority on the Sun across the web, in addition to developing engaging and interactive online visualizations that will enhance public understanding of solar science.

6.3 K–12 Formal Education

6.3.1 Virtual Journey through the Universe

2021 Journey through the Universe, an educational program of NSF's NOIRLab, was held online for the first time due to risks associated with the COVID-19 global pandemic. Despite the additional challenges, the program enabled astronomy educators to virtually visit almost 6000 students in Hilo-Waiākea, Honokaʻa, Waimea, Maui and Lānaʻi area schools. In order to share the wonders of the universe and the possibilities of a career in solar science and technology in Hawaiʻi, NSO staff members provided solar astronomy-focused presentations geared towards specific grade levels. Contributers included a solar astronomer, an engineer, and a science educator.

6.3.2 NSO's Google Classroom

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 and activity plans, videos, science education resources and more. Our classrooms currently have the following numbers of students: K12 STEM Online Resources: 75 Students; NSO Youth Classroom: 20 Students.

The following are new content developed for 2021:

- Fun Sun Science Educational Activity Brochure — The activities in this brochure help students explore the layers of our Sun. Descriptions and QR codes guide students through activities that cover the photosphere and chromosphere. First, students learn about convection at the surface of the Sun and create a science demo of convection at work. Next, they use an online tool (*helioviewer.org*) to explore the Sun's chromosphere.
- Helioviewer Activity YouTube Video — A video demonstration on how to use the helioviewer.org online tool to create movies of solar flares on our Sun.

6.3.3 FY 2022 Plans for K-12

The ongoing status of the COVID-19 global pandemic has left the nature of public outreach in limbo. Many teachers are expected to teach both in-person and asynchronous at the same time, making additional engagement in voluntary astronomy outreach programs overwhelming. Students in turn, are increasingly fatigued by excessive amounts of screen time and use of Zoom, and other platforms, while parents are keen for stimulating ways to engage their children. This leaves our team in a predicament of how to engage our audiences effectively and constructively. We will continue to innovate and seek ways to address this, exploring two primary mechanisms for 2022:

- Virtual solar camp: Summer camp environment for Hawaiʻi students to explore the Sun and solar system. Still under consideration, this program would be 1-2 weeks in duration and aimed at Hawaiʻi-based middle and/or high school students (in two separate cohorts). Students would receive activity packs in advance of the camp so they can engage in activities from home. The program would be free (or have very minimal cost, charged only to mitigate attrition).
- Hands-on, asynchronous exploration activities: We are investigating short, engaging activities that children of middle school age can participate in on their own time. When possible, they involve outdoor activity, and explore some of the fundamental aspects of solar science and Inouye Solar Telescope engineering. They will be available for free on our website and shared via social media.

6.4 Higher Education

6.4.1 Undergraduate Research Programs

The 2021 Boulder Solar Alliance Research Experience for Undergraduates (REU) program was held virtually, with students and mentors engaging from home in a similar setup to 2020. This summer, we trialed the participation of NSO mentors from Hawai‘i as part of the program, and it was deemed a success. This will provide an outlet for Hawai‘i-based NSO scientists and engineers to mentor undergraduate students who (in the future) will be participating in an in-person program from Boulder, CO, but with mentors located in Hawai‘i in addition to Boulder. This trial was considered successful as a result of feedback from the students. The biggest challenge for participants was in cohort development. On average, they had a positive time engaging with mentors remotely. This would suggest that students who participate with the rest of the cohort from Boulder will be able to overcome the most significant challenges of a remote project, even if their mentors continue to be remote.

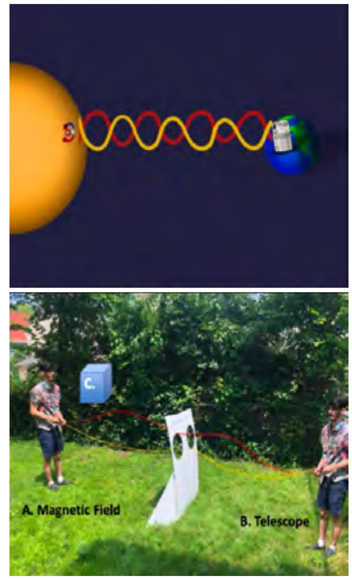


Figure 6-2. The schematic (top) and activity setup (bottom) used to explain spectropolarimetry in a kinesthetic manner to the general public, developed by an EPO REU student. Participants use a predetermined set of codes to communicate characteristics of a shape (box c.) to their counterpart, using different color string to convey different types of information.

In addition, an REU student was mentored by the NSO EPO team for the first time. This student designed and developed a hands-on demonstration to explain the purpose and benefits of spectropolarimetry as they apply to the Inouye Solar Telescope. This effort was successful, and the student presented his activity at the AGU conference in December 2021. This activity will be utilized by the outreach team to explain some of the more complex elements of the Inouye Solar Telescope’s science techniques.

NSO participated in the Akamai Workforce Initiative by mentoring three interns through the DKIST project. The program was recognized in the Astronomy 2020 Decadal Survey, where the programs efforts in supporting Hawai‘i based students in STEM was applauded. Run by the Institute for Scientist and Engineer Educators at UC Santa Cruz, the Akamai program provides internships at research telescopes, including DKIST, to students with a connection to Hawai‘i. The Akamai program is demonstrating the value of investing in STEM students at an undergraduate level are directly translating into future recruits. Three of DKIST’s engineering leaders are female alumni of the Akamai program, and many more will follow suit.

6.4.2 NSO Supervision of CU Boulder Graduate Students and Postdocs

NSO scientists have continued broadening their engagement with students at CU Boulder 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 NSO scientist Dr. 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 Dr. 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 (former 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

<u>Undergraduates (2020 Spring Semester):</u>

- Yudai Katsumata (Advisor: Alin Paraschiv) – Undergraduate Research Opportunities 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 FY 2021 Plans for Higher Education

NSO continues to support the integration of students, both undergraduate and graduate, into work conducted at the observatory. We continue to explore ways to break down barriers under-represented students face in pursuing STEM careers, on both small and large scales. We hosted an information session for REU students interested in applying to the program, but who may have questions, while also developing a post-baccalaureate internship concept for first-generation students who are not sure whether to pursue graduate school.

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 can 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 FY 2020, and with some innovations as a result of student and mentor feedback to improve a FY 2021 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 (HNP)

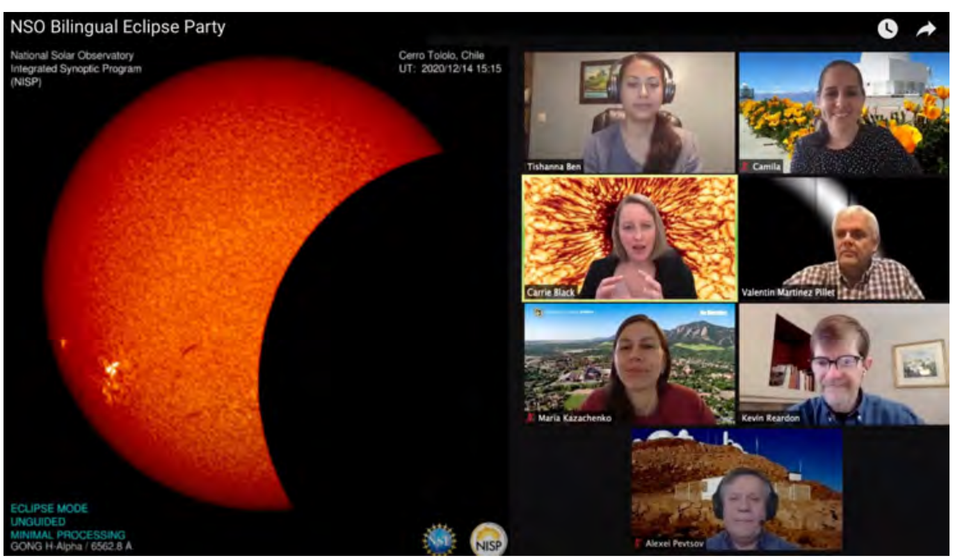
We continued to build a collaboration with Haleakalā National Park interpreters through FY 2021. This included supporting the development of a space weather pop-up activity for their staff to conduct in the park, an informational call with the entire interpretation department, reviewing Haleakalā resource briefs written by HNP Interpretation Team members, and beginning the process of updating the wayside sign at Red Hill. So far, we've provided the National Park with updated text for the sign that has been reviewed by relevant Haleakalā Observatories (HO). The text will appear on an updated picture of the HO site, featuring Inouye Solar Telescope and Pan-STARRS, which weren't yet built when the photo for the current sign was taken.

6.5.2 Public Outreach

With the cancellation of the planned Middle School Eclipse Leaders visit to Chile for the 2020 total solar eclipse, we instead hosted a bilingual "Eclipse Party" via Zoom stream to YouTube. This included livestreaming the eclipse from the GONG Cerro Tololo site, and a panel of experts to answer questions in both English and Spanish. In order to continue our relationship with the La Joya school district in Texas, which had been identified as a partner for the original eclipse trip to Chile, we invited their student to draft questions about the Sun and the eclipse in both English and Spanish (they reside in a Hispanic community in south Texas). We had six experts on the panel:

- Dr. Valentin Martinez Pillet, NSO Director. Spanish/English speaker
- Dr. Carrie Black, NSF Program Officer and solar physicist. English speaker
- Dr. Maria Kazachenko, NSO/CU Boulder researcher. Spanish/English speaker
- Dr. Kevin Reardon, NSO researcher and eclipse expert. English speaker
- Dr. Alexei Pevtsov, NSO Associate Director. English speaker
- Tishanna Ben, NSO Education and Communication group. English speaking host
- Camila Ibarlucea, NOIRLab Education and Communication group. Spanish speaking host.

The recording is hosted on YouTube (*https://www.youtube.com/watch?v=WxCDGmhW40A*) and has more than 8,000 views as of the writing of this report.



In addition to this major event, the EPO staff continued to participate in a series of virtual or hybrid public engagement events with hosts such as the Girl Scouts, Mauna Kea Observatories, UH Institute for Astronomy, Kamehameha Schools, Thelma Parker Library, and ʻOhana Kilo Hōkū.

Girl Scouts of Hawaiʻi**:**

- *Virtual Astronomy Camp - June 19, 2021.* Provided a video recording guiding Girl Scouts through an exploration of the Sun and creating movies of solar events using *helioviewer.org*.
- *Virtual STEM Camp* - November 11, 2021. Provided two 20 minute live streamed activity sessions. Sessions covered the Inouye Solar Telescope's first light image and some of the science behind the convection that drives granules that are seen at the surface of the Sun.

UH Institute for Astronomy (UH IfA):

- *AstroDay East - April 26-29, 2021.* Provided an NSO brochure that included QR codes that link to educational videos and other resources developed by NSO.
- *AstroDay Wes*t - *November 14, 2021.* This was a hybrid event in that it was in person, yet certain rules were applied to minimize any COVID related effects. NSO staff ran an outdoor booth and spoke to people in person about the Sun and our facilities, as well as provided brochures and educational materials. Participants were not allowed to do any hands-on activities at the booth. Instead, staff demonstrated convection while providing a brief explanation regarding what can be seen at the surface of the Sun.

Kamehameha Schools:

- *5th Grade Science Fair (virtual judging) - April 28-May 2.* NSO staff helped to judge student projects. Judges were given the opportunity to provide meaningful feedback and advice to young scientists.

Maunakea Observatories:

- *Solar Video for 2021 Hawaiʻi Science Walk - November 22-January 2.* The event took place in Waimea, on Hawaiʻi Island. On Ala 'Ohi'a street, decals and signs with QR codes were placed along the road. Each QR code links to a different video describing research being done in Hawaiʻi that "broadens our understanding of our world". NSO provided a video segment about the Sun and research being done by the Inouye Solar Telescope on Maui. Videos from all participants were uploaded to a YouTube playlist and made available for public viewing post-event.

Thelma Parker Library:

- NSO Granulation Game and Inouye Solar Telescope coloring sheets distributed as part of holiday keiki packs at a local food distribution.

6.5.3 FY 2022 Plans for Informal Education and Outreach

Plans for FY 2022 will likely continue in a similar fashion to FY 2021. NSO EPO will participate in virtual outreach events as much as possible, and will host virtual engagement events, preferably in partnership with other organizations in order to maximize our reach. As restrictions from the global pandemic are withdrawn, we will return to in-person engagement whenever possible.

7 DIVERSITY AND INCLUSION THIS SECTION WAS NOT UPDATED FOR THE FY2022-FY2023 APRPP

This section summarizes FY 2021 activities that promoted or increased diversity within NSO, its user community, and the undergraduate and graduate student populations. It also describes the NSO's ongoing broadening participation efforts for FY 2022. Gender, ethnicity, and other metrics are provided for our educational programs as in past years.

NSO has two Diversity Advocates, each with a focus that prioritizes, but not limited to, diversity issues at their sites: Stacey Sueoka (DKIST, located in Maui) and Niles Oien (NISP, Boulder-based). Both DAs are members of AURA's Equity and Inclusion Council (EIC). The DAs regularly meet with the NSO Director to discuss diversity and inclusion activities and concerns. 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. There is a general expectation that DAs will serve for approximately two years.

A more formal procedure for turning over the Diversity Advocate (DA) role has been developed. This procedure is currently being used to transition the Boulder DA role. The procedure involves announcing the role requirements to the broad NSO. Staff who wish to be considered for the role can then apply by providing a brief description explaining their interest in becoming a DA and their vision of the opportunity. The NSO DA role requirements are aligned with those circulated by the AURA Chief Diversity Officer (CDO). We provide those requirements in Section 7.3.

In 2020, the NSO DAs started an NSO broad discussion forum, the Diversity, Equity, and Inclusion Working Group (DE&I-WG). This forum provides an opportunity for all staff to meet and discuss informally any Diversity, Equity, and Inclusion topics, often dominated by workplace environment issues. Because of the nature of the discussions, the DE&I-WG has split into three subgroups with a location focus, a Maui-specific WG, a Boulder WG, and a joint DE&I-WG encompassing all-NSO. The three WGs meet on alternating months. These WGs have proven to be an effective method of commnication among staff and management for issues around diversity and workplace environment at NSO.

The WG discussions helped explain to our workforce the new competency on diversity included in the 2021 annual performance reviews that weigh 10% of the total. Several LinkedIn training courses have been made available to staff to facilitate meeting the requirements of this competency. The LinkedIn courses include practicing diversity in the workplace and effective communication. This initiative originated from the AURA's Human Resources team.

In FY 2021, the NSO DAs started a voluntary Diverse Discussions (DD) forum on specific topics that can help maintain an inclusive environment for all employees and that are more focused than the regular DE&I-WG conversations. DD sessions are scheduled to allow NSO employees at all sites to attend if they desire. One intended outcome is the gathering of ideas pertaining to procedures such as hiring, performance reviews, and management techniques that may be incorporated to improve their effectiveness and eliminate unintended "blind spots". Relevant source materials are distributed beforehand to initiate the discussions that are guided by a Diversity Advocate, or a facilitator designated by the Diversity Advocates.

The first Diverse Discussion took place in February of 2021. The session was split into two half-hour parts. The first part was visualizing a YouTube Technology, Entertainment, Design (TED) talk ("Implicit Bias - How We Hold Women Back", Maureen Fitzgerald), and the second part was a discussion of implicit bias in general. Comments were made relevant to the topic with respect to NSO, specifically, there was some discussion of the composition of hiring committees and how best to support them in avoiding implicit bias while still giving them relevant information regarding candidates. A series of setbacks, primarily COVID-19 related, have delayed further Diverse Discussions, but the intent is to continue the series.

As explained above, NSO regularly organizes multiple internal discussions on DEI topics. There is an interest in clarifying how staff should charge for time spent on DE&I. This issue was brought to the Solar Observing Council (SOC) in the fall of 2021, as some staff had expressed concern about how such activities should be charged. The SOC, in its recommendations, concluded that NSO should establish a robust process for charging time to DEI activities that are reflected on the Observatory Work Breakdown Structure (WBS) system and that is communicated to the staff. NSO is setting up new WBS accounts to allow charging and proper tracking of these efforts in the various Programs.

In FY 2021, NSO successfully ran a test of "blind" hiring practices for a position within the EPO team. These practices included removing identifying information from resumes before passing them to the hiring committee. NSO intends to extract the lessons learned from that experience and incorporate some of these practices into our normal hiring processes in FY 2022. NSO and AURA continue to post job vacancies on diversity friendly web sites targeted to the specific openings.

In addition to NSO's specific initiatives, AURA's CDO organized a virtual talk on "Building an Organizational Culture of Inclusion and Support for Asian American and Pacific Islander Colleagues" on June 28, 2021. The presenter was Mai Khou Xiong, Director of Multicultural Student Services at University of Wisconsin-Stout. This was reasonably well attended and is a good example of how AURA-wide diversity presentations can benefit NSO.

7.1 Diversity Metrics of the NSO REU Program

Section 6.4.1 describes the highly successful 2021 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). The Table provides the demographics of 2021 Research Experience for Undergraduates applications throughout the recruitment process. 238 eligible applicants were first shortlisted to approximately 100. Mentors then selected their top applicant, and a placement was offered (First Choice). If the placement was refused, offers were made to successive applicants until the position was filled (follow-up offers), resulting in the final cohort demographics (accepted). Both Female and Hispanic accepted participants percentages are larger than the corresponding applicant numbers. American Indian and African Americans unfortunately show the opposite trend.

Table 7-1. 2021 REU Program Diversity Metrics					
2021	**238 Eligible Applicants**				
	Applicants	**Shortlisted**	**First Choices**	**Follow-up offers**	**Accepted**
Male	47.48%	40.26%	31.58%	40.00%	36.84%
Female	49.58%	57.14%	68.42%	60.00%	63.16%
Non-binary	2.94%	1.30%	0.00%	0.00%	0.00%
White	63.45%	70.13%	57.89%	80.00%	68.42%
Hispanic or Latinx	10.92%	20.78%	26.32%	6.67%	15.79%
Choose not to answer	6.30%	3.90%	5.26%	0.00%	5.26%
Asian	13.45%	7.79%	5.26%	0.00%	0.00%
American Indian	2.10%	2.60%	0.00%	0.00%	0.00%
Black or African American	3.36%	9.09%	5.26%	0.00%	0.00%
Pacific Islander	0.00%	0.00%	0.00%	0.00%	0.00%

Table 7-2 provides the evolution of REU participants' demographics since 2018. Note the decrease in the number of the applicants for the two years affected by the COVID-19 pandemic.

Table 7-2. 2021 REU Program Diversity Metrics				
Eligible Participants	**404**	**314**	**244**	**238**
Year	***2018***	***2019***	***2020***	***2021***
Male	35%	36%	36%	37%
Female	57%	64%	64%	63%
Non-binary	0%	0%	0%	0%
Choose not to answer	9%	0%	0%	0%
White, not of Hispanic Origin	83%	74%	52%	68%
Hispanic	9%	0%	4%	16%
Choose not to answer	9%	9%	0%	5%
Asian	0%	13%	43%	0%
American Indian or Alaskan Native	0%	0%	0%	0%
Black, not of Hispanic Origin	0%	4%	2%	0%
Pacific Islander	0%	0%	0%	0%

7.2 Akamai Workforce Initiative (AWI)

The goal of the program is to develop a workforce that reflects the diverse population of the state of Hawaiʻi, therefore there is an emphasis on broadening participation to include more Native Hawaiians, women and other groups underrepresented in STEM. As mentioned in the 2020 APRPP, the Akamai Program was canceled for the 2020 intern cohort due to the constraints of the COVID-19 pandemic. The Akamai Program resumed in 2021 with a smaller applicant pool and smaller cohort, this resulted in the poorest year on record for placing women and Native Hawaiians as the continued COVID-19 disruptions added many complications. DKIST supported three interns, two of which worked remotely with their mentors.

Table 7-3. Demographics of Akamai Interns

	Total interns	% Native Hawaiian	%Under-represented Minorities	%Women
DKIST Supported 2017-2021	18	11%	39%	28%
All interns 2017-2021	132	20%	45%	39%
All interns 2003-2021	451	23%	47%	36%

7.3 Description of the Role of the Diversity Advocates at the NSO

We provide below a list of tasks describing the role of the NSO Diversity Advocates, adapted from a similar memo by the AURA Chief Diversity Officer. A Diversity Advocate is committed to:

1. Serve as a primary point of contact at NSO for diversity, equity, and inclusion, including the development, implementation and delivery of programs and activities related to these topics.
2. Serve as a positive example of diversity in the workplace through actions and conduct that supports equity, disrupts bias and discrimination, and partners with the Chief Diversity Officer in maintaining an inclusive workplace culture.
3. Prepare reports on the diversity-related initiatives at NSO for presentation and distribution at committee meetings, typically including advisory board meetings and the Annual Planning Review and Program Plan document.
4. Consult, as needed, with the Chief Diversity Officer and/or NSO Director on issues related to diversity and workplace climate at NSO that may require intervention or additional resources.
5. With the support and approval of your direct supervisor and/or NSO Director, spend a minimum of three to five working hours per month on Diversity Advocate related initiatives in conjunction with your regularly scheduled job duties.
6. Serve as Diversity Advocate for approximately two calendar years.
7. Report to the Solar Observatory Council on initiatives developed to promote a diverse and inclusive culture at the Observatory.
8. The role typically involves some travel to other AURA centers to attend the Equity and Inclusion Council.

Diversity Advocates are expected to discuss these guidelines with their direct supervisor to determine the impact on their regularly scheduled job duties. The dedication is expected to stay below 10%.

8 FY 2022 SPENDING PLAN

The NSO CSA AST-1400450 spending plan is based on receiving in FY 2023 $25.46M for NSO as described in the President's Budget Request (PBR) (see Table 8-1), excluding the Special Projects (see below). The FY2023 PBR includes $19.58M for DKIST operations and $5.88M for other NSO infrastructure operations and maintenance. 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 reprofile of the carryforward funds in the DKIST Operations Program discussed in Section 10 of the FY 2020 – FY 2024 Long Range Plan (LRP) and updated in the FY 2021–2022 APRPP. This reprofile is based on updated estimates of the costs of operating the facility obtained during the early operations phase.

Table 8-1 FY 2023 President's Budget Request

Total Obligations for NSO
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
NSO	$4.65	-	$7.06	$6.24	$6.24	$6.24	$6.24	$6.24
Operations and Maintenance	*4.65*	-	*5.88*	*6.24*	*6.24*	*6.24*	*6.24*	*6.24*
Special Projects[2]	-	-	*1.18*	-	-	-	-	-
DKIST Operations[3]	$19.54	-	$20.68	21.30	21.30	21.30	21.30	21.30
Operations and Maintenance	*19.54*	-	*19.58*	*21.30*	*21.30*	*21.30*	*21.30*	*21.30*
Special Projects[4]	-	-	*1.10*	-	-	-	-	-
Total	**$24.19**	**-**	**$27.74**	**$27.54**	**$27.54**	**$27.54**	**$27.54**	**$27.54**

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends September 2024.
[2] Includes research infrastructure funding for transition activities at Sacramento Peak Observatory.
[3] FY 2021 Actual includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the compliance
[4] Reflects additional funding for research infrastructure to optimize community access.

The $25.46M allocation is the same as received in FY 2022, effectively making the Observatory's budget flat. The Special Projects are a new category that appeared for the first time in FY2023 PBR. The Special Project for transition activities in Sunspot ($1.18M) is budgeted in section 8.2.5. NSO submitted a Supplement Funding Request in FY 2022 to receive these funds. The second Special Project is intended to facilitate community access to DKIST ($1.1M). NSO has not yet received clear guidance about the process to solicit and potentially receive these funds.

The NSO's budget was augmented in FY2022 by $3M (to a total of $25.46M) following the recommendations of the LRP review panel in 2019. The FY 2021-2022 APRPP discussed how these funds were allocated to the various programs. In the current flat budget situation, the allocations of the augmented funds to the programs stay the same this year. However, all programs have been instructed to use a fraction of the augmented funds to accommodate the 3% escalation for payroll missing in the FY2023 PBR. This rebudgeting, in practice, imposes a funding reduction in all subdivisions excluding Sunspot (that did not receive any budget augmentation in FY 2022).

The spending plan presented here is structured in five subdivisions: The Director's Office (HQ), which includes the EPO Program; the DKIST Operations Program; NISP; NSO Community Science Program (NCSP); and Sunspot. Figure 8-1 describes the organizational structure of the Observatory and includes all cost-account managers with financial responsibilities.

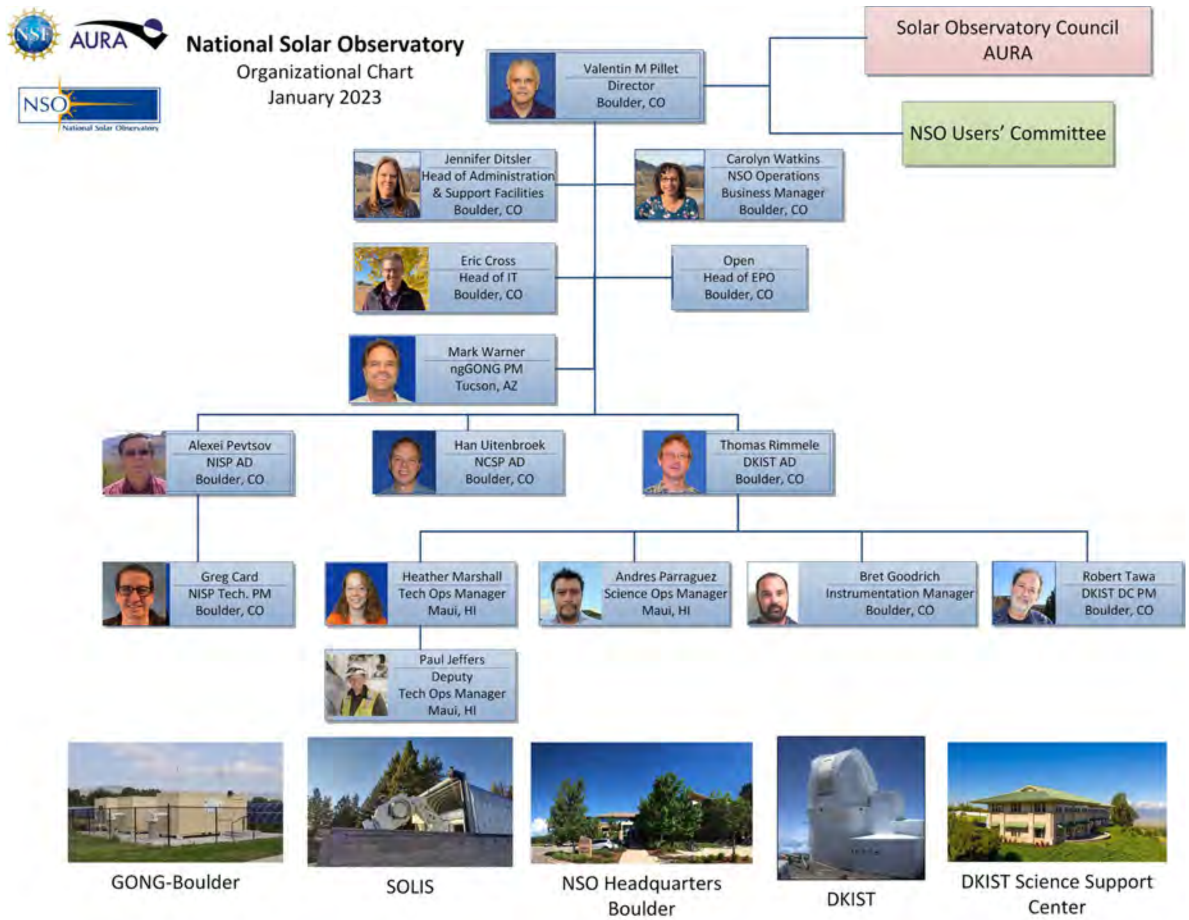


Figure 8-1. *Organizational structure of the National Solar Observatory.*

In FY 2021, NSO started using the Deltek platform for all business and accounting practices. The NSO business team and AURA/CAS worked to upload the final detailed FY 2023 budget following the guidance from the subdivision leaders described here. We expect the final budgets for CSAs AST-1400450 and AST-1023439 to be available in the system by Q2 FY 2023.

As part of the improved business practices at NSO, we note that we implemented a change-control process in FY 2018 that we are adapting to the Deltek platform in FY 2023 to document changes in the annual budgets.

8.1 FY 2023 Budgetary Assumptions: NSF New Funds, Carry Forward, and Non-NSF Funds

Table 8-2 summarizes the funding that NSO expects to receive as new NSF funding (Base Funding from the AST division, Special Projects, and Supplement Funding Requests) and anticipated non-NSF (NOAA) support for operations in FY 2023. The NSO Spending Plan in FY 2023 was developed based on receiving $25.46M of NSF funding for the regular base operations, including DKIST.

For Sunspot operations and transition activities, an SFR that includes multiple deferred site maintenance elements was submitted jointly by NSO (lead institution) and NMSU (subaward). Budgetary pressures are forcing a renegotiation of this SFR, which might see decreased support for deferred maintenance. NSO has not yet submitted an SFR to access the DKIST Special Project funds ($1.1M) targeted at optimizing the facility community access. Table 8-2 also includes the second year of the FY 2021-awarded WoU-MMA SFR ($660K) allocated to NCSP and the first year of the FY 2022-awarded WoU-MMA SFR ($985K) given to NISP. The funding received from NOAA in FY 2023 for GONG operations is $1.06M and is entirely managed by NISP.

Table 8-2 Expected NSO FY 2023 Funding (Dollars in Thousands)	
NSF Astronomy Division Funding	$25,460
Special Projects (transition activities Sunspot)	$1,180
Special Projects (DKIST community access)	$1,100
SFR WoU-MMA NCSP (Year 2)	$660
SFR WoU-MMA NISP (Year 1)	$985
Subtotal NSF Astronmy Division Funding	$29,385
FY 2023 NOAA Support	$1,060
Total NSO Funding	$30,445

Table 8-3 shows the six subdivisions and the corresponding FY 2023 NSF new funds allocations for NSO Headquarters (NSO HQ, also referred as Director's Office); DKIST Operations; NISP; Sunspot Operations (NSO SP), NCSP; and the NSO Fee (NSO-F). The funds include base funding and SFRs when applicable. Note that Table 8-3 does not include the DKIST community access in Table 8-2. For Sunspot Operations, Table 8-3 provides the total of the submitted SFR ($1.35M), which is slightly above the corresponding Special Project in Table 8-2 ($1.18M). For these reasons, the Subtotal for NSF/AST in Table 8-2 and the Total in Table 8-3 differ by an amount slightly below $1M. There is a reduction in the allocations for each program corresponding to their use of the NSO Fee (last row). These contributions to the NSO Fee were negotiated with the NSF in FY 2017. NSO intends to submit a new Fee proposal in FY 2023 to adjust the use of the funds following the end of the DKIST construction project and the unique circumstances created by the COVID-19 pandemic.

Table 8-3 NSO Allocations of NSF Funds

Fiscal Year: 2023
Funding Source: New Funds

Project ID	Project Name	FTEs	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
CS006.1	NSO Directors Office	8.50	1,455,750	1,008,783	2,464,533	0	2,464,533
CS006.2	NSO NISP	15.82	2,404,269	1,516,095	3,920,364	0	3,920,364
CS006.3	NSO Sunspot	3.61	374,037	974,012	1,348,049	0	1,348,049
CS006.4	NSO NCSP	6.45	765,368	359,904	1,125,272	0	1,125,272
CS006.5	NSO DKIST Ops	66.26	10,310,484	9,216,442	19,526,926	0	19,526,926
CS006.9	NSO AURA Management Fee	0.00	0	69,012	69,012	0	69,012
Overall - Total		**100.64**	**15,309,908**	**13,144,248**	**28,454,156**	**0**	**28,454,156**

Table 8-4 provides the distribution of carry-forward funds for each program. The Director's Office (NSO HQ) carryforward is of $818K, similar to FY 2022. The unspent budget originates primarily from the delays in the DKIST construction project due to the pandemic and the postponed start of Operations. The DKIST carry forward of $28M has been re-profiled in a manner explained in the FY 2021 – FY 2022 APRPP and updated in Section 8.2.2. For NISP, the $743K balance results mostly from unused GONG refurbishment funds and pending hardware upgrades. Two components contribute to the NCSP carry forward, the remaining funds from the Level-2 SFR ($1.53M) and the WoU-MMA first-year funds ($547K). Table 8-4 includes $103K carry forward in the NSO Fee account, reflecting the reduced use of these funds primarily due to the COVID-19 pandemic restrictions.

Table 8-4 NSO Carryforward

Fiscal Year: 2023
Funding Source: Carryforward

Project ID	Project Name	FTEs	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
CS006.1	NSO Directors Office	1.08	251,712	564,600	816,312	0	816,312
CS006.2	NSO NISP	0.00	0	746,190	746,190	0	746,190
CS006.4	NSO NCSP	6.45	744,479	1,332,408	2,076,887	0	2,076,887
CS006.5	NSO DKIST Ops	35.42	5,916,958	22,247,684	28,164,642	0	28,164,642
CS006.9	NSO AURA Management Fee	0.00	0	103,542	103,542	0	103,542
Overall - Total		**42.96**	**6,913,149**	**24,994,424**	**31,907,573**	**0**	**31,907,573**

We list next the budgetary assumptions used to create the NSO's FY 2023 Spending Plan. The fringe benefits and indirect rates were applied per the FY 2023 approved Provisional Indirect Rate Agreement letter from the NSF, dated December 1, 2021. The spending plan used escalation on payroll per the Cost Model Proposal submitted to the NSF on December 14, 2018, at a rate of 3%.

Post-Retirement Benefits costs were based on FY 2022, escalated by 3%, and allocated to the sub-divisions based on payroll distribution. 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 2022, escalated by 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 2022, escalated by 3%, and allocated to subdivisions based on projected headcount. AURA/CAS Human Resources software application (Ultipro) costs were based on FY 2022, escalated by 3%, and allocated to subdivisions based on projected headcount. Insurance costs were based on FY 2022, 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).

8.2 Subdivisions Breakout

This section presents an overview of the most significant expenses projected for each subdivision (or program) and the changes concerning the original CA proposal and the LRP document. The tables in this section show the major functional areas' spending plan in more detail, breaking out payroll (FTEs) and non-payroll. The budget tables are provided as separate line items for three different funding sources:

NSF FY 2023 new funds, carry forward, and non-NSF funds when applicable. Work package disclosure will be available on the Deltek platform.

The corresponding subsections below detail the spending plan using the targets provided in Tables 8-3 and 8-4. These spending plans include all AURA's indirect rates.

8.2.1 Director's Office (NSO HQ)

The NSF base funding allocation for the Director´s Office in FY 2023 is $2.46M (Table 8-3), and the program carryforward in FY 2023 (Table 8-4) totals $816K. Table 8-5 presents the FY 2023 NSF spending plan for the Director's Office. Staff included in the Director's Office budget are the Director, the NSO Director's Office Executive Administrator, the NSO Business Manager and a Budget Specialist, a combination of several fractional FTEs from various administrative positions and 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. The Director's Office supports two NSO Diversity Advocates with base funding. A significant fraction of the non-payroll budget (typically $350K) pays for about a third of the lease of the 3rd floor at the CU Boulder HQ, including all common areas.

In FY 2023, the Director's Office is budgeting an additional $70K in travel to cover the cost of the Search Committee for the next NSO's Director. Search Committee activities (listening sessions in Boulder and Maui, candidate interviews, etc.) will occur throughout CY 2023.

Table 8-5 NSO Headquarters

Fiscal Year: 2023

NSO Director's Office

Project ID	Project Name	FTEs	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
CS006.1	New Funds NSO Directors Office	8.50	1,455,750	1,008,783	2,464,533	0	2,464,533
CS006.1	Carryover Directors Office	1.08	251,712	564,600	816,312	0	816,312
Overall - Total		**9.59**	**1,707,462**	**1,573,383**	**3,280,845**	**0**	**3,280,845**

The NSO EPO program, under the Director's Office, consists of three FTEs, one in Colorado and two in Hawaiʻi. The EPO officer is located at NSO HQ, and the communications specialist, serving the entire NSO, resides in Maui. On the island, an EPO assistant promotes solar physics within the local community, particularly with local K-12 students and teachers. In FY 2015, the late hire of EPO positions provided some carryforward funds re-budgeted as a start-up package for the program. These resources are available primarily to increase the visibility of NSO in general at conferences such as the AGU, SPD/AAS, etc.

Since FY 2022, NSO has consolidated all IT services into a unified program. This service is the second component of the matrix structure for the Observatory (the first was the administrative services). The Head of the IT service, reporting to the NSO Director, allocates IT resources across all subdivisions each year and in consultation with the respective program's Directors. The Director's Office uses a non-payroll budget of $120K, including aspects of cybersecurity.

The most relevant items covered by the Director's office carryforward funds are:

1. The dedication in FY 2023 of the DKIST PM (50% level) to the ngGONG project. This allocation disseminates the MREFC Project Management expertise and lessons learned from the DKIST Construction Project to the broader NSO.
2. Additional science support at around $140K. These funds support a broad spectrum of scientific opportunities not directly included in the programs, such as payroll for cross-calibrations of GONG and spacecraft data, computers, and page charges for publications by NSO's emeritus scientists.
3. Equipment moves to Boulder and Maui that have not occurred yet because of delayed divestiture of the DST. The carryforward funds are $90K for these pending transition activities.
4. The EPO start-up package with a remnant of $31K.
5. Additional (extraordinary) travel expenses ($50K) occur in FY 2023 as we are planning to hold the annual Users Committee meeting in Maui for the first time. A similar amount is allocated to kick off the ngGONG Science Working Group which will meet at least once in FY 2023.
6. Miscellaneous expenditures such as Boulder vehicles ($50K) and improvements to the HQ audio-video systems ($50K).

8.2.2 DKIST Operations Program

The DKIST Operations Program is under the direction of Thomas Rimmele as DKIST Associate Director. In FY 2023, the DKIST Operations Program, with 102 FTEs, is the largest program at the NSO. The staffing of 98 FTE listed in the APRPP 2021-2022 was for slightly less than a full year of operations following the end of construction. The 102 FTEs reflect full year of operations. The DKIST new funds for FY 2023 are $19.527M including the base funding augmentation; the program's carry forward is $28.16M (Table 8-6). Approximately half of the carry forward is budgeted in FY 2023 to fund the operations of DKIST. The remaining carry forward of about $14M (see Table 8-7) will be required to fund DKIST operations in FY 2024. The carry forward of operations funds is due to a) the delay of construction, including the impact of COVID-19, and subsequent delay of full operations, and b) a delay of one large instrumentation program contract that was planned for spending in FY 2022 but were pushed into FY 2023. This section explains how the program is reprofiling these carry-forward funds to operate DKIST for FY 2023 and FY 2024.

Table 8-6 NSO DKIST Operations

Fiscal Year: 2023

NSO DKIST Operations

Project ID	Project Name	FTEs	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
CS006.5	New Funds NSO DKIST Ops	66.26	10,310,484	9,216,442	19,526,926	0	19,526,926
CS006.5	Carryover NSO DKIST Ops	35.42	5,916,958	22,247,684	28,164,642	0	28,164,642
Overall - Total		**101.68**	**16,227,442**	**31,464,126**	**47,691,568**	**0**	**47,691,568**

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 following the delays of the start of operations due to COVID-19 but also a more substantiated understanding of the cost of science and technical operations. The handover to operations finally occurred on November 20, 2021. The updated operations budgets presented here are based on this starting date.

The NSO Solar Observatory Council recently issued several recommendations, including one to develop a staffing plan with a "*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. In FY 2022 significant progress was made with refining and updating of resource requirements for DKIST operations using actual expenditures and refined planning of resource requirement (staffing and non-payroll) for maintenance and upkeep of the complex summit facility. Science operations staffing requirements were also refined, including the development of detailed shift schedules for Science Operations Specialists and Resident Scientists. The resource estimates summarized below are based on our best understanding of what it will take to operate DKIST with the assumptions described in the NSO LRP.

An AURA organized DKIST operations budget review was held in September 2022 with presence of NSF Program Officers.

In FY 2022 we gained experience from operating this unique, one-of-a-kind telescope facility in OCP mode as DKIST. The current budget estimates by actual expenditures and encumbrances over approximately ¾ of a year, as well as updated program plans in the instrumentation development WBS. Technical Operations staffing plans were also iterated with the Technical Operations Manager (TOM) and the Deputy TOM. Detailed bottom-up estimation of the summit technical operations effort, including operations support, maintenance, repairs, and upgrades were refined. Estimates for non-payroll expenses such as electricity have been refined based actual expenses during operations and the current observing campaign schedule for FY 2023.

The data center realized the risk associated with calibration engineer staffing. Data center staffing plan were updated accordingly.

We expect the OCP1 to conclude in early CY 2023. The proposal call for OCP2 was released in June 2022. The proposal review process and experiment generation will occur in the first quarter of FY 2023. The support provided to the community during the proposal process continues to be taxing on the science team. As expected, the level of required science support increased significantly during the proposal preparation and execution phase, when selected proposals must be converted to executable experiments, tested, and executed in service mode. In FY 2022, we were able to hire two science positions. Hiring and on-boarding of staff continues to be a challenge in all areas, including science support.

Staffing plan updates (see Figure 8-2, which contains information for the next two years) resulted in minor changes to the total number of FTEs for years FY 2023–2024 as compared to what was projected with APRPP FY 2021 FY 2022. The total staffing amounts to: FY 2023: 104.5 FTE and FY 2024: 106.2 FTE. We note that approximately 7 FTEs that were previously budgeted in Technical Operations for instrument maintenance and upgrades are now budgeted in the Instrument Maintenance and Development WBS. This constitutes an internal re-allocation driven by changed management responsibilities.

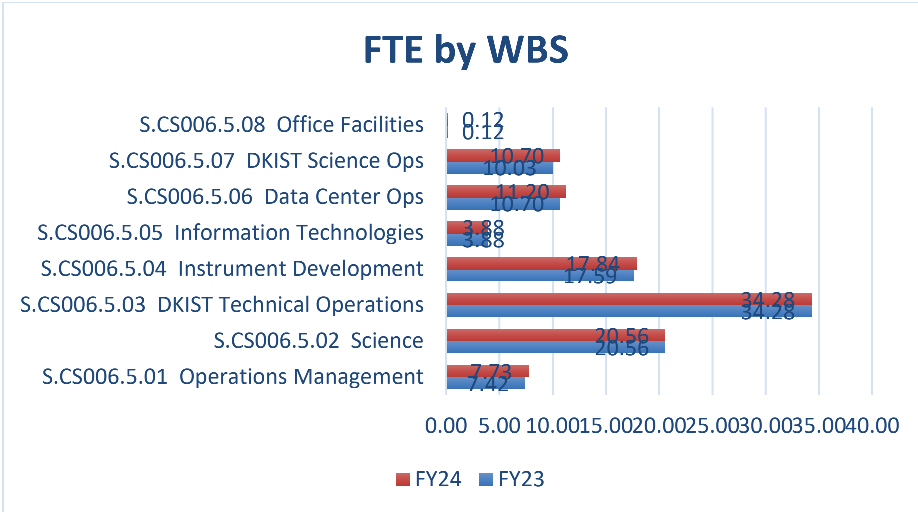


Figure 8-2. *FTE by WBS for the year's FY 2023, and FY 2024. CS006.5.04 Instrument Development includes the R&M of the complex set of first-generation instruments.*

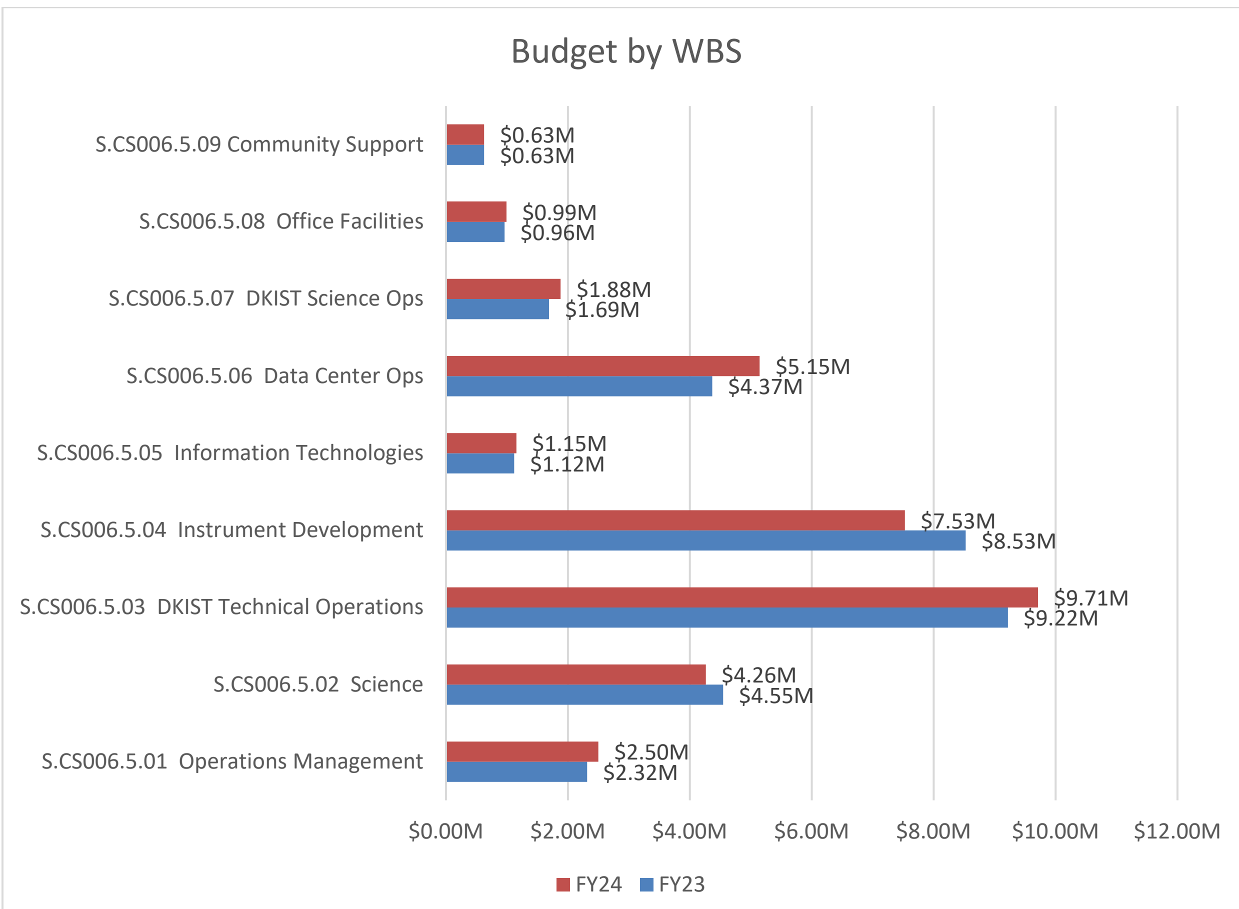


Figure 8-3. *WBS total cost for the year's FY 2023, and FY 2024.*

For FY 2022, a significant fraction of the operations personnel corresponds were transfered from the construction team to operations functions. New hires have occurred for the Data Center, technical staff, and additional scientific support staff, including graduate students and postdocs.

The DKIST Scientists' support for DKIST operations is budgeted (payroll, non-payroll and travel) at $4.55M for FY 2023. Seven scientists and, currently, one postdoc are based in Maui, where they interact with our instrument partners on the island.

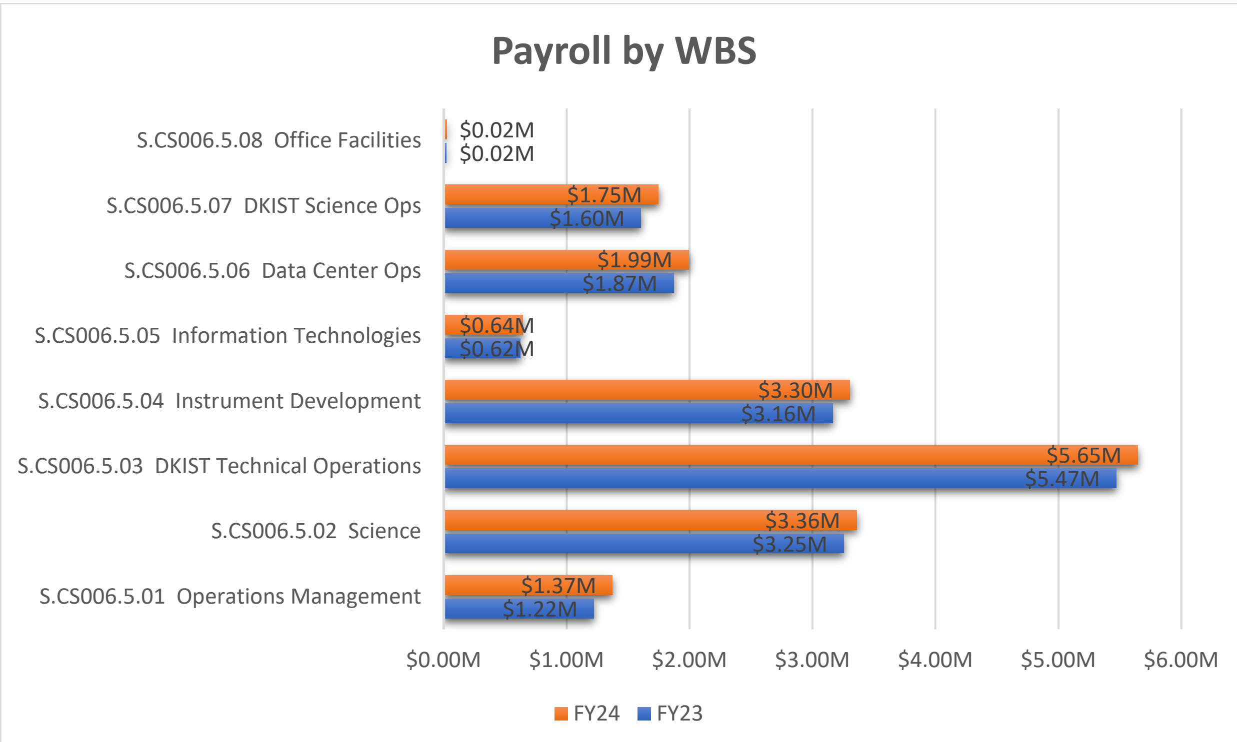


Figure 8-4. *WBS payroll cost for the year's FY 2023, and FY 2024.*

As described in the LRP, the Science Operations (SciOps) WBS includes the Science Operations Specialist (SOS) team, the SciOps Manager, and the budget for the Operations Tools development and maintenance. A DKIST Chief Science Operations Specialist in Maui provides local management of the SOS team on the island. The team reports to the DKIST SciOps Manager and is directed by the SciOps Program Scientist, whose management function is budgeted in the WBS Operations Management. The total FY 2023 budget for the SciOps WBS, including the management function provided by the Data Center PM, is $1.69M.

The FY 2023 staff cost for the DKIST Technical Operations of the summit is $5.47M. As most of them often participated in 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 as we gain operations experience. We note that DKIST continues to face challenges in terms of staffing up to full operations levels. The challenges arise from the overall staffing shortage that the overall economy experience, in particular in engineering fields but also from cost-of-living pressures. The latter is particularly severe on Maui. DKIST continues efforts to develop staff locally.

The DKIST Data Center at at this point is mostly staffed. Two additional recruitments of calibration engineers to support the Level-1 data calibration effort are planned for FY 2023. The Data Center team is focusing on implementing and testing calibration pipelines for VBI, ViSP, CRYO-NIRSP and DL-NIRSP for OCP data and delivering data to proposal PI teams. 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 with significant hardware procurement planned for FY 2023-2204. In FY 2023, the total Data Center expenditures amount to approximately $4.37M.

The DKIST program budgets for IT support in Boulder and on Maui is a total cost of $1.12M in FY 2023.

Non-Payroll estimates (see Figure 8-5) have undergone several update cycles since the LRP budget estimates were performed. More recent actuals are now available for a significant number of equipment and supplies items. Firm vendor quotes for equipment have been received where previously only ROM pricing and/or scaling from previous similar items was available, leading to an increase of the annual non-payroll expenses in the areas of Maui Technical and Facilities operations and new instrumentation development. For example, firm contract pricing for the development and fabrication of IR detectors has resulted from a formal and competitive RFP process and implementing a contract. The cost of new and much more capable IR detector technology that within approximately three years will replace the aging, limited performance H2RG detector technology, is significantly higher than previously estimated. Similarly, a firm price contracts for the procurement of an image slicer device and the MCAO deformable mirror conjugate to 11km conjugate and slated to replace M7 are now in place. A formal quote for the coronal image slicer for DL-NIRSP has been requested. We estimate the cost of this contract to be very similar to the recent on-disk image slicer contract.

The instrumentation program includes sustained support and maintenance of the current suite of instruments, major upgrades, and improvements to existing instrumentation, MCAO development, and the integration of a dual etalon VTF delivered by the German partners. We note that some large contracts, including the custom-built coronal image slicer, visible camera upgrades and replacements and optical components that were originally planned for FY 2022 have slipped to FY 2023 and are contributing to the carry forward. The deferred spending also explains the increased FY 2023 budget ($33.5M) as compared to the annual budget projection for FY 2023 ($30.1M) presented in the previous APRPP. System integration and testing in the lab and some summit integration activities will commence in FY 2023-2024. Summit integration and acceptance testing will continue within the scope of the next CSA (expected duration: FY 2025-2029).

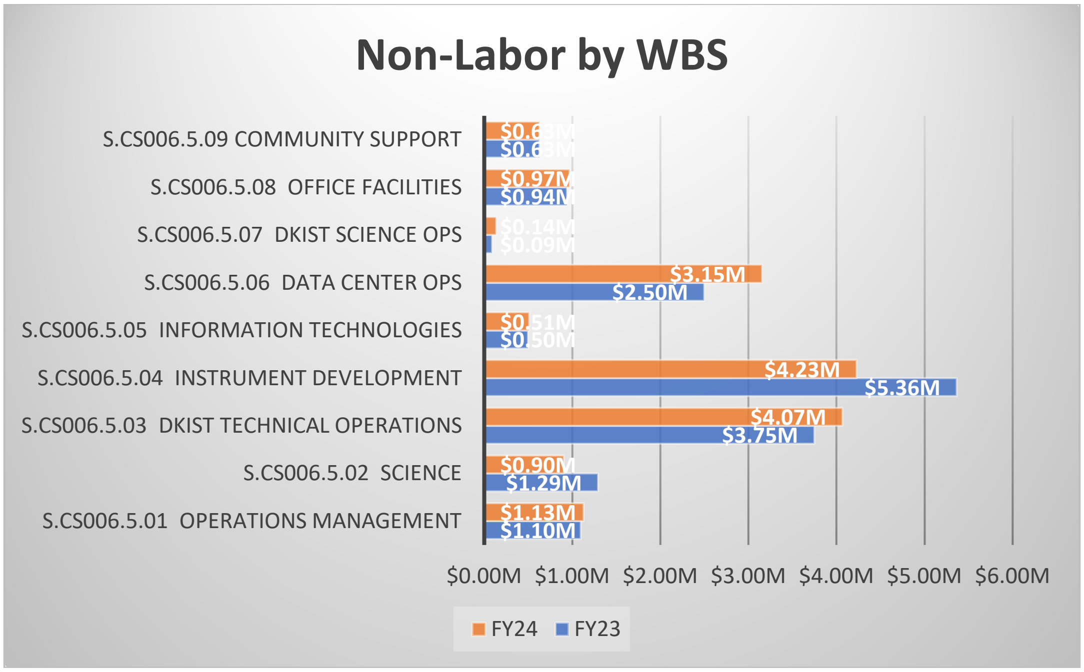


Figure 8-5. *WBS non-payroll cost for the year's FY 2023, and FY 2024.*

Table 8-7 provides a top-level description of the carry forward allocations to support DKIST operations over the next three years. The yearly cost of the DKIST program (including scientific support and the Data Center) appears in the second column under Budget Profile. The column variance (5th column) indicates the missing funds for each of the years compared with the CSA DKIST operations budget profile (4th column). Remaining carry-forward funds are provided in the 6th column. At the end of the current CA, the program has a predicted deficit of $271K (see Table 8-7).

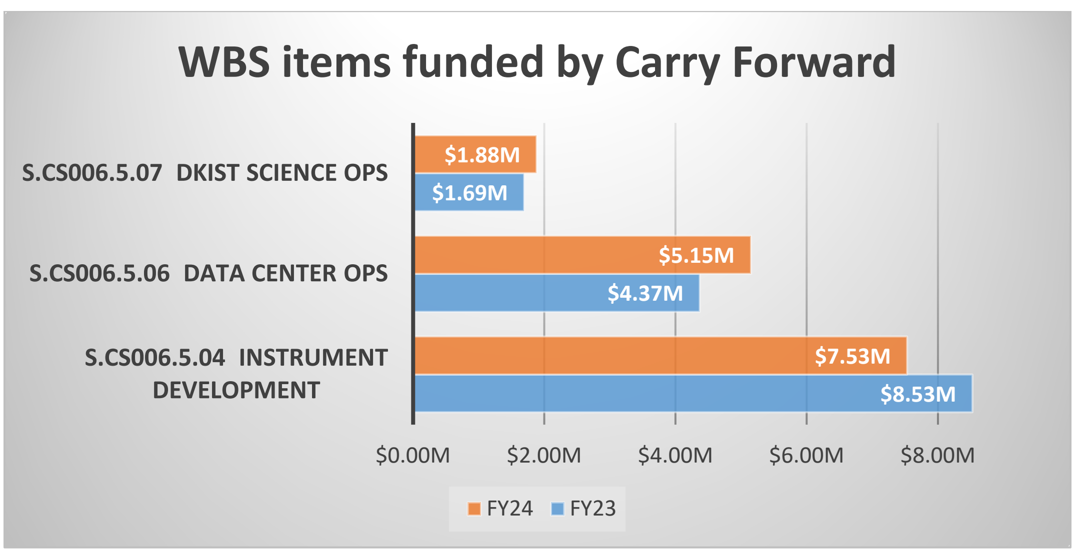


Figure 8.6. *FY 2023-2024 allocation of carry forward funds to WBS items. Carry Forward funds are used to fund Instrument Maintenance and Development, the Data Center and Science Operations.*

It is important to point out the following that in FY 2023, carry forward in the amount of about $14M is used to fund the Instrument program, the Data Center, and Science Operations. In FY24 a similar amount will be required to fund these WBS items, which again will be funded from remaining carry forward funds that will be carried forward into FY 2024. The current projection for the DKIST operations budget for FY 2025 is $28.2M (in FY2 2025 dollars). As is the case for all budget figures presented in this section, escalation of 3% is included. However, the significantly higher inflation rates that we are currently experiencing are not fully considered in these budget projections.

Table 8-7 FY 2022 President's Budget Request						
Year	Budget Profile ($M)	Presidents Request Budget Profile($M)	PRB - Management Fee	Variance	CarryForward ($M)	Note
					$28,164,000	carry forwad from FY22 to FY23
FY23	$33,495,383	$19,526,926	$19,501,370	($13,994,013)	$14,169,987	planned carry forward FY23 to FY24
FY24	$33,942,152	$19,526,926	$19,501,370	($14,440,782)	-$270,795	
FY25	$28,150,000	?	?	?		new CSA

Table 8-7. *FY 2022 President's Budget Request. The proposed profile reflects the best estimates based on current information and an improved understanding of the cost structure for DKIST Operations. The carry forward from FY 2022 is depleted during FY 2023-2024 to fund the DKIST Operations budget profile and funds the WBS items displayed in Fig. 8.6. The draw-down profile of carry-forward funds during FY 2023-2024 is indicated in the 'CarryForward' column. According to these budget estimates, a small funding deficit exists in FY 2024.*

Our strategy has been to acquire complex and costly, often custom-built hardware items during the current CSA. These are typically long-lead items, which require multi-year development contracts with vendors. Our approach is motivated by budget realities and projections, but also takes into account the significant delays of scheduled development milestones we continue to experience with vendors for custom built hardware (e.g. MCAO DMs). It is important to note that the FY 2025 budget estimate of $28.15M presented at the recent DKIST operations budget review assumes significantly reduced (compared to FY 2022-2024) non-payroll budgets for instrumentation, but also the data center, where significant hardware investements occur in FY 2023-2024.

By Resource Type, OBS

	FY23	FY24	Total
Labor	$17,228,097.47	$18,083,031.02	**$35,311,128.49**
Nonlabor	$14,757,662.54	$14,008,619.86	**$28,766,282.40**
Travel	$1,389,062.97	$1,717,328.36	**$3,106,391.33**
Total	**$33,374,822.99**	**$33,808,979.24**	**$67,183,802.23**

Table 8-8. *Current projections for the DKIST Operations cost split in Labor, non-Labor, and Travel for years FY 2023 and FY 2024. The projected increased travel in FY 2024 is due to instrument integration efforts that require multiple trips of Boulder personnel to Maui and a major international telescope & instrumentation conference (SPIE Japan).*

8.2.3 NSO Integrated Synoptic Program (NISP)

The NISP combines staff from SOLIS and GONG under Alexei Pevtsov as Associate Director. The Program also provides partial support to NSO Administrative and IT staff. In its funding philosophy, NISP continues to rely on a three-pronged approach: NSF base funding, NOAA support, and external grants. For future large-dollar amount items (i.e., new data center servers), the Program is following its previously established plan and allocates an annually prorated amount. The Program is on track to achieve this goal by the end of FY 2024.

The NSF base funding for NISP in FY 2023 corresponds to $3.92M (Table 8-3), which is a combination of the $2.94M base funding contribution (same as in FY 2022) and $985K from the first year of the NISP's WoU-MMA SFR (Table 8-1). NISP carryforward in FY 2023 (Table 8-4) totals $743K. Additionally, the non-NSF funding available for GONG operations, about $1M (see Table 8-2), corresponds to the second year of the renewed IAA between NOAA/SWPC and the NSF (CSA AST-1023439). The updated budget considers revised costs for operating the network, reflecting scalability and new site fees at various locations, and runs until FY 2026. NSF base funding supports research with GONG and network operations deficit as needed. The corresponding spending plan for these budget items is presented in Table 8-9.

Table 8-9 NSO NISP

Fiscal Year: 2023
NSO NISP

Project ID	Project Name	FTEs	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
CS006.2	New Funds NSO NISP	15.82	2,404,269	1,516,095	3,920,364	0	3,920,364
CS006.2	Carryover NSO NISP	0.00	0	746,190	746,190	0	746,190
Overall - Total		**15.82**	**2,404,269**	**2,262,285**	**4,666,554**	**0**	**4,666,554**

As in previous years, the NISP budget is alleviated by a series of non-NSF 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. Unlike previous years, in a search for external support, emphasis was made on projects closely aligned with NISP priorities. This helped mitigate a negative impact of external funding while still benefiting from its positive aspects. NSF's WoU-MMA SFR is one example of this approach.

Currently, NISP has a total of approximately 20 FTEs. The NSF base funding covers about 16 FTEs (including one new hire for engineering technician, and 3.5 FTE for scientific programmer staff funded by NISP's WoU-MMA SFR)). GONG operations (engineering and Data Center groups) use 3.62 FTEs funded from the NOAA/SWPC contribution.

NISP comprises an Atmospheric Section and an Interior Section, each led by a project scientist/project lead who reports to the NISP Associate Director. As the rest of the scientific staff, both project leads are only partially supported by NSF base funding. The engineering support staff, supervised by the NISP Engineering Manager, supports SOLIS and GONG operations and instrument upgrades. The base-funded fraction of scientific staff 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.

The Program continues to use the FY 2016 one-time contribution for GONG refurbishment, and the remaining funds are part of the Program's FY 2023 carry-forward (Table 8-4). Specifically, $201K is budgeted to ensure completion of all remaining activities under the GONG refurbishment. The scope of "GONG refurbishment" is summarized in the FY 2021-2022 APRPP.

In FY 2022, the Program made significant progress in SOLIS construction (see Section 4.4 for details). NISP base funding in FY 2023 uses $239K and $267K from the program's carryforward to cover the final phases of the SOLIS relocation to BBSO and a restart of its operations. It is now expected that limited SOLIS operations will be restarted in the spring of 2023.

GONG data used for the operational space weather forecast are analyzed at SWPC/NOAA using the data reduction pipelines maintained by NISP. The more research-oriented aspects of GONG data are reduced daily by the NISP Data Center. All datasets are collected by the NISP Data Center and made available for downloading by the solar community. While SOLIS instruments took no new observations in FY 2022, the Data Center staff did several reprocessing of SOLIS VSM data, including implementing 8542V weak field approximation and corresponding synoptic maps. In FY 2023, NISP allocates $1.09M base funding for the Data Center (including all payroll) and $275K as part of the program's carryforward for Data Center equipment upgrades.

As a positive change from recent years, in FY23 the Program will see a modest expansion via hiring supporting personnel including a new Data Center Coordinator, one engineering technician/technologist, and three scientific programmers. The latter are funded by NSF's WoU-MMA SFR, and thus, are only two-year positions.

To enhance scientific collaboration, the Program allocated a modest amount of funding ($60K) to support long-term visitors to NISP.

8.2.4 NSO Community Science Program (NCSP)

The LRP document described a new synergistic program, the NSO Community Science Program, aimed at scientific activities that benefit from the combined expertise of DKIST and NISP. NCSP uses supplemental funding from initiatives that have a research impact extending to DKIST and NISP. The first such initiative was the DKIST Level-2 data project aimed at producing physical quantities derived from the observables produced by the spectropolarimeters of DKIST. More recently, we have added to the program funding from a three-year SFR that integrates DKIST and GONG data products to improve coronal modeling in preparation for the 2024 total solar eclipse.

The NSF new funds for NCSP in FY 2023 corresponds to $1.12M (Table 8-3), which is a combination of the $464K from the base augmentation (same as in FY 2022) to continue the DKIST Level-2 effort and $660K from the second year of the NCSP's WoU-MMA SFR (Table 8-1). NCSP carryforward in FY 2023 (Table 8-4) totals $2.08M, which is equally split in the Level-2 SFR remanent ($1.53M) and the WoU-MMA unspent funds ($547K). The NCSP will exhaust most Level-2 carryforward funds in FY 2023, including the expenditures needed for the Level-1 to Level-2 hardware interface ($500K). Table 8-10 shows the program's spending plan for the new funds and carry forward.

Table 8-10 NSO NCSP

Fiscal Year: 2023
NSO NCSP

Project ID	Project Name	FTEs	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
CS006.4	New Funds NSO NCSP	6.45	765,368	359,904	1,125,272	0	1,125,272
CS006.4	Carryover NSO NCSP	6.45	744,479	1,332,408	2,076,887	0	2,076,887
Overall - Total		**12.90**	**1,509,847**	**1,692,311**	**3,202,158**	**0**	**3,202,158**

The program's primary mission is the development of DKIST Level-2 data products. Testing for creating these data products started following the availability of the first DKIST Level-1 data public release as part of the DDT coordinated observations with Parker Solar Probe.

The DKIST Level-2 proposal included three interrelated initiatives: the Level-2 data product initiative, a community-oriented initiative, and a university-oriented initiative that will continue in FY 2023. All three initiatives use logistics and outreach support provided by the NSO.

The Data-Products Initiative represents an effort at NSO and will deliver Level-2 data products following OCP. It uses about 50% of the total funding throughout the program. Currently, the program includes two part-time NSO scientists and an additional three-year position acting as DKIST Level-2 Project Scientist. The Project Scientist ensures that the Level-2 data follows the original requirements and serves as the scientific point of contact to interface with the DKIST Data Center. The Project Scientist is a shared position with the CU-Boulder Cooperative Institute for Research in Environmental Sciences (CIRES) laboratory.

The Community-Oriented Initiative has exhausted almost all the funds. In FY 2023, and to operationalize the inversions of ViSP data using the DeSIRe code, the program will support ($46K) an extended stay (3 months) at NSO of the scientists and software engineers from the Instituto de Astrofisica De Canarias (Tenerife, Spain) that participated in the creation of the code.

The University-Development Initiative helps grow the DKIST community and occurs at graduate programs. Support for the Level-2 DKIST Ambassadors has a remanent of $240K. NCSP intends to offer additional support to existing Ambassadors with executed observing proposals during OCP to help promote the early scientific impact of the facility. We note that future calls for the Ambassadors Program will be directed via the DKIST program as the scope of the new early career scientists encompasses all aspects of the facility, not just the creation of Level-2 data products.

The spending plan for the WoU-MMA follows the original scope of the SFR. The relatively large FTE allocation within the program (Table 8-9) is due to the graduate students' support included in the original proposal, which will be identified in FY2023. Some of these students will collaborate on the 2023 (Australia) and 2024 (continental US) total solar eclipse campaigns that will also receive support from NSO's scientists and outreach team.

The program is considering using a subaward with the IfA/UH to benefit from the knowledge at the institution responsible for the DKIST coronal instruments as they are more closely related to the work in one of the SFR data products (DKIST coronal synoptic program). The proposal also included a new data product combining the Solar Orbiter mission and GONG magnetograms. The recent release of full disk magnetograms from the space mission will accelerate this activity in FY2023 and require travel to the collaborating partner institutions.

8.2.5 Sacramento Peak (Sunspot)

As in previous years, the NSO plans to continue operating the Sunspot site using a dedicated SFR. In FY 2023, we request funds included in the PBR Special Projects category ($1.18M). The SFR in FY 2023 considers, as in the past several important site deferred maintenance aspects (totaling $266K): repairing the potable water tanks, moving the fiber communication lines to the DST, and acquiring a skid steer loader. The SFR request is for a total of about $1.34M, slightly above the PBR allocation. Table 8-11 provides the spending plan for the requested funding. The SFR (submitted in FY 2022) includes a subaward to NMSU of $426K. As in FY 2022, the NSO leads the SFR, and all NMSU activities are included in the subaward. This model consolidates all utility payments at the NSO, simplifying the administrative processes between the NMSU and AURA.

Table 8-11 NSO Sunspot

Fiscal Year: 2023
NSO Sunspot

Project ID	Project Name	FTEs	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
CS006.3	New Funds NSO Sunspot	3.61	374,037	974,012	1,348,049	0	1,348,049
Overall - Total		**3.61**	**374,037**	**974,012**	**1,348,049**	**0**	**1,348,049**

This supplemental funding request contemplates one year of continued support to consolidate the ongoing implementation of Alternative 2 from the Final Environmental Impact Study and lays out the foundations for a transfer of the site's management to NMSU.

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APPENDICES

THESE SECTIONS WERE NOT UPDATED FOR THE FY2022-FY2023 APRPP

APPENDIX A. SCIENTIFIC AND KEY MANAGEMENT STAFF

APPENDIX B. NSO STATEMENT FOR THE ASTRO2020 DECADAL SURVEY

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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 instru-ments 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 helio-seismology; 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 atmo-sphere modeling and observational astronomy and spectroscopic analysis; student mentor.
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

Gregory Card	NISP Engineering & Technical Manager.
Eric Cross	Head of Information Technology.
Jennifer L. Ditsler	Head of Administration & Support Facilities.
Bret D. Goodrich	DKIST Instrumentation Manager.
Heather K. Marshall	DKIST Technical Operations Manager.
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.
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.
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 2021)					
Name	Admin/Mgt[1]	Research[2]	Service[3]	Project Support[4]	TOTAL
Alexov, A.				100.0	100.0
Anan, T.		58.8	0.3	40.9	100.0
Beck, C.		25.0		75.0	100.0
**Bertello, L.		96.3	1.4	2.3	100.0
Card, G.	3.0			97.0	100.0
Cauzzi, G.		27.3	72.7		100.0
Criscuoli, S.		81.4	18.6		100.0
Davey, A.		26.0		74.0	100.0
Ditsler, J.	80.0			20.0	100.0
Fehlmann, A.				100.0	100.0
Goodrich, B.	64.8			35.2	100.0
**Gosain, S.		43.7	32.7	23.6	100.0
Harrington, D.				100.0	100.0
Jaeggli, S.	73.5	18.4	1.5	6.6	100.0
**Jain, K.		10.9	28.2	60.9	100.0
***Kazachenko, M.		50.0			50.0
*Kholikov, S.S.		100.0			100.0
**Komm, R.W.		97.3	2.7		100.0
***Kowalski, A.		50.0			50.0
Marshall, H.				100.0	100.0
Martinez Pillet, V.	100.0				100.0
**Petrie, G.J.D.		93.5	6.5		100.0
Pevtsov, A.A.	100.0				100.0
Raftery, C.			100.0		100.0
**Reardon, K.P.		38.1	61.9		100.0
Rimmele, T.R.	100.0				100.0
Schad, T.A.		50.0	40.3	9.7	100.0
**Schmidt, D.		19.0	3.3	77.7	100.0
**Tarr, L.		65.7	34.3		100.0
Tawa, R.E.				100.0	100.0
**Tripathy, S.C.		76.6	23.1	0.3	100.0
Tritschler, A.	32.2	1.1	47.7	19.0	100.0
Uitenbroek, H.		35.4	64.6		100.0
Warner, M.	100.0				100.0
Watkins, C.	100.0				100.0
Woeger, F.	65.9		34.1		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
***NSO-CU Boulder shared tenure-track faculty

APPENDIX B.

NSO STATEMENT FOR THE ASTRO2020 DECADAL SURVEY

The ASTRO2020 Decadal Survey recognizes that Solar Physics is (p. 1-20):

"…directly relevant to astronomy, as it is the study of our nearest star, and interacts with stellar astrophysics; is input to studying the Earth-Sun connection and expanding to stellar-planetary interactions; and is vital to understanding Earth's climate and space weather."

In the past, the prioritization of solar physics projects has been split in two decadal surveys, one corresponding to ground-based facilities (the Astronomy Decadal Survey) and one to space missions (the Solar and Space Physics Decadal Survey). This division has often prevented a holistic approach to prioritizing research on the Sun and its consequences on Earth. The ASTRO2020 Decadal Survey, released in November 2021, recognizing this fact, proposes that:

"…The survey committee concluded that an appropriate role for astronomy and astrophysics decadal surveys is to comment on the value of ground-based solar physics projects for astronomy and astrophysics priorities, with the solar and space physics decadal survey being the more ***appropriate body to prioritize and rank*** *ground-based solar physics projects within the context of the full range of multi-agency activities in solar physics."*

Effectively postponing prioritization of ground- and space-based project to the Solar and Space Physics Decadal Survey due in 2023. This survey has traditionally been chartered by NASA-Heliophysics and NSF/GEO, but in its 2023 formulation will also include NSF/AST and NOAA. The inclusion of the two NSF divisions responds to the traditional split in grants (with a bigger role in NSF-GEO) vs. operating ground-based solar facilities (a focus of NSF/AST). The additional participation of NOAA opens the Decadal Survey discussion to space weather research and its potential transfer into operational aspects. In this manner, a more unified discussion of the research about the Sun and how it creates and controls the Heliosphere will be possible. This new format directs the Observatory to participate and promote community input for the preparations of the 2024 Solar and Space Physics Decadal Survey.

Throughout the document, the ASTRO2020 Decadal Survey recognizes the imminent start of operations of the Inouye Solar Telescope and states that (p. 7-2):

"The Daniel K. Inouye Solar Telescope (DKIST) will complete commissioning this year and will ***begin to observe*** *the Sun's fundamental magnetic and plasma processes to elucidate the role that magnetic fields and their interactions play in driving solar activity."*

And identifies the most important research aspects that the telescope will address:

"A crowning achievement for ground-based solar astronomy is the recent completion of NSF's 4 m DKIST, whose unprecedented spatial resolution and spectropolarimetric sensitivity will ***open a new window*** *on the magnetohydrodynamic phenomena that affect convective motions and drive the storage and release of magnetic energy (reconnection)."*

With its unique coronagraphic capabilities, DKIST will also address in detail major missing components on our current abilities to observe the diffuse outer atmosphere of the Sun. Specifically, DKIST is uniquely qualified to fill this gap identified in the ASTRO2020 (p. G-13):

"Coronagraphs capable of ***measuring coronal magnetic fields*** *are required to obtain a complete picture of the entire magnetic Sun; current coronagraphs measure only intensity."*

And inform future projects in this field of solar research.

The ASTRO2020 Decadal Survey also recognizes the need to provide the context for the detail observations by DKIST and states that (p. G-12):

"…observing with DKIST will be like watching the Sun through a microscope. The telescope will provide observations of magnetic fields in exquisite detail, but these observations need to be put into a ***global context****, and this will require new synoptic facilities that measure the global magnetic fields of the Sun at high cadence, as well as helioseismic observations that will allow us to determine associated changes in solar structure and dynamics below the photosphere"*

But recognizes the aging character of the synoptic programs operated by the NSO and establishes the need to continue developing the concept for a future ground-based synoptic network generically called ngGONG:

*"The current ground-based solar synoptic network has two aging components: the Global Oscillation Network Group (GONG) and Synoptic Optical Long-term Investigations of the Sun (SOLIS). The six-site GONG network has limited capability owing to modest spatial and spectral resolution, and the more capable SOLIS instrument suite has only one site that is not currently operating. Space-based observations currently fill this gap but have finite life expectancy and measure quantitatively the magnetic field at only one height in the atmosphere. Continuous measurements of velocity, magnetic field, and intensity at multiple heights in the photosphere and above are required****. Currently a conceptual design, ngGONG*** *would be a global network (six) of highly capable solar observatories, including coronagraphs at three sites."*

It is, thus, imperative that the Observatory continues furthering the definition of ngGONG in consultation with the broader solar and space weather communities and stakeholders. The ASTRO2020 offers a new venue for continuing this definition by proposing strategic mid-scale areas as reflected in this recommendation:

"Recommendation: The National Science Foundation (NSF) Division of Astronomical Sciences (AST) should create ***three tracks*** *within the AST Mid-Scale Innovations Program and within (its share of) the NSF-wide Mid-Scale Research Infrastructure Program. The first track should be for regularly competed, open calls, the second track should solicit proposals in* ***strategically identified priority areas****, and the third should invite ideas for upgrading and developing new instrumentation on existing facilities. All tracks should solicit proposals broadly enough to ensure healthy competition."*

The strategic character could be applicable to ngGONG given its role in Space Weather research and in the context of the recent PROSWIFT Act.[13]

[13] *https://www.aip.org/fyi/federal-science-bill-tracker/116th/space-weather-research-and-forecasting-act*

DKIST, SOLIS, and GONG represent the current facilities portfolio of the NSO. Future development lines are ngGONG and the second generation of instruments for DKIST. These existing and future capabilities are present in ASTRO2020. But another component critical to the Observatory, data management and analysis, also appears highlighted as a key aspect of modern astronomy. The Decadal Survey recommends that:

"Recommendation: The National Science Foundation Division of Astronomical Sciences should establish a mechanism of associated research funding for data analysis and production of ***high-level data products*** *for large principal investigator-led programs on MREFC-scale astronomical facilities in order to accelerate the scientific output and maximize the timeliness and community impact of these key large projects."*

For which the Observatory has been thoroughly working in the previous years by implementing the NSO Data Center and the NSO Community Science Program. The creation of a program that provides community PI opportunities to develop high-level data products from DKIST will enormously enhance its scientific output given the complexity of its data.

The ASTRO2020 Decadal Survey contains strong recommendations about the importance of investing in people and of attracting the younger generations to astronomy and astrophysics. NSO continues to strengthen our partnerships with US Universities (CU Boulder, University of Hawaiʻi, and others) and participates in well-recognized programs that target the early formative years in the STEM field such as the REU and Akamai programs. We thus see with great interest initiatives recommended by ASTRO2020 such as the following:

"Recommendation: NASA, NSF, and DOE should reinvest in professional ***workforce diversity*** *programs at the division/directorate levels with purview over astronomy and astrophysics. Because academic pipeline transitions are loss points in general, supporting the creation and continued operation of* ***"bridge" type programs*** *across junctures in the higher-education pipeline and into the professional ranks appear especially promising."*

The Observatory will deepen our alignment with the overall recommendations of ASTRO2020 as it pertains to the state of the profession. We also look forward to investments in past programs that have shown progress in increasing the presence of historically underrepresented groups as promoted by the ASTRO2020 document.

APPENDIX C. NSO FY 2022 STAFFING SUMMARY

(In Full-Time Equivalents)

APPENDIX G. NSO FY 2022 Staffing Summary

	Director's Office			NCSP	NSO	DKIST				NISP		TOTAL
	Tucson	*Boulder*	*Maui*	*Boulder*	*Sunspot*	*Tucson*	*Sunspot*	*Maui*	*Boulder*	*Tucson*	*Boulder*	
Scientists	-	1.00	-	3.00	-	-	-	9.00	8.00	0.05	6.45	27.50
Engineering/Science Support Staff	-	1.00	-	-	1.00	1.00	-	30.00	25.00	3.00	4.00	65.00
Administrative Staff	0.15	6.00	2.00	-	2.00	0.25	-	6.00	1.00	-	-	17.40
Technical Staff	-	-	-	-	1.00	-	-	12.00	1.00	-	3.00	17.00
Maintenance & Service Staff	-	-	-	-	1.00	-	-	3.00	-	-	-	4.00
												0.00
Total Base Program	0.15	8.00	2.00	3.00	5.00	1.25	-	60.00	35.00	3.05	13.45	***130.90***
Other NSF Projects (AO, FTS/CHEM)	-	-	-	-	-	-	-	-	-	-	-	0.00
Graduate Students	-	-	-	-	-	-	-	-	-	-	-	0.00
NASA Supported Science Staff	-	-	-	-	-	-	-	-	-	0.95	0.55	1.50
NASA Support Engineering Staff	-	-	-	-	-	-	-	-	-	-	2.00	2.00
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	0.95	2.55	***11.50***
Total Working at NSO	3.15	9.00	2.00	3.00	8.00	1.25	-	60.00	36.00	4.00	16.00	**142.40**
Scientists	-	-	-	-	-	-	-	2.00	-	-	-	2.00
Engineering/Science Support Staff	-	-	-	-	-	-	-	1.00	2.00	-	-	3.00
Administrative Staff	-	-	-	-	-	-	-	-	-	-	-	0.00
Technical Staff	-	-	-	-	-	-	-	-	-	-	1.00	1.00
Maintenance & Service Staff	-	-	-	-	-	-	-	-	-	-	-	0.00
Total Open Positions	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***3.00***	***2.00***	***0.00***	***1.00***	***6.00***
Total NSO FTEs	**3.15**	**9.00**	**2.00**	**3.00**	**8.00**	**1.25**	**0.00**	**63.00**	**38.00**	**4.00**	**17.00**	**148.40**

APPENDIX D. PUBLICATIONS

(OCTOBER 2021 THROUGH SEPTEMBER 2022)

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 2021 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. Abduallah, Y., Wang, J. T. L., Shen, Y., Alobaid, K. A., Criscuoli, S., & Wang, H. (2021), Deep Learning Based Reconstruction of Total Solar Irradiance, arXiv e-prints, arXiv:2107.11042.

2. **Afanasyev, A. N., Kazachenko, M. D.,** Fan, Y., Fisher, G. H., & Tremblay, B. (2021), Validation of the PDFI_SS Method for Electric Field Inversions Using a Magnetic Flux Emergence Simulation, ApJ, 919, 7.

3. 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, 16.

4. Amerstorfer, T., Hinterreiter, J., Reiss, M. A., Möstl, C., Davies, J. A., Bailey, R. L., Weiss, A. J., Dumbović, M., Bauer, M., Amerstorfer, U. V., Harrison, R. A (2021), Evaluation of CME Arrival Prediction Using Ensemble Modeling Based on Heliospheric Imaging Observations, SpWea, 19, e02553.

5. **Anan, T., Schad, T. A**., Kitai, R., **Dima, G. I., Jaeggli, S. A., Tarr, L. A**., Collados, M., Dominguez-Tagle, C., & Kleint, L. (2021), Measurements of Photospheric and Chromospheric Magnetic Field Structures Associated with Chromospheric Heating over a Solar Plage Region, ApJ 921,39.

6. **Bahauddin, S. M.,** & Rast, M. P. (2021), Identifying Acoustic Wave Sources on the Sun. I. Two-Dimensional Waves in a Simulated Photosphere, ApJ, 915, 36

7. **Bahauddin, S. M.,** Bradshaw, S. J., & Winebarger, A. R. (2021), The Origin of Reconnection-Mediated Transient Brightenings in the Solar Transition Region, NatAs, 5, 237.

8. Bain, H. M., Steenburgh, R. A., Onsager, T. G., Stitely, E. M. (2021), A Summary of National Oceanic and Atmospheric Administration Space Weather Prediction Center Proton Event Forecast Performance and Skill, SpWea, 19, e02670.

9. Basu, S. (2021), Evidence of Solar-Cycle-Related Structural Changes in the Solar Convection Zone, ApJ, 917, 45.

10. **Beard, A**., **Wöger, F.,** & **Ferayorni, A**. (2020), Real-Time Speckle Image Processing with the DKIST, Proc SPIE, 11452, 114521X.

11. **Beck, C.,** Choudhary, D. P., & Ranganathan, M. (2020), Center-to-limb Variation of the Inverse Evershed Flow, ApJ, 902, 30.

12. Berezin, I. A., & Tlatov, A. G. (2020), Comparative Analysis of Terrestrial and Satellite Observations of Photospheric Magnetic Field in an Appendix to Simulation of Parameters of Coronal Holes and Solar Wind, Ge&Ae, 60, 872.

13. Bommier, V. (2020), Master Equation Theory Applied to the Redistribution of Polarized Radiation in the Weak Radiation Field Limit. VI. Application to the Second Solar Spectrum of the Na I D1 and D2 Lines: Convergence, A&A, 644, A65.

14. Braun, D. C., Birch, A. C., & Fan, Y. (2021), Probing the Solar Meridional Circulation Using Fourier Legendre Decomposition, ApJ, 911, 54.

15. Campbell, R. J., Shelyag, S., Quintero Noda, C., Mathioudakis, M., Keys, P. H., & Reid, A. (2021), Constraining the Magnetic Vector in the Quiet Solar Photosphere and the Impact of Instrumental Degradation, A&A, 654, A11.

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APPENDIX E. SCIENTIFIC STAFF RESEARCH AND SERVICE

(*Grant-supported staff)

Tetsu Anan, Assistant Scientist

Areas of Interest

Solar chromospheric heating; integral-field-unit spectropolarimetry; electric field diagnosis.

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 presenting measurements of shock heating energy in a sunspot umbra using an integral-field-unit spectrograph of the Dunn Solar Telescope (Anan et al. 2019, ApJ, 882, 161). Another paper, which has been accepted for publication in the Astrophysical Journal, reveals magnetic field structures in the photosphere and the chromosphere associated with strong chromospheric heating over a plage region using another integral-field-unit spectropolarimeter of the GREGOR telescope (Anan et al. 2021, arXiv: 2108.07907). He contributed to interpretations of He I 1083 nm Stokes profiles of a strong shock resulting from a coronal downflow within a sunspot umbra (Schad, Dima, and Anan, 2021, ApJ, 916, 5).

Future Research Plans

Dr. Anan will continue to develop the DL-NIRSP. He will develop a new electric field diagnosis using DKIST data.

Service

Dr. Anan is a member of Technical Review Committee for DKIST proposals for the Operations Commissioning Phase (OCP) Cycle 1 and Resident Scientist for the OCP Cycle 1.

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 collaborations with D. P. Choudhary (California State University Northridge, CSUN) and R. Louis (Udaipur Solar Observatory), Dr. Beck has published a paper on the formation of an atypical light bridge in a sunspot umbra through the emergence of magnetic flux (Louis et al., *ApJ*, **905**, 153, 2021). A detailed study of the properties of the light bridge using the recently released NLTE CAISAR code provided for the first time a clear observational confirmation of heating in the solar chromosphere through Ohmic dissipation of electric currents (Louis et al., *A&A*, **652**, L4, 2021). The collaboration with New Mexico State University (NMSU) on data acquired at the Dunn Solar Telescope led to a publication on the velocities inside an erupting filament that caused a minor coronal mass ejection (Wang et al., ApJ, submitted). This study opens a possible direct application in space weather prediction by measuring both velocities and magnetic fields in the host filaments that precede coronal mass ejections.

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 the successful execution of the first and all subsequent observation cycles of DKIST. In collaboration with CSUN and members of the solar physics group of University of Alabama in Huntsville two more studies on the magnetic topology (Prasad et al., A&A, in prep) and the height dependence of the inverse Evershed flow (Beck et al., ApJ, in prep) are being conducted. The expected long-term future research focus will be on the development of analysis tools for chromospheric spectral lines, especially Hydrogen α (NSF Grant "*Multi-wavelength Spectroscopic and Spectropolarimetric Diagnostics of the Solar Atmosphere*", PI D. P. Choudhary/CSUN) and the continued collaboration with NMSU on the topic of a successful connection between properties of filaments in high-resolution observations of the solar atmosphere and the resulting coronal mass ejection properties for erupting filaments with a potential application in the space weather forecast.

Service

C. Beck is a member of the DKIST Operations team during the 1st call for DKIST Operations, acting as DKIST Help Desk agent, member of the Technical Review Committee and Resident Scientist on Maui for the execution of Cycle 1 of DKIST Operations. C. Beck is the DKIST point of contact for the Visible Spectro-Polarimeter (ViSP). During the past year, Beck has reviewed publications for *The Astrophysical Journal*, *Astronomy & Astrophysics*, the *Journal of Astronomical Telescopes, Instruments, and Systems* and *Solar Physics*.

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.

Recent Research Results

Over the course of 2021, in collaboration with different national and international research groups, I have been involved in several distinct projects. Some of these projects are briefly described here. A major task I have undertaken with my colleagues at NSO is the testing and validation of a new GONG camera. This new camera will replace the old camera at each of the six GONG sites starting in 2022, with the major goal of improving the quality of current GONG data. In addition, as a PI for a NASA-funded project, I have coordinated the activity of two engineers. Performed at the NSO optical lab, this project will explore a novel instrument concept based on measuring a broad-band polarization which could be done without moving elements and complicated optical schemes. If successful, this concept will lead to creation of extremely simple and compact magnetograph suitable for space missions. Another ongoing project is a collaboration with colleagues at the University of Michigan. For this project, my major responsibility is to provide Carrington synoptic maps of the photospheric solar magnetic field derived from SDO/HMI observations to be used in a 3-D MHD numerical coronal and heliospheric model. In 2021 I have also initiated collaborations with the University of Graz (Austria), Georgia State University, Stanford University, University of Tor Vergata (Rome, Italy) on a variety of topics, ranging from the analysis of the 24-hr periodicity detected in HMI magnetograms and Dopplergrams, multi centuries long solar irradiance reconstruction, to the operational use of GONG H-alpha images using machine learning for solar flare predictions. Finally, as part of my continued effort to improve the quality of the products used by modelers, I have developed a new algorithm based on singular spectrum analysis to fill the unobserved polar regions in a Carrington solar magnetic synoptic chart. It is well known that results from current coronal and heliospheric models are limited by how well these regions can be reproduced. This new algorithm should provide a better representation of these regions and addresses some of the limitations found in previous approaches.

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 his 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, my major responsibility is to provide the solar and helio-physics community with high-quality and reliable NISP data. During 2021 I have 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. Outreach and education of the broader research community.

Current and Future Research Plans

Dr. Cauzzi is working on chromospheric spectroscopy of flare ribbons, as a diagnostic of dynamics and other properties during the impulsive phase of flares of different strength, to be compared with 1D radiative-hydrodynamical models. Work is also in progress in better understanding the thermodynamics of the quiescent solar chromosphere by means of novel ALMA data, acquired in concomitance with visible and IR data. This project will inform on how to best leverage the complementary diagnostic power of DKIST and ALMA. Dr. Cauzzi is currently involved in the definition phase of a possible future instrument for IR observations, utilizing large area FP interferometers.

Service

Dr. Cauzzi continues leading the 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 July 2021 and January 2022, with two more planned for late spring 2022. She is also helping with the organization of a Spectro-Polarimetric School led by HAO personnel, that will take place in late summer 2022. She is chairing the SOC for a big international meeting (IAU Symposium) that will highlight DKIST and its synergies with other major solar facilities currently operating.

Dr. Cauzzi routinely helps with student projects and currently serves on the PhD committee of one of the first NSO-associated students to receive their title, Elizabeth Butler. Since late 2021, she also serves as the

reference scientist for the DKIST Ambassadors program. She routinely serves as reviewer for various astrophysical journals (ApJ, A&A, Solar Physics), and international research agencies.
Finally, Dr. Cauzzi is the Chair of the Science Review Committee for the DKIST OCP (Operation Commissioning Phase) and is currently working on updating the procedures guiding the overall review process, in view of the upcoming second Call for Proposals for DKIST OCP.

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 investigated the puzzling variability of solar Balmer lines at different temporal scales in order to improve our understanding of both solar and stellar chromospheric variability. She also worked on the development of new models to estimate solar irradiance in the past and make predictions for future solar cycles. She finally continued her work on comparing radiative transfer codes and numerical schemes employed for the synthesis of solar and stellar spectra.

Service

Dr. Criscuoli is a scientific consultant for the DKIST. She actively contributed to several aspects of the execution of the first DKIST Call for Proposals (member of the scientific panel review, development of DKIST Experiments, development and review of parts of the OCM procedures).
Dr. Criscuoli also actively contributed to the DKIST level-2. She was a referee for scientific journals, member of NASA review panels 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.

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. Dr Davey is a member of the EarthCube sponsored working group "Uniform Semantics and Syntax of Solar Observations and Events" and part of a NASA sponsored working group looking at capabilities that enable open science across NASA's scientific disciplines. In 2020-2021, he was a referee for a number of scientific journals.

Andre Fehlmann, Associate Scientist

Areas of Interest

Infrared instrumentation; precision spectropolarimetry; coronal magnetic fields; infrared camera systems; student engagement and community outreach.

Recent Research Results

A. Fehlmann performed final alignment and installation of the Cryogenic Near-Infrared Spectropolarimeter (CryoNIRSP), a DKIST first-generation facility instrument, at the summit of Haleakala. He performed the site acceptance tests and science verification for the instrument.

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 working on the next generation of infrared camera systems for the facility and upgrades to the CryoNIRSP instrument. 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. He was working on setting up a data reduction pipeline for CryoNIRSP. In preparation of the first observation phase he was involved in preparing experiments that can be executed at the telescope. In the Summer months Fehlmann helped co-mentor two AKAMAI students during their internship at DKIST.

Sanjay Gosain, Associate Scientist

Areas of Interest

Astronomical instrumentation: optical design of instruments for polarimetry and spectroscopic imaging. Solar Physics Research: Study of key physical parameters and their evolution in relation to flares, eruptive filaments and coronal mass ejections; Three-dimensional magnetic field properties of active regions via photospheric and chromospheric spectropolarimetry.

Recent Research Results:

NASA MIDEX Phase-A study award to design "Solaris", a solar polar mission: Dr. Gosain is designated as the Instrument Scientist for the CDM instrument on the proposed Solaris mission. He led the Phase-A study for the CDM instrument. After a rigorous nine-month study a detailed mission Concept Study Report (CSR) was submitted to NASA in July 2021. He provided key inputs and was heavily involved in the prototype development of Compact Doppler Magnetograph (CDM) in collaboration with LASP and SWRI. He critically supported the thermal and vacuum testing of the CDM prototype and radiation testing of the liquid crystal variable retarders. He led the effort for a successful demonstration of CDM performance by obtaining a time series of Doppler and magnetic observations using NSO's TC light feed facility.

GONG new camera system functionality test and data validation: As the NISP Instrument Scientist, Dr. Gosain led the effort of the camera upgrade for GONG refurbishment project. He performed an exhaustive market survey for the cameras and selected few candidate cameras that met the science requirements and finalized on Sony CMOS based camera. He designed the optics needed to adapt new camera to GONG and designed sensor acceptance tests and trained technical staff to perform these tests. He worked closely with technical staff to provide opto-mechanical tolerances and alignment procedures. He designed the

camera performance tests at GONG TC as per the science requirements and worked closely with technical staff to benchmark camera performance. He led the effort of upgrading the camera sensor window with a custom anti-reflection coated cover glass, via a third-party service provider. After the coverglass upgrade the cameras were again tested for acceptance in the lab under his supervision.
ngGONG proposal study: Dr. Gosain participated in the preparation of "Next generation GONG" or ngGONG proposal submitted to NSF to design a future generation network to replace GONG and SOLIS.
Publications: (i) "Analysis of the space radiation effects on liquid crystal variable retarders', Casti, M. et al., in Proceedings of the SPIE, Volume 11814, id. 118140P 8 pp. (2021).
(ii) "SOLARIS: Revealing the mysteries of the Sun's poles" Hassler et al., A Concept Study Report (CSR) submitted to NASA towards Phase-A study award for MIDEX opportunity.

Future Research Plans & Service

Dr. Gosain plans to: (a) participate in Phase-B of the Solaris mission, if selected, (b) build a prototype for GONG H-alpha tunable Doppler imaging system, (c) provide support for the re-commissioning of SOLIS/VSM, FDP and ISS instruments at Big Bear, CA, (d) provide support the final testing and deployment activities of the new GONG cameras, and (e) carry out independent scientific research.

David M. Harrington, 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, Associate 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 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 and is still under review by NASA. 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. 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 provided 1/4 FTE for Dr. Jaeggli until October 2021. A publication describing the datasets and public release of the co-aligned datasets is forthcoming. Dr. Jaeggli is currently preparing the DL-NIRSP instrument paper for publication in the journal *Solar Physics* at the end of 2021.

Future Research Plans

Dr. Jaeggli is looking forward to science with CryoNIRSP and DL-NIRSP. She is PI on an accepted cycle 1 proposal for CryoNIRSP observations of the carbon monoxide transitions at 3.7 µm, and a co-investigator on many other experiments which will be conducted within the next year. Sarah also continues 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, preparation, and execution of the experiments during DKIST proposal cycle 1. Dr. Jaeggli is also serving as a member of the AURA Diversity and Inclusion Council as the Astronomer representative.

Kiran Jain, Scientist

Areas of Interest

Helioseismology and solar activity – solar oscillation mode characteristics, helioseismic mapping of the far hemisphere, sub-surface flows and dynamics, active regions, Sun-Earth connection.

Recent Research Results

The Sun's magnetic field varies in multiple time scales. Observations show that the minimum between cycles 24 and 25 was the second consecutive minimum which was deeper and wider than several earlier minima. Since the active regions observed at the Sun's surface are manifestations of the magnetic field generated in the interior, it is crucial to investigate/understand the dynamics below the surface. In this context, using the uninterrupted solar oscillation data from GONG, Jain and collaborators studied the epochs of seismic minima during the last three activity minima and found that have been occurring about a year earlier these in deeper layers than that at the surface for the last two consecutive solar cycles. These findings also demonstrate a decrease in strong magnetic fields at the base of the convection zone, the primary driver of the surface magnetic activity

Using the GONG farside maps, Jain made a successful prediction of a big active region in November 2020 several days before it came in the direct view of Earth or any other space-borne instrument. Once it crossed the east limb, NOAA gave it the designation 12786. This prediction is unique since the sudden, unexpected emergence of such a large concentration of intense magnetic flux in the early phase of the solar cycle has not been seen in previous cycles. It has remained the largest active region of the current cycle so far.

The oscillations of a slowly rotating star have long been classified into spheroidal and toroidal modes. The spheroidal modes include the well-known 5-min acoustic modes used in helioseismology. Jain, in collaboration with the MPS Group in Germany, worked on identifying toroidal modes in the Sun, for which the restoring force is the Coriolis force and whose periods are on the order of the solar rotation period. These are the high-latitude inertial modes, the critical-latitude inertial modes, and the equatorial Rossby modes. The observed modes were also compared with the model where the high-latitude and critical-latitude modes have maximum kinetic energy density at the base of the convection zone

Jain also carried out a detailed analysis of the duty cycle using GONG observations spanning over 18 years to assess the duty cycle that has been achieved from the ground. She also studies the duty cycle of individual sites and identified various factors that may impact individual site or network duty cycles. The mean duty cycle of the network is 93%, however it reduces by about 5% after all images pass through the stringent quality-control checks. These findings agree with the site-survey studies carried out for selecting the GONG sites. The standard deviations in monthly and yearly duty cycle values are found to be 1.9% and 2.2%, respectively. These results provide a baseline that can be used in the planning of future ground-based networks.

Future Research Plans

Jain will continue to work on improving the quality of far-side seismic maps and their prediction capabilities. These maps are crucial for the space weather forecasting and have proven their capability to locate and track medium-large active regions at the non-visible hemisphere. She also plans to include the tools of machine learning in the forecast.

Jain, in collaboration with the NWRA - Boulder scientists, will work on improving the flare forecast model where farside information will be included for near-limb flares.

Jain will continue to study the variability in solar oscillation characteristics with the changing level of magnetic activity to improve the understanding of their complex relationship. With the availability of helioseismic observations for more than two solar cycles, the long-term trends will be investigated.

Jain will continue to work on the International Solar Rotation Project for computing an unbiased internal rotation profile.

Jain will work on the effect of inclined magnetic fields 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.

Jain is partially supported by the various NASA-funded projects where major topics being addressed are; sub-photospheric flows in active regions and their influence in solar eruptions, long-term variations in sub-surface flows and their depth dependence. She will use observations from both ground-based and space-borne instruments.

Service

Jain continued 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. She composed three blog posts for the NSO website for public outreach. These blogs highlight the capabilities of GONG data in various science projects. In addition, she verified various GONG helioseismology data products and regularly monitored their quality. She also participated in the testing of new GONG camera for helioseismic studies. In addition, she hosted the regular monthly meetings of the International Solar Rotation Project.

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", *Astrophysical 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* 879, 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 lead an article accepted for publication in ApJ (*The Atmospheric Response to High Nonthermal Electron Beam Fluxes in Solar Flares. II. Hydrogen Broadening Predictions for Solar Flare Observations with the Daniel K. Inouye Solar Telescope;* https://arxiv.org/abs/2201.13349) 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 2022. 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 is a member of the DKIST experiment generation team. He is PI of a grade-A DKIST proposal, which is being turned into a PhD thesis for a student. 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.

Gordon J. D. Petrie, Scientist

Areas of Interest

Solar magnetic fields.

Recent Research Results

Petrie continued working with Valentin Martinez Pillet (NSO) and Julian Blanco Rodriguez (U. Valencia, Spain) on 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, which are calculated from an MHD simulation using a radiative transfer code. A major challenge was that the MHD simulation data have stratified and complex structure, imposing high resolution requirements on the spectral line synthesis calculation. Petrie therefore began using the Rybicki-Hummer (RH) radiative transfer code (Uitenbroek 2001, ApJ 557, 389), on the CU Blanca cluster, making these large calculations tractable. Furthermore, contribution functions can be derived as a byproduct, telling us line formation heights, enabling a meaningful comparison between the instrument simulator results and ground-truth information from the MHD data cube.

Comparisons between SOPHISM-simulated and real HMI spectra, and between RH-simulated and FTS spectra were successful. Petrie began applying the RH code to the GONG Ni I line at 676.8 nm for use with a version of SOPHISM already adapted for GONG. He also began applying the original SOPHISM code, for Solar Orbiter PHI, to the RH data. A major task is to cross-calibrate GONG and PHI full-disk magnetograms for merging in composite synchronic synoptic magnetograms. A cross analysis of not only GONG and HMI but also PHI data will follow.

Petrie participated in the ISSI team led by Louise Harra (PMOD, Switzerland), “Exploring The Solar Wind In Regions Closer Than Ever Observed Before”. Initially he contributed PFSS model results to this team effort. More recently, he used the Yet Another Feature Tracking Algorithm (YAFTA) code with HMI data to study the dynamic evolution of a coronal hole believed to have been magnetic connected to PSP, key to understanding the PSP in situ observations taken during its first perihelion. Using SDO Atmospheric Imaging Assembly (AIA) 193 angstrom images to identify the evolving coronal hole boundary, he found that the coronal hole area, magnetic flux, and bipole 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.

Petrie wrote a chapter entitled "Solar Magnetism and Radiation" with S Criscuoli and L. Bertello (NSO) for the volume "Solar Physics and Solar Wind", ed. N.E. Raouafi et al., AGU, Wiley (2021).

Service

Petrie has participated in regular meetings with NISP colleagues on the status of the GONG zero-point correction pipeline as it faces the approaching cycle 25 activity maximum and polar reversal. Petrie presents regular status updates to the group based on a selection of data products, and he suggests and helps to develop improvements to the pipeline.

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.

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 and (2) new initiatives in synoptic long-term observations for space weather. He and his colleagues used the photospheric magnetic field measured by NASA/NSO Spectromagnetograph, VSM/SOLIS, SDO/HMI and the surface flux-transport (SFT) model to determine the effect on polar fields from small short-lived active regions, which may develop and disappear on farside of the Sun. Statistical properties of active regions were derived from synoptic maps of the photospheric magnetic field between 1975 and 2019. Based on the properties of observed active regions with sufficiently short lifetimes, artificial active regions were created and inserted into an SFT simulation. It was found that adding active regions with short lifetimes to the far-side of the Sun results in significantly stronger polar fields and slightly delayed polar field reversals. The far-side active regions do not significantly affect poleward flux surges, which are mostly caused by larger long-living active regions. The far-side emergence leads to a weak continuous flow of flux, which affects polar fields over long periods of time. Pevtsov and his colleagues compared the vector magnetic fields and their changes with the position of observed area on solar disk. They discovered an important limitation that may affect the determination of the true magnetic field orientation. This limitation stems from our ability to interpret the differing character of the Zeeman polarization signals which arise from the photospheric line-of-sight vs. the transverse components of the solar vector magnetic field, and is likely exacerbated by unresolved structure (non-unity fill fraction) as well as the disambiguation of the 180° degeneracy in the transverse-field azimuth.

Future Research Plans

Dr. Pevtsov will continue his research on evolution of magnetic fields on the Sun, studies aimed at better characterization of benefits of an instrument at Lagrange L_5 and L_4 points for space weather forecasting, and the solar-stellar research. He will continue promoting development of next generation ground-based networks for solar research and operational space weather.

Service

Dr. Pevtsov is an NSO Associate Director and the Director of NSO Integrated Synoptic Program (NISP). In FY2021, he served on the Executive Committee of NASA's Living with a Star Program Analysis Group (LPAG). He 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.

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.

Kevin Reardon, Associate Scientist

Areas of Interest

Dynamics and structure of the solar photosphere, chromosphere, 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 and has contributed to training 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 procedures for the operations commissioning phase (OCP), as well as on the generation of observational experiment definitions for execution at the DKIST.

Reardon is collaborating with several graduate students at CU and beyond to perform research on a variety of topics. He has worked with Momchil Molnar (CU) on a study of the wave power and energy propagation in the photosphere and chromosphere using ALMA, IBIS, and IRIS. They published their results showing the distribution of wave power across different solar structures and calculating that these waves might not carry sufficient energy flux upward to heat the chromosphere. He has continued efforts with Ryan Hofmann (CU) to understand how well spectral inversions can incorporate the ALMA measurements of the temperature brightness in the millimeter continuum to better understand the structure of the solar atmosphere. Similarly, he worked with NJIT graduate student Yi Chai and Dale Gary on the study of oscillations in the sunspot penumbra measured with ALMA and Hα from Big Bear Solar Observatory. They were able to detect these oscillations in the millimeter continuum and correlate them with variations in the spectrally resolved chromospheric profiles. Reardon also collaborated with Johnathan Stauffer (CU) on the comparison between observations of the CO molecular line taken from McMath-Pierce Telescope and observations of atomic lines obtained simultaneously with IBIS at the Dunn Solar Telescope. Connected to this research, Stauffer submitted an ALMA Cycle 8 observing proposal, which was successfully selected, to get joint observations in the millimeter and in the 4μm CO lines in 2022. Reardon is also working with NSO post-doc Dr. 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 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.

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 is co-investigator on 11 DKIST proposals selected for possible execution in the first observation commissioning phase.

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.

Reardon was one of the co-investigators on an NSF proposal for developing innovative methods for combining observations from DKIST and GONG with the measurements obtained from the Parker Solar Probe and Solar Orbiter. The proposal involves studies of multi-viewpoint photosphere magnetic field measurements and comparison of synoptic coronal magnetic field maps from DKIST with fields extrapolated into the heliosphere. Reardon will lead efforts in preparing experiments to be carried out at total solar eclipses in 2023 and 2024 aimed at measuring the coronal electron temperature and large-scale structuring for comparison with in-situ measurements from Parker Solar Probe.

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, which solar scientists can use to make the DKIST data better amenable to scientific analysis of the calibrated DKIST data. When data from the commissioning phase 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 also serves on several community eclipse committees and on NASA's Study Analysis Group on exoplanet detection using transmission spectroscopy.

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 and operations; student engagement and community outreach.

Recent Research Results

Dr. Schad's recent work continues to provide a number of advancements relevant to remote sensing the coronal magnetic field using DKIST coronagraphic polarimetry. Schad & Dima (2021, Solar Physics, accepted) extends the work first published in Schad & Dima (2020, Solar Physics, V295) to consider the role of photospheric radiation symmetry breaking on forward synthesized polarized coronal emission lines. Meanwhile, Schad, Dima, & Anan (2021, APJ, V916) investigated the impact of a coronal downflow within the chromosphere of a sunspot and discovered the strongest magnetic field signals in the He I 1083 nm spectral line ever reported. Collaborative work with Dr. Tetsu Anan led to a detailed publication exploring the relationship between chromospheric heating rates and the spatial distribution of magnetic fields and currents in the photosphere and chromosphere (see Anan et al. 2021, ApJ, in press). In addition, Dr. Schad continues to work with Dr. David Harrington and colleagues on polarization modeling for DKIST (Harrington et al., 2021 JATIS 7c8002H and Harrington et al., 2021, JATIS, 7a8004H), and was involved in the DKIST telescope overview publication (Rimmele et al. 2020, Solar Physics, V295) and DKIST critical science plan (Rast et al., 2021, Solar Physics, V296).

Future Research Plans

As DKIST early science operations begins, Dr. Schad has been involved in a large number of proposing collaborations aimed at novel chromospheric and coronal observations using DKIST. Twelve proposed programs that he is involved in are being prepared for execution during DKIST Cycle 1. 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, *e.g.*, by acting as a judge in the Maui County science fairs, giving outreach talks to students on the Nepris website, and participating in the NOIRLab's Gemini's Journey Through the Universe. Tom also served as a mentor/co-mentor for two students during the 2021 virtual REU program run by the Boulder Solar Alliance.

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.

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 generating operational experiments based on user-submitted proposals and acting as Resident Scientist during science operations at the telescope.

Recent Research Results

Dr. Tarr performed a detailed study of the spatial distribution of unbalanced Lorentz forces in a simulation of the low solar atmosphere, in collaboration with colleagues at the US Naval Research Laboratory. We simulated the emergence of an untwisted torioidal flux rope. We found large filamentary or sheet-like pressure-balanced features associated with strong currents everywhere throughout the simulated atmosphere above the model photosphere. Comparison to semiempirical models and other large-scale MHD simulations that include a variety of physics suggest that these may be generic features of the quasi-static solar atmosphere. This work has implications for the formation, distribution, and dissipation of electric currents throughout the solar atmosphere, and for modeling the magnetic and plasma state above the photosphere. A paper based on this work is near submission to the Astrophysical Journal, for which I will be first author.

In a recently submitted paper, co-authors and Dr. Tarr describe the calibration, coalignment, initial results, and public release of an extensive data set that combines photospheric, chromospheric, and coronal observables. Coordination was keyed to our ALMA Cycle-4 solar observations and included co-spatial and -temporal observations from DST-IBIS/FIRS, Hinode-SOT/XRT/EIS, and IRIS, as well as synoptic observations from SDO. I was primarily responsible for the IBIS data and coalignment of the IBIS and ALMA data to SDO/HMI. Our initial results show spatial correspondence between the width of the H-alpha line observed by IBIS and the brightness temperature of ALMA band 3 data, which is a direct measure of the electron temperature in the emitting plasma. We also report on a spatially localized transient brightening that was temporally offset in multiple data series spanning the chromosphere and corona, and lasting approximately 20 minutes. This event is evidence for bi-directional energy transfer between the chromosphere and corona within a single dynamic process. This paper received an initially positive review and is expected to be fully published shortly. Colleague Adam Kobelski (NASA-MSFC) is first author.

In collaboration with Dr. Tarr's recently hired post-doc Dylan Kee, he has developed a new open boundary condition for 3D magnetohydrodynamic simulations. This boundary condition is based on a specific mathematical formulation of the MHD equations that allows for the transfer of large-scale electric current systems through the boundary in a way the preserves important dynamical constraints of the system, including energy and (potentially) magnetic helicity. It is intended to allow, first, non-reflecting boundary conditions that enable a broad array of numerical experiments, and second (and most importantly), data-driven simulations that use observational data to directly evolve 3D simulations of the low solar atmosphere. Currently, the non-reflecting boundary condition has been made fully functional, and the extension to a data-driven framework is well underway. Two papers describing the technique are near completion, one detailing the method itself and how it allows for data-driving (first author myself), and the second focusing on the application to non-reflecting boundary conditions (first author Dylan Kee).

Observational comparison of radiative losses versus magnetic fields inferred at multiple heights in the solar atmosphere using the Si I and He I lines at 1000nm. The primary result is that we found a significantly different relationship between the magnetic field strength (both photospheric and chromospheric) and the radiative losses within plage interior regions compared to plage periphery regions. This implies either a shift in the proportions of relevant heating mechanisms between the two regions, although our observations could not conclusively distinguish between different proposed models. First author: T. Anan (NSO).

Dr. Tarr is building an extensive set of radiative MHD simulations using the MURAM code, in collaboration with colleagues at UH-IfA and HAO. The simulations cover quiet sun, weak network, and strong plage conditions, including the development of small pores, and will encompass ~10hrs of solar time at a 40s cadence once complete. These simulations are matched to a series of expected observations using the DL-NIRSP instrument at DKIST, and are intended to enable the rapid inversion of spectropolarimetric of the new data. Publications still TBD.

Dr. Tarr is also involved in developing a new method for the ad hoc polarization calibration of spectropolarimetric data based on numerical optimization techniques. The new method relaxes certain assumptions about the form of the Mueller matrix describing telescopes to use a more general, and physically consistent, form for the matrices, which results in a more physically meaningful decomposition of the Stokes vector. Essentially, the new method conserves energy, whereas previous methods did not, and this has a direct effect on recovered observables inferred from the Stokes vector, e.g., the magnitude of the magnetic field. This paper is already written and will be submitted shortly, first author S. Jaeggli (NSO).

<u>Future Research Plans</u>

My number one research priority over the remainder of this year is to complete the proof-of-concept demonstration of the data driven simulations. Over the last year I have completed the computational framework, and, with the addition of my post-doc Dylan Kee, have made great progress on the stability of the code. I am confident that this proof-of-concept, and the associated two initial papers on the topic, can be submitted by the end of the fiscal year; again, I stress that this is due in large part to the hiring of post-doc Dylan Kee to assist on this project. First author, paper 1: Tarr; paper 2: Kee.

A side-effect of the new theoretical framework for data-driven simualtions mentioned above is a new mathematical method for tracing the propagation of MHD wave energy through an inhomogeneous atmosphere. I am exploring the viability of this method in collaboration with NSO post-doc Dylan Kee and with colleages at the University of Newcastle, Australia. This project likely has observational consquences for DKIST, but the details are still in the realm of active research.

As mentioned in the *Recent Research Results*, a paper analysing force-balance in a quasi-static solar atmosphere is near completion, and should be submitted within a couple of months. This project found a rather interesting distribution of currents in the simulated solar atmosphere that may be related to the so-called Parker Problem, i.e., the spontaneous formation of current sheets that likely contribute to the heating of the solar atmosphere and other X-ray emitting stellar atmospheres. I anticipate continuing this collaboration to further explore that possiblity. First author: Tarr.

The collaboration to analyse coordinated observations between ALMA, DST, IRIS, and Hinode completed a major milestone by submitting Paper 1 and performing a formal public release of the data. With that achieved, the collaboration has shifted focus to the time-dynamics of the combined data series from IBIS and ALMA. There is an expected temporal relation, proposed by Dr. R. Rutten, between these observables that we will search for and report on (either confirmation of its existance or lack thereof) in an upcoming issue of the Frontiers journal (Paper 1). A second effort is to study the propagation of waves and disturbances through a model of the observed region using MHD simualtions. These simulations are currently being run by myself on the NASA Plieades compute node. They will provide an excellent test-case for the new wave-energy tracer mentioned above, and will form the basis of Paper 2 associated with this project. First author, paper 1 and paper 2: Tarr.

Complete running all Muram simualtion as part of the SPIN4D project, in collaboration with UH-IfA and HAO.

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 3: responsible for developing procedure to generate experiments from submitted proposals. This work is complete.

Served on Cycle 1 Experiment Generation Team (ongoing) – Responsible for transforming accepted proposals from Cycle 1 into experiments that can be run through DKIST’s Telescope Control System.

Served on Cycle 1 Operations and Commissioning Phase as a Resident Scientist – guiding the running of experiments at the summit (ongoing).

Expected to participate in some combination of Proposal Call, Scientific and Technical Review, Experiment Generation, and Resident Scientist for DKIST Cycle 2.

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 study the temporal variation of the sub-surface flow measurements during the early phase of solar cycle 23, S. Tripathy and collaborators used data from Michelson Doppler Imager (MDI) on board Solar and Heliospheric Observatory (SOHO). The data is processed through the standard ring-diagram analysis (RDA) pipeline to compute flows to probe the near surface shear layer which extends up to a depth of about 35 Mm. It is found that the associated errors with flows obtained from MDI are smaller in magnitude as compared to the errors measured from the Global Oscillation Network Group (GONG) data. They noted that the errors in flow measurements are uniformly distributed across the disk, with the smallest errors near the disk center. This work is funded by a NASA grant.

In order to investigate how the sub-surface flows agree between different instruments, Dr. Tripathy and collaborators have derived subsurface flows from the GONG, MDI and Helioseismic and Magnetic Instrument (HMI) observations covering the period of May –July, 2010. It is clear that the large-scale flows derived using the GONG RDA pipeline are consistent with each other near the disk center while small deviations are noted near the higher latitudes. Center-to-limb corrections will be carried out to obtain a comprehensive picture.

Dr. Tripathy in collaboration with several other scientists from various institutes studied the solar activity in relation to spotless days during the descending phase of solar cycles 11-24 to predict the amplitude of sunspot cycle 25. Using precursor methods, it is deduced that the solar cycle 25 will be weaker than cycle 24 and will peak between February-March of 2024.

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. In this context, using the long-term solar oscillation frequencies from the Global Oscillation Network Group, they found that that the seismic minima in deeper layers have been occurring about a year earlier than that at the surface for the last two consecutive solar cycles. The findings further demonstrate a decrease in strong magnetic fields at the base of the convection zone, the primary driver of the surface magnetic activity.

Dr. Tripathy and collaborators have investigated the behavior of the quasi-biennial oscillation (QBO) seen in the observed oscillation frequencies and many other solar activity indices by focusing the differences between solar cycles 23 and 24, which have the lowest amplitudes in recent history. Using frequencies computed from GONG, MDI and HMI, they reported that the number of detections of QBO-like behavior is reduced in cycle 24 compared to cycle 23. The study found no correlation between penetrating depths or oscillation frequencies which leads to believe that the magnetic field associated with generating the QBO must be located in the near-surface region.
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.

Future Research Plans

S. 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. 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 continue his participation in the international collaborative project to derive a better solar rotation profile using the longest and best possible splitting coefficients and inversion technique. Dr. Tripathy will further continue his work on subsurface flow measurements over a period of more than twenty years and investigate their variations with different solar cycles. Dr. Tripathy will work on various NASA funded proposals where he serves as a PI and 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 has been scrutinizing and apprising 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 and answers queries from external users. Dr. Tripathy actively participated in the new GONG camera selection procedure by validating the observations and providing other required scientific support. Dr. Tripathy participated in writing of several proposals e.g. the ng-GONG proposal submitted to NSF. Dr. Tripathy is also actively participating in the science discussions for a future space based solar mission, "Multiview Observatory for Solar Terrestrial Science (MOST)".

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 has been 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 the DKIST Operations Commissioning Phase. She has been mentoring numerous summer REU and SRA students over the years. 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; spectropolarimetric 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 helping to create 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). It has been incorporated as the forward engine in two recently developed 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 (Ruiz Cobo et al., 2022 Accepted by A&A). RH is also extensively used as Non-LTE spectral line modeling code for RADYN simulations.

Dr. Uitenbroek has contributed to several papers investigating the diagnostic capabilities of spectropolarimetric observations, including in photospheric Zeeman sensitive lines, and the Mg I 12-micron lines (Quintero Noda et al, 2021, A&A 652A, 161Q; Li et al, 2021, A&A 646A, 79L). He also contributed to a paper using machine learning to make DeSIRe based inversions more efficient by choosing better starting conditions.

Future Research Plans

Development and maintenance of the RH code will continue. Concentration will be on the new inversion code DeSIRe.

Service

Dr. Uitenbroek 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, helps guide the organization of DKIST Data Training workshops, and teaches lectures in these 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. Han chairs the NSO Scientific Personnel Committee.

Friedrich Wöger, Senior Scientist

Areas of Interest

Image reconstruction techniques; adaptive optics; two-dimensional spectroscopy and spectropolarimetry; DKIST instrument systems, in particular the visible broadband imager (VBI); DKIST wavefront correction system (WFC); DKIST data handling system (DHS).

Recent Research Results

F. Wöger studies image processing techniques related to enhancing the resolution by reducing the impact of atmospheric turbulence (e.g. image reconstruction using triple correlation), photometric calibration of images using models for atmospheric transfer functions, and denoising of images impacted by noise sources ranging from characteristic detector artifacts to photon noise. This work provides the foundation for the characterization of the photometric precision in images generated by DKIST's imaging instrumentation such as VBI and visible tunable filter (VTF).

Wöger oversees, guides and aids in the definition, construction, integration and testing of all DKIST instrumentation subsystem components.

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 is researching denoising techniques using neural networks. 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. He has been involved in the DKIST VBI instrument effort as its principal investigator, overseeing its construction at NSO Boulder, and its integration and verification at the DKIST site on Maui. As the DKIST Data Handling Scientist, he has been supervising the DKIST data handling system development, ensuring the integration and verification of the system on Maui. Furthermore, Wöger has created and is responsible for the data model for DKIST that is a vital interface for the DKIST Data Center in Boulder. As the DKIST Wavefront Correction Scientist, Wöger has guided the DKIST WFC team towards successful site acceptance of the WFC subsystem at DKIST.

Wöger is supervising a calibration pipeline engineer who implements the prototype data calibration pipelines for the majority of DKIST's first light instrumentation. These pipelines are provided to the DKIST Data Center for integration into its automated system.

Wöger will guide and support the efforts for new instrumentation for DKIST; he is involved in the multi-conjugate adaptive optics program, the procurement of new optics for the facility instrument distribution optics, the upgrade with new infrared sensors and other instrumentation efforts.

Wöger is part of the Technical Review Committee for DKIST proposals and is participating in the technical feasibility review of proposals for DKIST observing time, and is involved in generating Experiments for the DKIST Observatory Control System that are executable at the DKIST site.

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
AOX	Adaptive Optics Associates – Xinetics Inc.
APRPP	Annual Progress Report and Program Plan (NSF)
APL/JHU	Applied Physics Laboratory, Johns Hopkins University
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 (Hawai‘i)
AWS	Amazon Web Services
BE2E	Boulder End-to-End (DKIST)
BiFOIS	Birefringent Fiber-Optic Image Slicer
BLNR	Bureau of Land and Natural Resources
BB	Big Bear (GONG site)
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)
CDO	Chief Diversity Officer (AURA)
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
CMMS	Computerized Maintenance Management System
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

CT	Cerro Tololo (GONG site)
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
DD	Diverse Discussions (NSO)
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
DE&I-WG	Diversity, Equity, and Inclusion Working Group (NSO)
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
FCR	Final Construction Review
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
FSR	Free Spectral Range
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 (DKIST)
GRIS	GREGOR Infrared Spectrograph (GREGOR Telescope)
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
HAZEL	HAnle and ZEeman Light
HCP	Habitat Conservation Plan (HI State Division of Forestry & Wildlife)
HCS	Heliospheric Current Sheet
HIDEE	Heliophysics Infrastructure and Data Environment Enhancements (NASA)
HIS	Heavy Ion Sensor
HLS	High-Level Software
HMI	Helioseismic and Magnetic Imager
HNP	Haleakalā National Park
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)
IAA	Interagency Agreement (US Government)
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
JCI	Johnson Controls
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
LE	Learmonth (GONG site)
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
ML	Mauna Loa (GONG site)
MOU	Memorandum of Understanding
MLSO	Mauna Loa Solar Observatory (HAO)
MOI	Memorandum of Intent
MPI	Message Passing Interface
MPR	Midterm Progress Review
MR	Management Reserve
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
NCSP	NSO Coudé Spectro-Polarimeter (DKIST)
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
NSOC	NMSU Sunspot Observatory Committee
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
PLC	Programmable Logic Controller
PM	Project (or Program) Manager (NSO)
PM	Preventive Maintenance
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
RTC	Real-Time Control (DKIST)
SACNAS	Society for the Advancement of Chicanos and Native Americans in Science
SAMNet	Solar Activity Monitor Network
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 Hawaiʻi)
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
SRC	Science Review Committee
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)
SWx-TREC	*Space Weather* Technology, Research and Education Center (CU Boulder)
SUC	Science Use Case
SUCR	Summit Control Room (DKIST)
SUMI	Solar Ultraviolet Magnetograph Investigation (NASA, MSFC)
SUP	Special Use Permit
SV	Science Verification
SVP	Science Verification Phase
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
TD	El Teide (GONG site)
TED	Technology, Entertainment, Design (YouTube)
TEOA	Top End Optical Assembly (DKIST)
TI	Tenant Improvement
TMA	Telescope Mount Assembly
ToO	Target of Opportunity
TOP	Technical Operations
TPC	Total Project Cost
TRC	Technical Review Committee
TRACE	Transition Region and Coronal Explorer
TRC	Technical Review Committee
UA	University of Arizona
UD	Udaipur (GONG site)
UH	University of Hawaiʽi
UBF	Universal Birefringent Filter

UCSC	University of California Santa Cruz
UK	United Kingdom
UPS	Uninterruptible Power Supply
UROP	Undergraduate Research Opportunities 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)
WFS	Wavefront Sensor (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