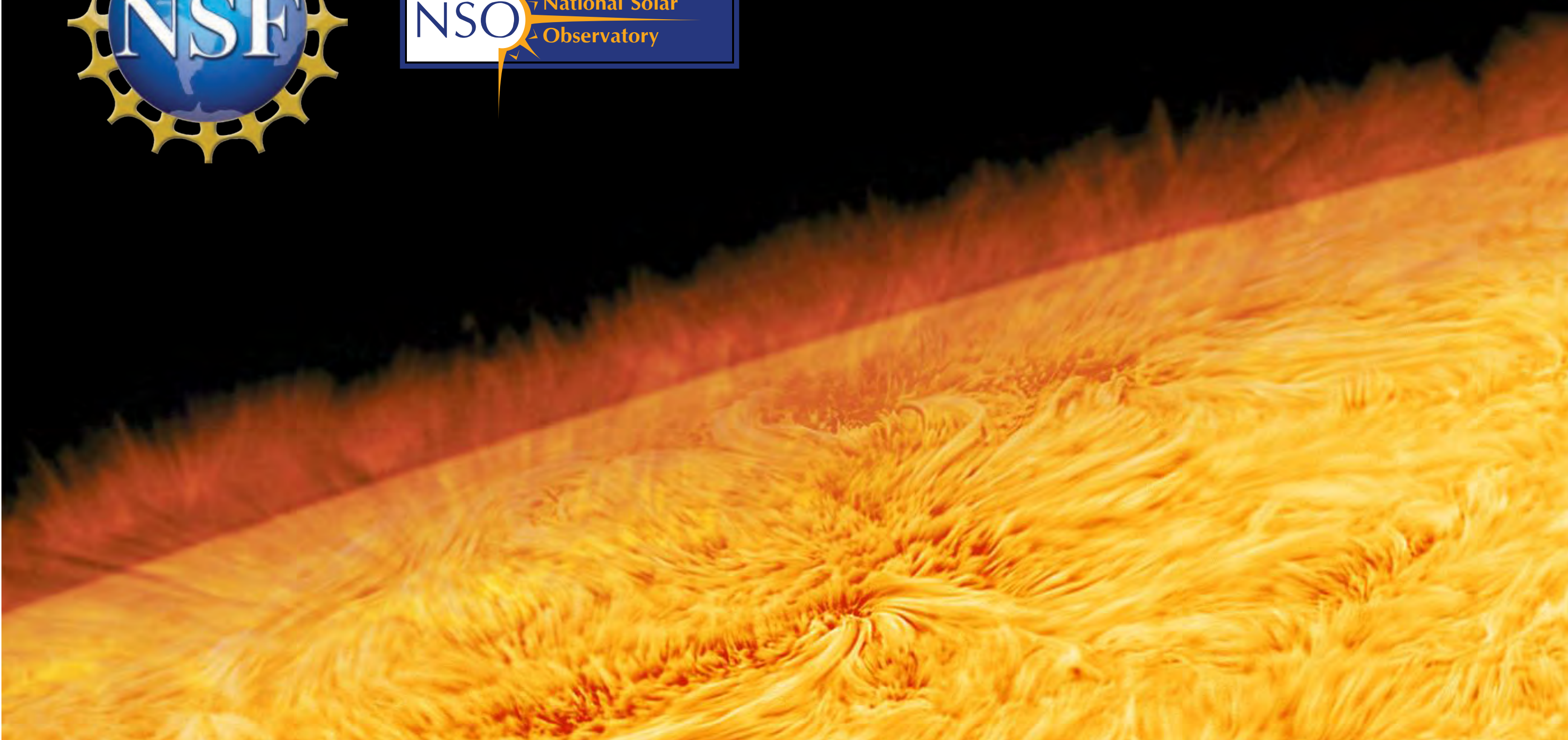
NSF

NSO National Solar Observatory



Mid-Term Progress Report

FY2020–2024

Long Range Plan

AURA

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

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1 EXECUTIVE SUMMARY

In 2013, the Association of Universities for Research in Astronomy (AURA) submitted to the National Science Foundation (NSF) a comprehensive proposal to lead a transformation of current US ground-based solar astronomy capabilities. This transformation has as a critical component the management and evolution of the National Solar Observatory (NSO) from the operation of its former major telescope facilities to the initiation of science operations at the transformative Daniel K. Inouye Solar Telescope (DKIST, Figure 1-1), the most formidable telescope ever built to observe the Sun (the current status of DKIST construction is presented in Section 4.1). As a result, in 2015, AURA and the NSF started a 10-year Cooperative Agreement (CA) that undertakes this transformation of ground-based solar astronomy in the US. The present Midterm Progress Report (MPR) and Long-Range Plan (LRP) outline the progress made to date and revisit, with new and more accurate information, the plan for early operations of the DKIST (Section 5 with special emphasis on Sections 5.3, 5.4, and 5.5).

NSO's long-range vision includes key measurements of the solar magnetic field on spatial and temporal scales on which the field interacts with the dynamic solar atmosphere and on which it evolves over the solar cycle. The former requires bringing online the large-aperture DKIST, while the latter requires long-term synoptic measurements of the ever-changing solar magnetic field as performed by the NSO Integrated Synoptic Program (NISP). Future NISP plans are presented in Section 6. A significant component of the NSO is to provide well-calibrated data to the community from a functional Data Center, which is critical for the success of our mission. Another critical aspect is the development of sophisticated tools that will generate "science-ready" data products that allow the study of highly structured magnetic fields that permeate the solar atmosphere, as well as training of the community in the use of these tools (Section 7). This report addresses in detail the efforts of NSO in both areas.

Figure 1-1. The National Science Foundation's Daniel K. Inouye Solar Telescope at Haleakalā, Maui, Hawaiʻi.

While the 2020 Astronomy and Astrophysics Decadal Survey is ramping up its activities, the 2010 Astronomy Decadal Survey, *New Worlds, New Horizons* (NWNH) (2010), made clear the importance of solar investigations that touch on its major science objectives and themes. NSO-supported facilities and instruments address several of these including: cosmic order, where the Sun acts as the Rosetta stone to understanding stars, which in turn are the foundation for understanding galaxies and the rest of the universe; habitability of planets, through understanding stellar activity, winds and mass loss which are related to magnetic fields, and the Sun is our primary laboratory for studying their fundamental physics (Frontiers of Knowledge) in an astrophysical setting. NWNH points out that DKIST will enable critical tests of models of these solar plasma processes and the NWNH *Midterm Assessment* (2016) states that DKIST will be "launching unprecedented capabilities for studying variability and magnetic phenomena in the Sun, with broad implications for plasma processes that underlie a wide variety of astrophysical phenomena throughout the universe."

The 2013 Solar and Space Science Decadal Survey, *Solar and Space Physics: A Science for a Technological Society* (STS), sees the DKIST as part of the "enabling foundation" for progress in solar and space physics. The survey states that DKIST "will be revolutionary in the capabilities it will provide to measure the dynamics of the magnetic field at the solar surface down to the fundamental density length scale. It will be able to remotely sense coronal magnetic fields where they have never been measured." The survey goes on to encourage NSF to fully fund its operation and data analysis: DRIVE (Realize) "requires adequate, sustained funding from NSF for operation, data analysis, development of advanced instrumentation, and research grant support for the DKIST user community." Within the bounds of the 2015 CA proposal, NSO has worked closely with NSF to develop an economical model for DKIST operations that is presented in this document (Section 5).

The STS survey also gives strong support to both ground- and space-based synoptic programs that provide measurements of solar variability and place high-resolution measurements in perspective. In particular, the survey strongly supports continuation of the kind of data obtained by NISP: "Synoptic and long-term measurements from ground-based instruments are essential for capturing the complex dynamics of geospace and observing long-term trends."

The NSO has undergone a significant transition over the past five years in preparation for DKIST operations. NSO presence in Tucson (AZ) and Sunspot (NM) ramped down almost entirely in 2017 as part of a three-year transition that relocated NSO Headquarters (HQ) to the East Campus of the University of Colorado (Boulder, CO) and that established the DKIST Science Support Center (DSSC) as the new base facility in Pukalani (Maui, HI). Section 4.2 explains the timing during which this NSO relocation occurred. In Maui, at the Haleakalā summit, DKIST is well into its last year of the Integration, Testing, and Commissioning (IT&C) phase and is firmly progressing towards a start of operations in late spring 2020. The five first-light DKIST instruments are being finalized at partner facilities all over the world or are ready for integration at the Coudé room at the telescope. Thanks to newly obtained support from the National Oceanic and Atmospheric Administration (NOAA) (Section 4.3), the distributed Global Oscillations Network Group (GONG), a component of NISP, continues to operate reliably at its six sites from where it provides data for monitoring space weather conditions and continued tracking of the Sun's interior flows that drive the solar dynamo. The Synoptic Optical Long-term Investigations of the Sun (SOLIS) facility, also operated by NISP, was moved from the Kitt-Peak Vacuum Tower (KPVT) down to the Tucson area in 2014 and, later, to its permanent site at the Big Bear Solar Observatory (BBSO) in California. SOLIS will resume operations in December 2019 (Section 6.3).

The past five years have also seen the consolidation of the early science phase with DKIST. The Science Working Group (SWG) has led the definition of the Critical Science Plan (CSP). The CSP includes high-priority science observations that the community desires to accomplish during the first years of operations (Section 5.2). Also, an important goal for the early operations phase is to optimize instrument and overall system performance and to refine and optimize service-mode operational procedures. The broader community has been able to provide input to the CSP through a series of eleven workshops organized by NSO. The community response to the CSP development workshops was overwhelmingly positive, with a large number of scientists being involved with ground-based solar observations for the first time. While NSO provided financial and logistical support, the specific research theme and selection of participants for the workshops was left to the local scientific leads; this ensured that the community self-organized in selecting both the most relevant topics and the most involved scientists. As a result, the DKIST team has available 260 Science Use Cases (SUC) that describe in various levels of detail the observations needed to address compelling scientific questions about the Sun. These SUCs are being analyzed by the SWG, which evaluates the level of definition and relevance.

The McMath Pierce Solar Telescope (McMP) at Kitt-Peak was fully decommissioned as a solar facility in 2017, and it is being integrated as part of the Kitt Peak Visitor Center (KPVC) of the Kitt Peak National Observatory (KPNO). The Kitt Peak Vacuum Telescope was demolished in the first two months of 2019. In Sunspot, the Dunn Solar Telescope (DST) continues to be one of only four solar facilities in the world equipped with adaptive optics (AO) and modern instruments. NSO worked closely with the New Mexico State University (NMSU) Astrophysics Department to establish a partnership to operate the DST and secure continued availability of the telescope to the community. Since 2018, the NMSU-led Sunspot Solar Observatory Consortium (SSOC) has been in charge of the scientific planning of the telescope and runs the Visitor Center. The NSO supports these activities by operating the site facilities. Divestiture of the McMP and the DST is in response to the 2012 NSF/AST Portfolio Review Committee recommendations and is described in Section 4.4.

In 2017, the NISP Data Center successfully completed its relocation to Boulder and started providing data to the NISP stakeholder community from there (Section 4.3). The DKIST Data Center has advanced through its phases of design and definition, culminating with a Critical Design Review (CDR) in February 2019. The two data-center groups will merge into a unified Observatory-wide Data Center that will navigate the NSO into an unprecedented Big-Data era that is approaching all areas of research including solar physics and astronomy. The future operations of the DKIST Data Center is presented in Section 5.4 and the operations for NISP in Section 6.4. Section 9 describes the implementation of the unified Data Center that occurs only after the first phases of DKIST operations and once the functionality of the DKIST data management system has been tested.

To cope with the challenges posed by this era and inspired by the intrinsic complexity of the data DKIST will produce, we have created the NSO Community Science Program (NCSP) as a new synergistic program that encompasses existing expertise at the Observatory and helps to fully exploiting the DKIST data. NCSP focuses on science efforts demanded by the solar community as users of the data from NSO facilities and offers training to the community for producing science-ready data products. NCSP uses supplemental funding awarded for the first time in 2018 to the Observatory to develop higher level data products from the DKIST. Section 7 describes the status of these efforts and the current and future plans of NCSP.

The transformation of NSO is profound and reaches all areas of the Observatory. In 2016, NSO started an engaging Education and Public Outreach (EPO) program with presence at both the Colorado and Hawaiʻi sites aimed at increasing the involvement of students at NSO, increasing community engagement, and increasing the visibility of the NSO, its DKIST and NISP programs, and its scientific achievements as expected from an institution responsible for a facility of the class of DKIST (Section 8).

By adopting the WEBUD budgeting tool developed by AURA/CAS, business practices at NSO have been adjusted to the standards of other AURA centers. Section 10 presents the five-year budget for each of the NSO programs using a multiyear WEBUD mode.

The consolidation of the DKIST and NISP programs in Boulder offers unique opportunities to prevent past duplications of effort, maximize resource allocation, and promote a unified culture at the Observatory. To facilitate these developments, NSO is planning to develop progressively over the next five years a matrix structure of the Observatory (Section 9) that will promote synergies while it continues supporting the community in advancing the frontiers of solar physics. The new structure establishes a minimal matrix organization of the NSO that allows for cross-program services in aspects, such as administration, IT, EPO, and data. By minimal we mean that the matrix system reallocates resources—typically dedicated to one program—only when there is a clear workforce expertise utilization rationale or an employee interest compatible with regular operations. The time frame for the implementation of various components of the matrix will carefully dovetail with the end of the DKIST construction phase and the early operations of the facility (Section 5.5.5).

The NSO instrumentation program is divided into the ongoing efforts at DKIST (Section 5.5) and NISP. As part of the first-light suite of facility-provided instruments, DKIST includes a state-of-the-art higher order AO system that uses one deformable mirror (DM) with more than 1200 actuators. Such a system will provide diffraction-limited images of a 4m-aperture telescope over a central field-of-view (FOV) of ten arcseconds or so, as only over this area are the wavefront errors induced by atmospheric turbulence closely correlated. Other points of the FOV farther from the center are affected by different wavefront errors and need additional DMs for its correction. The technique that uses multiple DMs and corrects a larger FOV is known as multi-conjugate adaptive optics (MCAO), and it is an area of active technological research in astronomy. MCAO is at the very heart of the instrumentation efforts within the DKIST program and is part of the planned second generation of instrument developments for the facility. A variety of upgrades for the first generation of DKIST instruments are also occurring under the DKIST program, most notably the fabrication of a second etalon for the Visible Tunable Filter (VTF), an instrument that uses optics produced to challenging specs similar to those required by the Laser Interferometer Gravitational-wave Observatory (LIGO).

The NISP focuses its instrumentation efforts on the refurbishment of the GONG network (Section 6.2). Owing to the role of the GONG network as the primary provider of reliable and uniform input data for basically all operational and research space-weather models, NISP received in 2015 a supplemental funding of $2.5M destined to ensure the continuation of the network for another solar cycle. The main technical components of the GONG upgrade project are the procurement of new liquid-crystal polarization modulators; new detectors; and tunable H-alpha filters. Only the first effort has been deployed to the sites, while the other two still require further developments, including interactions with potential vendors. No upgrades of the SOLIS suite of instruments is currently planned, and the program concentrates on bringing the facility back to an operational level similar to the one it had in Tucson.

The future of NISP relies on the replacement of the GONG network and SOLIS with a suite of instruments that fills the needs of the community and provides alternatives to space-based assets. The Next Generation GONG (ngGONG) (also referred to as the Solar Physics Research Integrated Network Group (SPRING) from a similar ongoing effort in Europe) is the most advanced concept that meets these needs and has broad international and national support. ngGONG is a ground-based network of telescopes capable of high-sensitivity measurements of the solar vector magnetic field, primarily designed to enable data-driven models describing the evolving magnetic connectivity between the Sun and the Earth (Section 6.5). ngGONG will also ensure the continuity of decades-long helioseismological observations that monitor the solar interior and the relationship between solar activity and the conditions below the photosphere. We anticipate the breadth of knowledge that ngGONG will provide about the magnetic linkages in the solar system to transfer into the developing field of exo space-weather and its impact on the habitability of other worlds.

To continue the diversification of NISP activities—as required by a 50% budget reduction over the past five years—the program started a collaboration with laboratories in Boulder with a space background to define a lightweight magnetograph for space missions. A concept for a compact magnetograph (CMAG) that condenses GONG functionality into an instrument that weighs only a few kilos and no more than ten inches long is under development at NISP. Its potential is described in Section 6.6.

As part of the HQ relocation to the CU Boulder campus, NSO has taken the necessary steps to integrate itself into the structure of the University, including defining the formal role of the Observatory as part of the CU Boulder administrative system (Section 4.2). In 2016, AURA and CU Boulder signed a Cooperative Agreement that laid out the foundations for a multi-year collaboration in the context of the relocation of NSO HQ to campus and the construction of DKIST. The CA establishes NSO as a research institution affiliated with the Vice Chancellor of research, and as such, it can manage bidirectional cash flow mechanisms to support the various forms of existing collaborations, such as lease payments, student-stipend transfers, or research-collaboration fund transfers. The CA also describes the components of the Hale Program, such as support for graduate students, post-docs, and faculty positions. Two 50% shared tenure-track faculty positions were filled in 2016 and 2017 with appointees that are now integrated into the CU Boulder Astrophysics and Planetary Science (APS) Department. As members of the APS Department, they regularly interact with students who also have the opportunity to meet other NSO scientists. At any given time, about five graduate students are present at NSO as part of their graduate activities or PhD projects. NSO scientists may act as PhD mentors of APS graduate students by achieving a temporary 50% Professor Adjunct position in the Department. The three-year-termed visiting faculty position (100% funded by CU Boulder) has been advertised and filled twice, first in 2015 at the APS Department and, in 2018, at the Physics Department, to broaden the reach of NSO in the CU Boulder student pool. Other collaborations exist such as the exhibit at the CU Boulder Fiske Planetarium project with the NSO EPO group.

The collaboration with CU Boulder has deepened NSO's reach to academia throughout the university system in the US, thanks to various editions of the Hale Collaborative Graduate Education (COLLAGE) that includes CU, the University of Hawaiʻi, New Jersey Institute of Technology (NJIT), New Mexico State University, and Montana State University. Starting in 2013, a total of seven different examples of the COLLAGE course have occurred, providing graduate-level courses on solar and stellar physics that are not available at any other institution in the US. By using remote education techniques, we increase NSO's access to the younger generation of astronomers and broaden the participation of students in NSO-related programs.

NSO Headquarters in Boulder is located on the third floor of the Space Science Center (SPSC) building that also hosts the Laboratory for Atmospheric and Space Physics (LASP), the lead institution of the CU Boulder bid to host NSO HQ. The first floor of the SPSC comprises common areas that both institutions can use, including large meeting rooms and Data Center space. Currently, first-floor space is used by DKIST and NISP and is offered by CU to NSO at no cost. The NSO instrumentation laboratory is hosted on the first floor. DKIST has used this lab space for first-light instruments and facility services, including the AO system and the Polarization Analysis and Calibration (PA&C) unit that will be integrated at the DKIST Gregorian focus in 2019. NISP uses a small fraction of the optical lab for their GONG refurbishment needs, but also uses the GONG engineering shelter units located within walking distance from the SPSC (Figure 1-2). These units provide access to solar light and allow for testing and verification of optical components and new instrument concepts.

Figure 1-2. The GONG engineering units on the east campus of the University of Colorado Boulder.

Our Boulder location has also resulted in the integration of NSO's Research Experience for Undergraduate (REU) program with the existing REU program in Boulder that includes the various institutions forming the Boulder Solar Alliance (BSA), with LASP as PI-institution of the joint REU proposal). Access to the broader Boulder solar community offers the students and their mentors a fundamentally richer experience. FY 2019 is the last of the three years of funding approved for the existing REU program, and we are already in contact with the other Boulder institutions to prepare a proposal for a new three-year program.

The DKIST Science Support Center (DSSC) in Pukalani was inaugurated in early 2018. Its primary function is to provide offices and work areas for 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. In addition to workspace, the DSSC supports specialized functions, including: hosting a remote operations room where staff and visiting scientists can participate in and guide summit operations; limited initial data processing and preparation for data transfer to the Boulder-based Data Center; and providing a small instrument laboratory for maintenance and future upgrades to DKIST instrumentation. During the steady-state operations phase, 35 permanent and visiting staff will use the facility daily. Thanks to its proximity to the UH Advanced Technology Research Center (ATRC) building—only a few hundred feet apart—the function of the DSSC is similar to Gemini's base facility in Hilo that's collocated the base facilities of other astronomical institutions on the island.

NSO continues to support the Akamai Workforce Initiative (AWI), 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. Both the REU program in Boulder and the AWI in Hawaiʻi have resulted in students redirecting their careers to solar-physics-related opportunities. NSO is investigating the possibility of integrating the REU and Akamai programs and providing similar mentoring opportunities at the two sites.

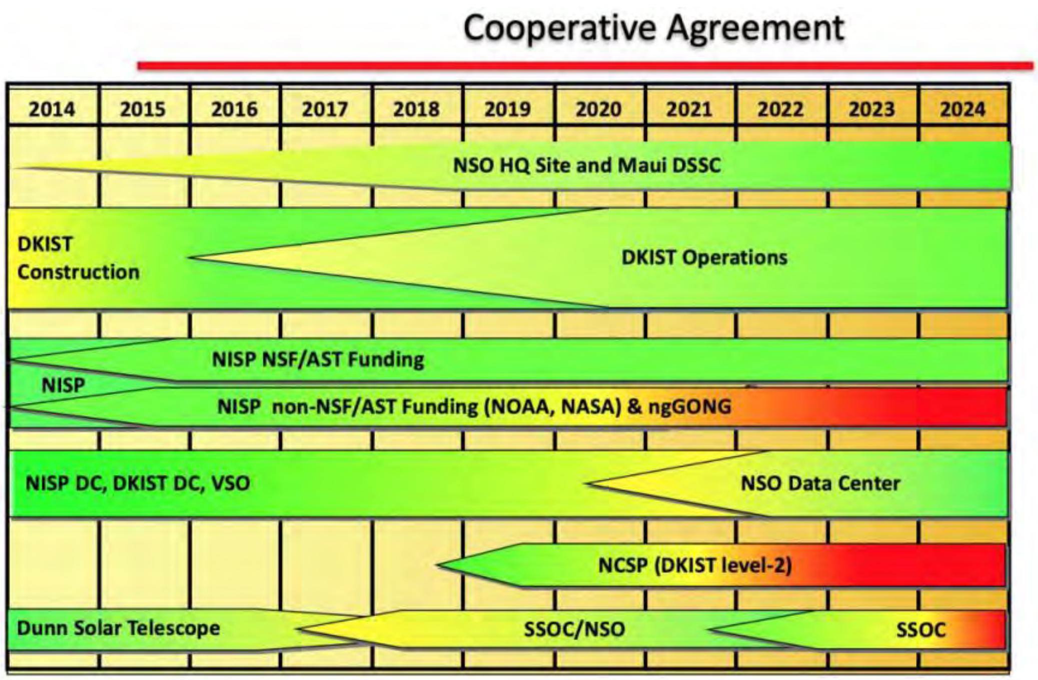


Figure 1-3. Strategic road map for NSO facilities and programs. Green color is used for scope included in the Cooperative Agreement funding profile presented in Table 10-1. Transitions to red indicate funding from existing supplemental funding from NASA or the NSF that runs out over the period of this Long-Range Plan or that have not been funded yet.

Over the second half of this Cooperative Agreement, the NSO will consolidate its position as the primary provider of essential ground-based solar facilities to the US solar community once DKIST comes online. NSO will make 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. While DKIST operations ramps up, NSO will continue to provide scientific and instrumentation leadership in high-resolution studies of the solar atmosphere in the visible and infrared, synoptic observations of solar variability and helioseismology, and establish links with other areas of astronomy.

An updated version of the NSO long-range road map presented in the CA proposal is shown in Figure 1-3. It has been coordinated with the solar community, the NSO Users' Committee, and the AURA Solar Observatory Council (SOC). It has strong community buy-in for the long-term future of ground-based solar physics. Ongoing and future NSO efforts are summarized in the figure and explained in detail in the body of this document. The ongoing program is strongly focused toward NSO operations in the DKIST era, while still maintaining NSO's support to synoptic science, community efforts, and a unified approach to data management and distribution. Activities that are supported via supplemental funding requests or external funds and that run out over the next five years appear in red. Continuing these activities will require identifying new funding sources, including the ngGONG effort.

A vital strength of the NSO, necessary to achieve its mission, is its scientific staff, who provide support for the users of NSO facilities, actively and visibly participate in the community, develop advanced instrumentation, participate in educational outreach, establish new initiatives, and engage in frontier research. A further strength is that, as a federally-funded research and educational institution, the NSO is able to provide leadership, continuity, and stability for the conduct of long-term programs (Figure 1-4) and projects that are a scientifically necessary component of solar and solar-terrestrial research. Finally, the interdisciplinary nature of, and multi-agency participation in, solar astrophysics enables the formation of productive partnerships with the NSO that result in a stronger and broader-based program.

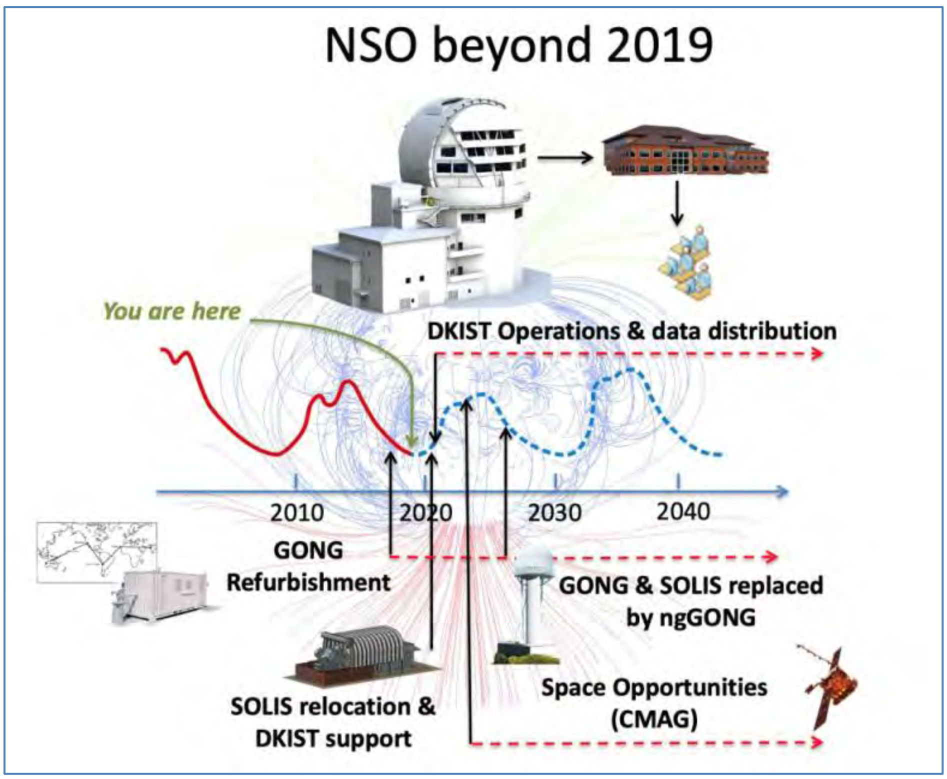


Figure 1-4. Long-term vision of NSO over half the lifetime of DKIST.

2 INTRODUCTION: NSO MISSION AND GOALS

The National Solar Observatory mission and goals are founded on community-based solar and astrophysical research objectives and requirements, and enable effective responses to new discoveries, synergistic research with planned and future space missions, and testing the results of advanced numerical models of solar and heliospheric phenomena.

2.1 NSO Mission and Statement of Work

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 its mission by:

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

The AURA/NSO Statement of Work includes working closely with NSF and the scientific research community to ensure that, within available resources, NSO supports, sustains, and advances frontier science as enabled by NSO's unique research capabilities and as promoted through a culture of excellence. Working in close collaboration with NSF and the university and broader scientific communities, the NSO is expected to perform the following tasks:

1. Develop and employ effective mechanisms for engaging the Observatory's full range of stakeholders in order to ensure that NSO facilities, services and programs best reflect its community's evolving needs and priorities.
2. Operate and modernize (as appropriate) the existing observational facilities and computational infrastructure and ensure that the primary criterion for their utilization be the scientific merit of the proposed research as judged by appropriate, merit-based review processes.

3. Serve as steward of high-quality scientific data from the NSO facilities on behalf of the US solar physics and space weather communities, through pipelines, reduction processes, dissemination and archiving.
4. Develop and incorporate new capabilities, such as the DKIST, cutting-edge instruments, and on-line services as required by the US solar community, within available resources, to ensure community access to state-of-the-art facilities and support.
5. Implement strategic partnerships with US universities, federal, non-federal and international entities that will enhance the scientific capabilities available to the entire solar physics and space weather communities.
6. Support the education and development of the future workforce for solar physics including, in particular, those groups that are underrepresented in the US STEM (Science, Technology, Engineering and Mathematics) workforce.
7. Recruit and develop an outstanding scientific staff that demonstrably support the community-based research carried out at NSO facilities.
8. Expeditiously implement the response to the recommendations of the NSF 2012 MPS/AST Portfolio Review.
9. Integrate research and education for the benefit of the public through a program of education and public outreach.
10. Manage the NSO staff and all activities carried out at the observatories according to current best-practices and in full compliance with all relevant laws and regulations, maintaining quality and relevance in administration and management in a cost-effective manner.
11. Create a scientific program that embodies the NSF strategic vision: advancing discovery, innovation and education beyond the frontiers of current knowledge, and empowering future generations in science and engineering.

2.2 NSO Research Goals and Strategic Objectives

The Sun is the only star whose interior, surface, and outer atmosphere can be resolved in detail, hence providing an important and unique basis for the study of fundamental physics, astrophysics, fluid mechanics, plasma physics, and magnetohydrodynamics. The interplay of these aspects of physics creates an essential range of phenomena occurring not only on the Sun, but also elsewhere in the Universe. The physical and temporal scales observable on the Sun are large enough to properly represent cosmic-scale phenomena, while the Sun is close enough that measurements can be made in great detail, enabling broad research objectives.

The research goals of the NSO are to:

1. *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.
2. *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.

3. *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.
4. *Explore the unknown* – Explore fundamental plasma and magnetic field processes on the Sun in both their astrophysical and laboratory context.

To achieve these goals, NSO's unique facilities include the world's largest solar telescope and a network of full-Sun imaging instruments to continuously observe the Sun's evolution and its magnetic fields. A resident scientific staff support the development and exploitation of these facilities, support a diverse community of users, and point the way to future frontiers.

The above research goals inspire specific activities at the Observatory. Using NSF base funding, the NSO will pursue over the second half of the current Cooperative Agreement the following specific objectives and milestones (revised and updated from the original CA Proposal list of objectives and milestones):

1. Develop and execute a DKIST operations model, including data handling and training the next generation of solar astronomers, that can fully exploit the DKIST.
2. During the first years of DKIST operations, execute the Critical Science Plan (CSP) under development by the project Science Working Group (SWG).
3. In close interaction with the national and international solar communities, define and, as funding allows, construct the second generation of instruments for DKIST (including MCAO).
4. Operate the suite of NISP instruments (GONG and SOLIS), distribute their data, and work with the community to continue improving the quality of the resulting data products.
5. Upgrade the GONG network to ensure its competitive continuation until the end of this CA.
6. Develop and implement an NSO organizational structure that effectively operates the DKIST and NISP by consolidating the staff at the new sites in Boulder and Maui, and that provides effective support for the observational and data needs of the solar research community.
7. Use the opportunities provided by DKIST and NISP to promote a strong university/student basis for solar physics. This includes working closely with CU Boulder on collaborative programs, participating in university partnerships to increase the diversity of NSO and the solar community by recruiting candidates from underrepresented communities.
8. Consolidate the NSO's vigorous EPO program that focuses on the development of the next generation of solar scientists and engineers, the inclusion of students in NSO's research activities, and on maintaining an international awareness of NSO's facilities and scientific achievements while focusing also on critical, local activities and community engagement.
9. Continue NSO scientific and instrumentation leadership by balancing staff responsibilities, increasing staff opportunities for research and postdoctoral support, and strengthening partnerships with other solar organizations.

10. Take a leadership role in developing a community-wide road map for ground-based solar facilities and work closely with NASA to link space-based and ground-based facilities to maximize their synergy for advancing understanding of the Sun.

Existing and future supplemental NSF funding will allow NSO to additionally pursue these objectives:

11. Continue supporting the activities of the NSO and the SSOC at the Dunn Solar Telescope and at the Sacramento Peak Observatory to finalize the divestiture of NSF assets.
12. Accelerate NSO's capability to apply spectro-polarimetric inversions to generate enhanced DKIST Level-2 data products, along the lines of the NSF Big Idea: *Harnessing the Data Revolution*. This effort resides at the newly created program NCSP.
13. Implement through the NCSP a series of activities aimed at preparing the community on DKIST data manipulation and Level-2 data products generation. Grow the DKIST user base with particular attention to the US university system.

Additional NSF supplemental funding over the next five years will enable:

14. The development of partnerships to produce a detailed design of a future network that replaces GONG and SOLIS (ngGONG/SPRING) and provides ground-based solar data adapted to the demands of space weather modeling (Section 6.5).
15. Initiation of the second generation of DKIST instruments (Section 5.9).
16. Continuation of the routine production of DKIST Level-2 data products, an activity that fosters synergies between the DKIST and NISP programs and that has raised strong community interest (Section 7.2).
17. Growth of the EPO team that will facilitate the promotion of NSO and NSF accomplishments nation- and world-wide (Section 8.3).

By working closely with other agencies and the broader international solar and heliospheric community, we aim at:

18. Expanding interagency collaborations for NISP, following the guidance in the National Space Weather Strategy and Action Plan, and consolidating non-NSF/AST funding support to ensure the continuation of a robust synoptic program.
19. Leveraging the interest of the space-based solar community in a lightweight, compact magnetograph that condenses GONG functionality and uses less resources than in previous missions.

NSO 2020 – 2024 Program

- **Daniel K. Inouye Solar Telescope (DKIST)**
  - Start DKIST operations at Haleakalā.
  - Execute the DKIST Data Center implementation plan.
  - Execute the DKIST Critical Science Plan.
  - Continue developing Multi-Conjugate Adaptive Optics.
  - Define second generation of DKIST instruments.
  - Continue further recruitment of national and international collaborations.
- **NSO Integrated Synoptic Program (NISP)**
  - Operate GONG and SOLIS. Continue their data distribution.
  - Refurbish the GONG network.
  - Conduct the design phase of the ngGONG/SPRING network.
  - Continue to seek outside funding for operations, including space opportunities.
- **NSO Community Science Program (NCSP)**
  - Create and distribute DKIST Level-2 data products.
  - Train the community on the generation of DKIST science-ready data products.
- **Sacramento Peak Observatory**
  - Operate the site.
- **NSO Directorate**
  - Continue definition of the NSO matrix structure.
  - Create a community-wide road map for ground-based solar physics.
- **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.

Figure 1-5. Planned and ongoing programs and projects at NSO.

3 SOLAR PHYSICS IN THE 2020s: DKIST, PARKER SOLAR PROBE (PSP), AND SOLAR ORBITER AS A MULTIMESSENGER CONSTELLATION

The next decade will see the start of DKIST operations coinciding with the first two encounter missions aimed at mapping the physical conditions in the vicinity of the Sun, the NASA mission Parker Solar Probe (PSP, launched in August 2018) and the ESA/NASA mission Solar Orbiter (launch planned for February 2020). DKIST, PSP, and Solar Orbiter will create an unprecedented solar corona and inner heliospheric campaign targeted at understanding how stars create and control the magnetically dominated environment surrounding them. DKIST will contribute in a multiplicity of ways to this campaign, but the fundamental aspect brought in by the Maui-based facility to the synergistic science is through the ability to measure the off-limb solar corona, including the quantitative mapping of its magnetic field.

PSP and Solar Orbiter in-situ instruments measure plasma particles kinetic properties, charges, and composition; but also, local electric and magnetic fields. DKIST and Solar Orbiter perform remote sensing imaging, spectroscopy, and polarimetry of the solar surface, covering the photosphere, chromosphere, and the solar corona. Both PSP and Solar Orbiter image the tenuous heliosphere they are flying through using imagers mounted on the side of the spacecraft. By combining the data and investigating the cause-effect relationship between the processes observed in the solar atmosphere and their consequences in the interplanetary medium, the three experiments will effectively create a multi-messenger era for solar physics.

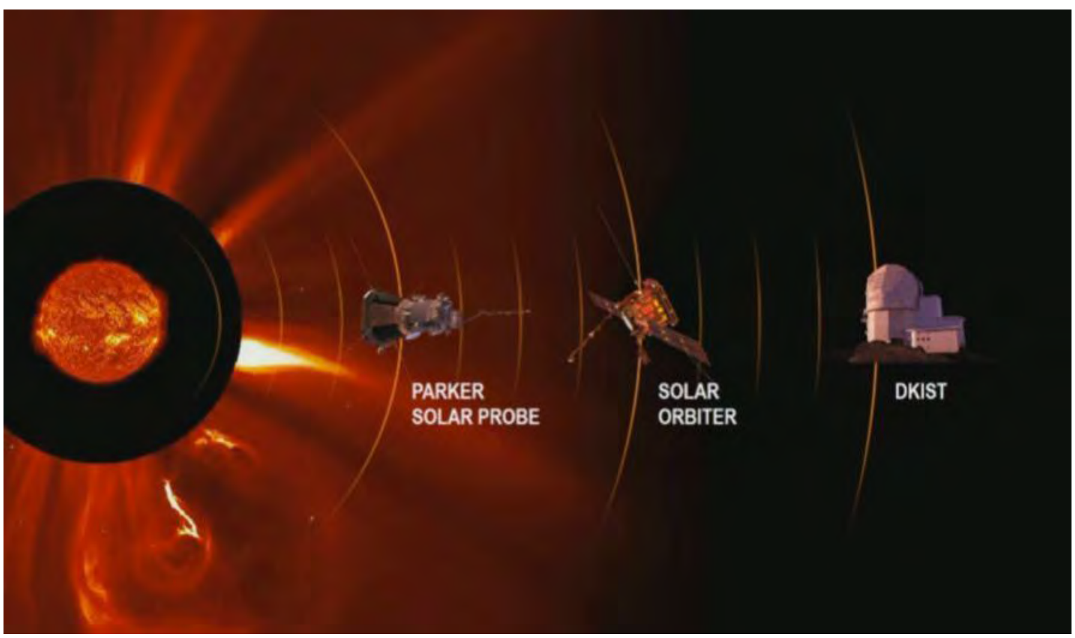


Figure 3-1. DKIST, PSP, and Solar Orbiter will form a multi-messenger constellation that will revolutionize coronal and heliospheric physics over the next decade. Image courtesy of NASA.

This section emphasizes the science enabled by the new DKIST capabilities in conjunction with PSP and Solar Orbiter. However, it is important to emphasize that NSO contributes also to this multi-messenger era with the data from our synoptic program, NISP. The predictions for the instantaneous magnetic connectivity of the spacecraft during the various encounter windows will be based on synoptic magnetograms produced by GONG (modeling of the PSP connectivity during the first encounter is explained in van der Holst et al., 2019 and Riley et al., 2019; for the Solar Orbiter mission, see Rouillard et al., 2019). We expect GONG and SOLIS to be a primary provider of contextual magnetogram data needed as input for the heliospheric models, but ideally data from the new network—providing much higher sensitivity to the critical polar fields—would produce far superior quantitative and qualitative predictions of the expected connectivity (see Section 6.5 for a description of the new proposed synoptic network, ngGONG).

This Chapter addresses Goals 3 and 4 and Activities 2, 7, and 10 described in Section 2.2.

3.1 Tracing the Magnetic Connectivity from the Sun into the Heliosphere

Understanding the magnetic connectivity between the Earth and the Sun, and by extension between exoplanets and their parent stars, requires being able to trace particles and fields measured in the heliosphere back to their source regions on the Sun. Only in this manner a complete description of how stars create their astrospheres emerges. Establishing the underlying mechanism responsible for this connectivity has been daunting from 1 AU. An exception is the major CMEs whose progenitors at the surface are often well-identified thanks to the association with flares, dimming effects, and the in-situ detection of the ejected cloud itself (Gopalswamy et al., 2018). Other more steady and subtler processes dictating this connectivity, such as the various forms of the solar wind, have not been conclusively linked with processes and configurations on the Sun. Broadly speaking, the fast solar wind is known to originate in open field regions or coronal holes, but the specific small-scale structures from where it emanates and the underlying physics remain elusive (Cranmer and Winebarger, 2019). By contrast, the slow solar wind is less satisfactorily mapped into any specific solar structure, and its creation is attributed to a multiplicity of regions such as the heliospheric current sheet and pseudostreamers (Abbo, 2016). Beyond that, our knowledge about the exact location of the processes that give rise to the expanding outer atmosphere of the Sun (see Zhao et al., 2017 and references therein) is rather inconclusive.

At 1 AU, plasma from the Sun has evolved and mixed with other constituents via transport and interactions resulting in conditions that prevent a satisfactory mapping to its sources on the Sun. It has been challenging to evaluate competing models of solar wind acceleration primarily because of the absence of measurements of the solar wind close to the Sun, where it can be mapped with sufficient precision to a solar source region and process. For this reason, the solar community has advocated for missions that approach our star and measure the fields and particles much closer, while they still preserve many of the properties (composition, charge, kinetic properties, etc.) that link with the remote sensing observations. This proximity to the Sun was the rationale behind the Parker Solar Probe (Fox et al., 2016) mission in the NASA Heliophysics portfolio and the Solar Orbiter mission as part of the European Space Agency (ESA; Müller, 2013) science program that also includes NASA participation.

PSP and Solar Orbiter are encounter-class missions instead of observatory-class missions. No observing proposals are submitted to the scientific teams operating them. Alternatively, predefined measurements are made during selected windows coinciding with the most scientifically interesting portions of the orbits such as the closest proximity to the Sun.

Both missions use Venus Gravity Assist Maneuvers (GAM) to get closer to the Sun and, in the case of Solar Orbiter, to increase the angle to the plane of the ecliptic allowing a better view of the solar poles and a more complete mapping of the 3D heliospheric volume. The proximity to the Sun generates for PSP and Solar Orbiter corotation opportunities (or quasi-corotation for Solar Orbiter) periods where the spacecraft flies right above the same solar feature for extended periods, allowing the study of their evolution and how the properties of the solar wind vary depending on changes in the source region. These corotation periods help disentangle spatial vs. temporal variations in the heliospheric structures and establish cause and effect relationships between solar processes and in-situ consequences.

While orbiting the Sun, the encounter windows are located in various Earth and spacecraft configurations. For DKIST, the most relevant arrangements for synergistic science are when the encounter windows coincide with a quadrature so that off-limb coronal DKIST observations map the inner solar vicinity of the spacecraft's trajectory. But encounter windows in alignment between the Earth and the satellites allow for additional complementary scientific opportunities, with DKIST observing the disk and/or the off-limb corona.

3.2 PSP and DKIST: Enabling Science by Combining In-Situ Near-Sun Measurements and 1 AU Coronal Observations

PSP was launched in August 2018 and has already performed two perihelia encounters at a distance of 35 $R_\odot$ (0.16 AU), following the first Venus GAM. The nominal mission includes a total of 24 perihelion encounters, with the last one occurring in June 2025. This duration encompasses four years after the expected start of DKIST operations in June 2020. Six additional Venus flybys will push PSP closer and closer to the Sun, reaching the closest approach of 9.86 $R_\odot$ (0.0459 AU), the distance during the last three encounters in 2024 and 2025. PSP will spend about a thousand hours below 20 $R_\odot$, and fifteen hours below 10 $R_\odot$. This inner region is crucial for the scientific objectives of PSP as in this part of the solar corona, the solar wind is sub-Alfvénic, and plasma interactions generate waves that can connect back to the Sun. When the solar wind becomes quicker and reaches the super-Alfvénic regime, these communications with the corona no longer occur, and this decoupling is often taken as the definition for the initiation of the heliospheric solar wind. Thus, PSP enters and measures the region of the inner heliosphere that is still controlled by the Sun’s magnetic field and the region where the solar wind plasma beta increases leading to a more passive role of the magnetic field.

PSP carries onboard four instruments, three in-situ suites, and one heliospheric imager. The Solar Wind Electrons Alphas and Protons (SWEAP) investigation (Kasper et al., 2016) measures the particles that compose the bulk of the solar wind: electrons, protons, and alpha particles. The four SWEAP sensors measure the velocity distribution functions of the particles with energy and angular resolution. SWEAP is the critical instrument onboard PSP that measures particles that one can trace back to elemental abundances on the solar atmosphere. Additional particle measurements at higher energies are performed by the Integrated Science Investigation of the Sun (ISIS, McComas, et al., 2016). ISIS is the primary instrument to detect the particles created by energetic events such as flares and CMEs. The instrument FIELDS (Bale et al., 2016) measures DC and AC magnetic and electric fields, plasma wave spectra, and solar radio emissions. From the measured local electric and magnetic fields, it produces an estimate of the Poynting flux, the energy flux crossing that region of space. The 3-components of the local magnetic field obtained by FIELDS allow mapping out the outer corona and the heliosphere and its connection to the surface. Finally, the Wide-Field Imager (WISPR, Vourlidas, et al., 2016) is the only imaging instrument aboard the spacecraft. It measures the white-light scattered by the dust (F-Corona) and by the electrons (Thomson scattering). WISPR looks at the large-scale structure of the corona, and solar wind before the spacecraft passes through it. It will image the fine-scale structuring of the solar corona, derive its large-scale 3D configuration, and determine whether a dust-free zone exists near the Sun. At closest approach (in 2024), the inner field-of-view of WISPR sees about two solar radii above the surface, reaching close to the farthest area observed by the DKIST Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP), that can observe out to 1.5 $R_{\odot}$. This fortunate coincidence will lead to a unique opportunity to test whether the diffuse coronal brightness seen in He I 1083 nm can be formed via the neutralization of alpha particles by dust as proposed by Moise et al. (2010). This is an example of unanticipated, synergistic science where progress has been difficult thus far, but that can be enabled by a combination of coordinated observations including Cryo-NIRSP, WISPR, and SWEAP.

Clarifying this detection of neutral Helium in the million-degree solar corona is an essential goal for DKIST since the He I 1083 nm line is the only permitted IR line available, and it has the potential to unlock new coronal magnetic field diagnostics through the Hanle effect as demonstrated by Dima et al. (2016). These authors describe an algorithm that combines linear polarization measurements of the Si X 1430 nm forbidden line, in the saturated Hanle regime, with polarization observations of the He I 1083 nm permitted coronal line to infer the three components of the coronal magnetic field. Such measurements will constrain the coronal topology significantly and can feed back into global coronal models, improving the accuracy of the heliospheric magnetic configurations predicted by them. While at solar minimum, coronal-heliospheric models using photospheric synoptic maps are already producing satisfactory mappings of the connectivity back to the Sun, it is clear that the more complex corona that PSP will encounter during solar maximum will need the best and most refined available input data (Raouafi et al., 2016). With this in mind, the DKIST Critical Science Plan is considering a synoptic program that measures regularly the solar corona in anticipation of future PSP encounters. We note that the lines and techniques used by this synoptic program can change as we learn how to generate the best input coronal magnetic data for the models.

The chemical composition of the solar wind is an indicator of the source region on the Sun (Geiss et al., 1995) and is critical to establish the magnetic connectivity. A well-known example corresponds to in-situ measurements of Helium abundances at 1 AU that shows a clear dependence on the solar wind speed and phase of the activity cycle (Kasper et al., 2007, 2012). Observations show that the smallest Helium abundances are observed during sunspot minimum, with slower solar winds showing a more pronounced correlation than faster solar winds. Indeed, the Helium abundance of the fast solar wind barely changes as a function of the cycle. These dependencies point to mechanisms that affect the second most abundant constituent of the solar corona and whose effectiveness changes depending on the levels of activity on the Sun. The exact mechanism remains unknown, but there are indications suggesting that high coronal Helium abundance prevents the escape of coronal plasma, which may also explain that one needs a CME ejecta to find Helium enriched regions. The combination of PSP and DKIST over the next decade will provide new ways to investigate this fundamental problem. Using the SWEAP instrument, PSP will measure the in-situ abundance of Helium much closer to the Sun, providing a less ambiguous identification of the source regions. DKIST can observe on the disk and the off-limb corona several Helium lines, most importantly He I 1083 nm with the Diffraction-Limited Near-Infrared Spectro-polarimeter (DL-NIRSP) (near limb corona) and Cryo-NIRSP up to 1.5 $R_{\odot}$. In the visible, ViSP can access a number of He I and He II spectral lines and observe them in the near-limb region, benefiting from the coronagraphic capabilities of DKIST and the skies of Haleakalā. Most likely the relevance of these measurements will become more critical at the closest PSP distances near solar maximum in 2024, but the solar cycle fluctuations described above indicate that synoptic measurements should start as soon as DKIST becomes operational in 2020, in the midst of what is expected to be a deep solar minimum. We plan to learn about the exact combination of DKIST instruments and lines during the first year of operations, but we note that the Helium depletion is known to occur lower down than in the corona (Laming, 2015), suggesting that chromospheric observations will play a crucial role here.

3.3 Solar Orbiter, PSP, and DKIST: Solving the Magnetic Connectivity Conundrum Using Multi-Messenger Techniques

Solar Orbiter will launch in February 2020 on a NASA Atlas V 411 rocket from Space Launch Complex 41 at Cape Canaveral. The joint ESA/NASA mission uses a combination of four in-situ instruments and six remote sensing telescopes intended to connect observed processes on the Sun with in-situ measurements. Solar Orbiter was defined from the beginning to answer the question of the origins of the magnetic connectivity between the Sun and the heliosphere and was built as a multi-messenger mission in and of itself. With openings in the heat shield that allow the onboard telescopes to observe the Sun, it cannot approach a distance to the Sun as close as the PSP. Solar Orbiter reaches at the end of the (extended) mission a distance to the Sun of 60 $R_\odot$ (0.28 AU), and an inclination to the ecliptic plane of 33^o. It uses a series of 8+8 (nominal plus extended missions) encounter periods that include three windows where the remote sensing instruments operate (in-situ instruments are always operational). These windows are centered on the most scientifically relevant parts of the orbit (see Figure 3-2), perihelion and maximum and minimum latitude that provide vantage points for observing the solar poles. The exact timing of these windows will be decided after the launch, and it might change to give the best coordination with the PSP encounter periods. Existing plans have the first Solar Orbiter remote sensing instruments commissioning window supporting the sixth PSP perihelion passage in September of 2020, a time when DKIST will be operational already.

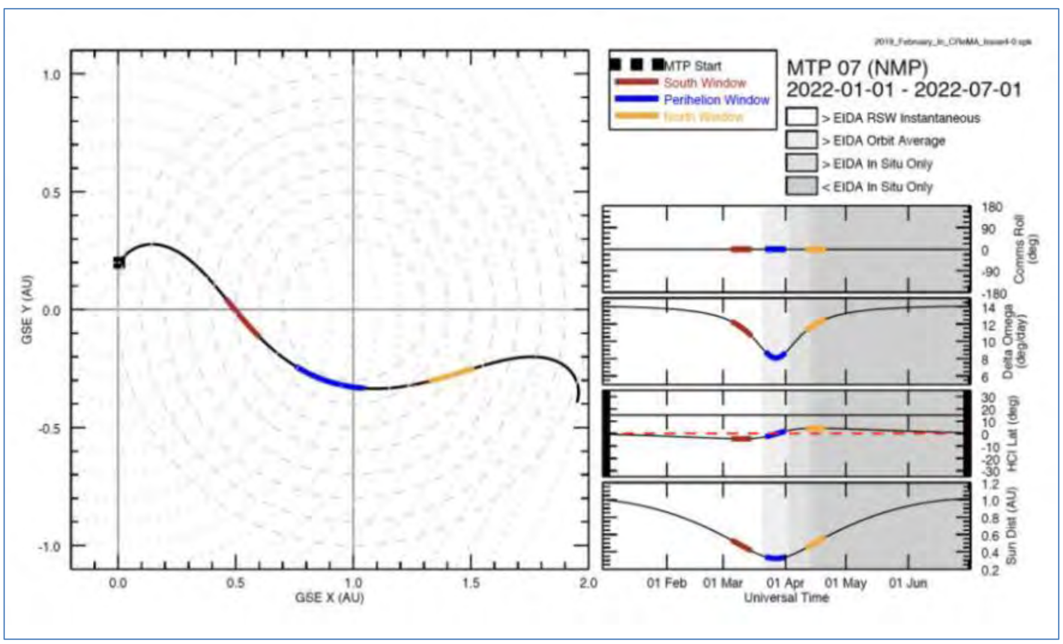


Figure 3-2. Sample encounter orbit for the Solar Orbiter mission. The three remote sensing windows are indicated by colors (minimum latitude in dark red, perihelium in blue, and maximum latitude in dark yellow). The red window corresponds to a conjunction configuration and the blue window to a quadrature encounter. Earth is at coordinates [0,0] on the left image, Sun at [1,0]. Image courtesy of ESA.

The Solar Orbiter payload is richer than the PSP payload, and we defer its description to the ESA/NASA mission's red book[1]. All remote sensing instruments offer multiple opportunities to coordinate with

[1] *http://sci.esa.int/solar-orbiter/48985-solar-orbiter-definition-study-report-esa-sre-2011-14/*

DKIST. The Solar Orbiter Polarimetric and Helioseismic Imager (PHI; Solanki et al., 2019), together with DKIST observations from ViSP of the same spectral line, will provide an opportunity to carry out magnetic field stereoscopy and solve the 180^o ambiguity intrinsic to all Zeeman measurements. This certainly will be done by other magnetographs along the Earth-Sun line-of-sight, but the sensitivity to transverse fields that DKIST will provide might prove crucial for a satisfactory disambiguation, in particular in the quiet Sun. The Extreme UV Imager (EUI) and the UV spectrograph (SPICE, Spectral Imager of the Coronal Environment) can complement the coronal measurements of DKIST in various ways depending on the spacecraft-Earth configuration during the encounters. Quadrature windows can help disentangle line-of-sight effects from the DKIST Cryo-NIRSP coronal measurements (see Judge et al., 2013) as EUI images from Solar Orbiter will provide the missing context of the structures contributing to the line-of-sight average. Additionally, field extrapolations from PHI can provide quantitative information of the vector magnetic fields contributing to that average.

Solar Orbiter conjunction configurations will provide an opportunity for simultaneous on-disk coordinated observations combining the Solar Orbiter remote sensing telescopes and the DKIST AO-fed instrument suite to maximize spectral coverage (from UV to the IR), temporal and spatial resolution, and sensitivity. Also, in conjunction, off-limb observations including the coronagraph onboard Solar Orbiter, (METIS) will benefit from DKIST coordinated observations. In particular, DKIST direct measurements of the magnetic field in the off-limb corona provide a unique opportunity to calibrate indirect inferences of the magnetic configurations by METIS.

The in-situ payload for Solar Orbiter includes a complete suite of instruments with analogs to those onboard PSP, but with some additional capabilities. The list consists of an energetic particle detector (EPD), a magnetometer (MAG), a radio and plasma wave sensor (RPW), and a solar wind analyzer (SWA). This last instrument is an analog to the PSP's SWEAP suite, but with an added —NASA provided— key component, the Heavy Ion Sensor (HIS). SWA will give the solar wind composition measurements between 0.3 and 1 AU, including electrons, protons, alpha particles, but now with HIS extending the composition analysis to heavier ions such as C, N, O, Si, Fe, S, and others. Measurements from SWA/HIS can help narrow the options for connectivity to the Sun, as charge-state ratios of heavy ions are an indication of the level of heating at the source and can help distinguish among source region candidates (coronal hole vs. streamer), although some modeling might be required (e.g., Oran et al., 2015).

A key strategy to trace plasma parcels from the Sun into the heliosphere is to track the so-called First Ionization Potential (FIP)-bias, the anomalously high abundance (relative to the photosphere) of elements with low First Ionization Potential (see, e.g., Schmelz, 2012). This effect is more pronounced in the slow solar wind than in the fast solar wind that often shows photospheric abundances (Lee et al., 2015). The nature of the FIP effect is still under debate, but the first ionization of neutral elements occurs in the chromosphere, a layer that DKIST will map with unprecedented detail. Indeed, it is thought that new active regions emerge with photospheric abundances and develop the FIP-bias at chromospheric heights that then propagate into the corona (Laming, 2015). Comparing elemental abundances and FIP-bias inferred from remote sensing observations with in-situ counterparts is the main objective of the SPICE and SWA/HIS combination. Both instruments can determine the strength of the FIP-bias for several chemical elements. Coordinated observations tracking the same plasma packages are planned for several perihelion windows. This intrinsically multi-messenger approach to study the magnetic connectivity between the Sun and the heliosphere is one of the overarching goals of the Solar Orbiter mission. Approaching the Sun to about 0.3 AU will certainly facilitate tracing the plasma blobs, but DKIST can provide invaluable support by observing nearly simultaneously various layers of the Sun with different instruments, depending on the orbital configuration.

One area where DKIST can critically contribute to this investigation is by providing accurate magnetic field configurations over the period when Solar Orbiter is trying to establish the connectivity between the SPICE composition measurements and the SWA/HIS detections. For orbital settings where the SPICE FOV is on the disk, DKIST can co-point and obtain vector magnetic maps in the photosphere and chromosphere. By adding the chromospheric magnetic information, DKIST can map the layer in which composition (FIP bias) changes and where field line reconfiguration is expected to occur. A key target is a process known as interchange reconnection (Fisk & Schwadron, 2001; Crooker, 2002) whereby a closed field region interacts and reconnects with an open field line, establishing a new route for plasma to escape the Sun. The FIP bias occurs in the closed loop before the interchange reconnection, but it is then transmitted via the newly open channel. It is crucial to understand if this is one of the main processes that give rise to the slow solar wind, and its identification and characterization require careful measurements of the varying magnetic connectivity. In quadrature encounters, DKIST will similarly try to quantify the degree of field line openings that are taking place at coronal levels and the expansion rate of the resulting open field lines. It is still unclear if one should target the near-limb region (DL-NIRSP), the more large-scale corona far from the limb (Cryo-NIRSP), or both. The two instruments can provide extra temperature and abundance diagnostics by observing the highly ionized lines of Si and Fe, and potentially others subject to the availability of order-sorting filters.

The coordinated observations just described have several potential target regions such as small-scale emergence episodes in the interior of coronal holes (e.g., Shimojo & Tsuneta, 2009) or the dynamics near the coronal hole boundaries as they have been consistently related with the slow solar wind (Ko et al., 2014). After the discovery by *Hinode* of ubiquitous upflows near the edges of active regions (Harra et al., 2008), these areas also constitute a potential source of the nascent slow solar wind. Using *Hinode* estimated FIP bias ratios and in-situ composition data at 1 AU, Brooks & Warren (2011) traced back slow wind-like composition measurements to the edges of an AR that displayed outflows for at least five days. Thus, active-region boundaries represent another evident target for coordinated observations between Solar Orbiter and DKIST similarly as described before.

Coordination including all three facilities, DKIST, PSP, and Solar Orbiter, also offers unique opportunities for synergistic science. The previous section explained the case for combining remote sensing and in-situ Helium observations between DKIST and PSP. Bringing Solar Orbiter into the mix can prove key to understanding the role of Helium in the various types of solar wind and its source regions. By using the EUI He II 304 Å channel in conjunction with Lyman-alpha observations from EUI and METIS, Solar Orbiter will be able to estimate the Helium abundance during the remote sensing windows. Coordinated observations with DKIST during on disk and off-limb passages using He I 1083 nm (and potentially other lines in the visible with ViSP) will allow tracking the highest first ionization element on the Sun from even deeper layers than what Solar Orbiter can do. Combining DKIST and Solar Orbiter data during conjunction windows to map the presence of Helium in the solar corona while PSP measures in quadrature alpha particles from within 10 $R_\odot$ might probe a crucial way to understand the evolution of Helium in the nascent solar wind. It remains to be seen if the orbital mechanics of both missions will make possible such a configuration, in particular, near the end of the PSP mission.

3.4 Opportunities for Discovery

The previous sections have emphasized some of the combined science cases already included in the DKIST Critical Science Plan as opportunities for enhanced, synergistic science. But the coordination of these three discovery missions will enable other—often unexpected—opportunities. For example, DKIST, PSP, and Solar Orbiter will shed light into the so-called open flux problem (Linker et al., 2017), i.e., the persistent underestimation—by as much as a factor of three—of the heliospheric magnetic field measured in-situ at 1 AU when compared with the predicted values from heliospheric models using synoptic magnetograms. First of all, it remains to be seen whether the open flux problem persists in the inner heliosphere after comparing the predictions of the models and the in-situ measurements form the onboard magnetometers. Second, the high sensitivity vector magnetograms from DKIST will unveil how much hidden flux remained undetected in the less sensitive full-disk magnetograms, and that can be responsible for the enhanced flux observed at 1 AU.

The processes leading to coronal heating are ultimately responsible for the escape of plasma from the Sun into the heliosphere. However, how the plasma is heated still debated. A new generation of numerical models of the solar atmosphere, including MHD and radiative effects (Hansteen et al. 2015; see also Klimchuk, 2006), have shown that the ever-present reconfiguration of chromospheric and coronal magnetic fields leads to the formation of magnetic discontinuities supporting the idea of nanoflares as the underlying process leading up to atmospheric heating. But it is also known from high-resolution imaging and spectroscopy that the corona is permeated by MHD waves that can find ways to dissipate and heat the coronal plasma (Cranmer & van Ballegooijen, 2005; De Pontieu et al., 2007). It is almost certain that both types of processes, reconnection, and wave energy dissipation, occur on the Sun in various forms and relevance depending on the specific region under study. Understanding which processes dominate the heating and the underlying physics is one of the most critical challenges in solar and stellar physics.

Figure 3-3 (see Cranmer et al., 2017) shows how the multi-messenger constellation formed by DKIST, PSP, and Solar Orbiter can synergistically produce data to constrain the various physical processes leading to heating. The lines in the figure indicate the magnitude of the transverse motions needed in a model of damped (solid) and undamped (dashed) Alfvén wave turbulence compatible with solar remote sensing and in-situ observations (Cranmer & van Ballegooijen, 2005; Crammer et al., 2017). The figure starts with the photospheric transverse motions observed in the so-called G-band bright points (GBPs). These transverse motions are thought to be responsible for shaking magnetic field lines leading to upward propagating Alfvén waves. While these GBPs motions have been measured using intensity proxies for decades, very few magnetized wave power estimates are available (but see Jafarzadeh et al., 2013). DKIST will perform much more accurate and quantitative measurements of these photospheric motions and their magnetic consequences as demonstrated recently by Van Kooten & Cranmer (2017). The *Hinode*/Solar Orbiter Telescope (SOT) box in yellow in the figure indicates the amplitude of the transverse motions detected by *Hinode* using Ca H chromospheric images of type II spicules (De Pontieu et al., 2007). Using DKIST higher spatial resolution and magnetic sensitivity, we will be able to quantify the energy fluxes carried out by these waves by measuring the perturbations in the magnetic field lines. Critical instruments for estimating the induced velocity and magnetic fluctuations are the DL-NIRSP and VTF. Moving away from the solar surface in Figure 3-3, the next set of measurements corresponds to nonthermal line widths

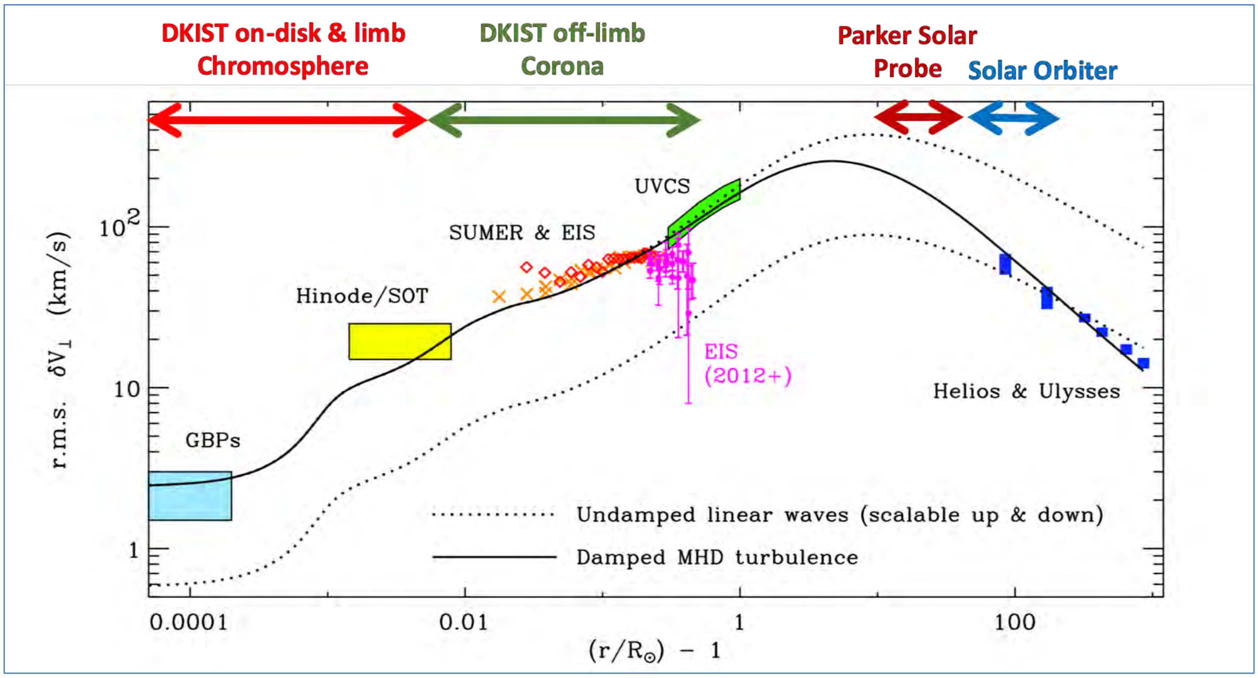


Figure 3-3. Velocity (rms) amplitude of transverse motions from the solar surface to the near-Earth environment. Squares and symbols inside one solar radius correspond to remote sensing observations as indicated. Blue squares are measurements from in-situ space missions. The solid and dashed lines correspond to damped and undamped Alfvénic wave turbulence (Cranmer & van Ballegooijen, 2005) models. The upper part of this figure indicates the regions accessible to DKIST observations (and, in some cases, Solar Orbiter remote sensing instruments) and to PSP and Solar Orbiter in-situ measurements. Adapted from Cranmer et al., 2017.

observed by instruments in Solar and Heliospheric Observatory (SOHO) and *Hinode*. They reach out to 1 R⊙ above the surface and display mixed indications of damping processes. The SOHO/UltraViolet Coronagraph Spectrometer (UVCS) (green square) shows little evidence of damping. However, more recent measurements by the *Hinode*/Extreme-ultraviolet Imaging Spectrometer (EIS) (magenta dots in the figure) show signs of damping mechanisms acting in the corona that disagree with the UVCS analyses. It is urgent to confirm the existence, or otherwise, of these damping processes and consolidate our understanding of how Alfvén waves deposit their energy and convert it to heat in this inner region of the corona. Cryo-NIRSP routine observations of spectral lines in this range of heights will undoubtedly provide the observational constraints needed to clarify the amount of damping present in this region of the solar corona. Solar Orbiter coordinated observations in conjunction windows can provide nonthermal line widths of other spices and confirm the presence or not of damping processes.

The models in Figure 3-3 reach out past the Earth and can be contrasted with the observed in-situ magnetic field fluctuating amplitudes by Helios and Ulysses. A good match with existing data (blue squares) requires the presence of wave damping in the heliosphere (solid line). The instruments onboard PSP and Solar Orbiter are going to provide much better coverage over a broader range of distances to the Sun and in a variety of solar and heliospheric structures. Fine tuning of models like those used in Figure 3-3 to fit the various observations from DKIST and Solar Orbiter and the in-situ detections from PSP and Solar Orbiter will fundamentally constrain the underlying physics behind wave heating models and uncover potential weaknesses in the theory.

3.5 Concluding Remarks

This section of the LRP has no programmatic or budgetary implications. It is intended to describe a unique scientific opportunity enabled by the DKIST capabilities, especially its coronagraphic design. But this section points towards the need for coordination between NASA and the NSF to maximize the scientific return that the combination of these facilities creates. During the period covered by this LRP, the NSO will act as a catalyst for such coordination.

Sections 5 and 6 address in various forms the specific science cases for DKIST and NISP.

4 MIDTERM PROGRESS REPORT

4.1 DKIST Construction Status

4.1.1 DKIST Development Time Line and Major Milestones

The DKIST project got its start back in the mid-1990s with work on the *Clear* concept studies. This work helped lead to prioritization of the project in the 2000 Decadal Survey. Beginning in 2000, high-level Science Requirements were established, technical design concepts generated and analyzed, and cost, schedule, and risk estimates were developed. This led to a funded Design and Development (D&D) phase that began in 2003 and ultimately resulted in a full construction proposal submitted to the NSF. In parallel with this work, a detailed site survey of potential locations for the telescope was undertaken, with the result being the selection of Maui 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 the summit lingered for the first two years of construction, but eventually were resolved and ground-breaking at the construction site took place in late CY 2012. This was followed immediately by site clearing and initial construction activities. Since 2010, the project has progressed steadily on schedule and budget in all major technical areas (e.g., telescope, wavefront correction, instrumentation, high-level software and controls, enclosure, and buildings).

Key recent milestones over the past few years include:

2017: Support and Operations (S&O) Building made weathertight.
2017: Primary mirror delivered to construction site.
2018: Telescope Mount Assembly (TMA) site acceptance testing successfully passed.
2018: Integration, Test & Commissioning (IT&C) plan established and approved.
2018: Primary mirror successfully aluminized and readied for integration.
2019: System Integration Module (SIM) #1, Telescope Pointing, successfully completed.
2019: SIM #2, Primary Integration, successfully completed.
2019: SIM #3, M1+M2 Integration, started.

The DKIST project continues its construction and IT&C efforts toward full completion and handover of the observatory to operations; this handover is expected to occur in mid-2020.

4.1.1.1 Telescope

The Telescope Mount Assembly (TMA) passed its Site Acceptance Testing (SAT). The Primary Mirror (M1) was successfully cleaned and coated at the Air Force facility on Haleakalā, Maui (Figure 4-1). The M1 was then integrated into the Primary Mirror Cell Assembly (M1CA) and installed into the TMA (Figure 4.2). Testing of pointing and delivered wavefront at prime focus were successfully completed. Top End Optical Assembly (TEOA), including the Secondary Mirror (M2), was delivered

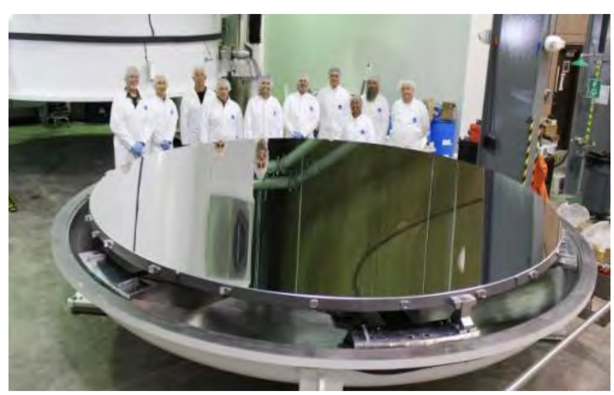


Figure 4-1. The DKIST mirror coating team with the freshly-aluminized primary mirror. Photo by Erik Starman.

to Maui and integrated into the telescope. Testing of pointing and delivered wavefront of the combined M1+M2 was successfully completed. Additionally, all other TMA-mounted optic assemblies (M3-M6) have been delivered to site.

4.1.1.2 Wavefront Correction

The Wavefront Correction (WFC) team passed its Critical Design Review (CDR). All procurements, fabrication, and assembly of the WFC system was completed and testing in the Boulder NSO lab performed. With the exception of a number of additional lab tests, the WFC was deemed ready for disassembly and transport to the construction site for integration into the telescope; this is expected to occur in early summer of 2019.

Figure 4-2. *The telescope mount with the coated primary mirror (M1) installed and ready for first night-sky pointing tests. Photo by Heather Marshall.*

4.1.1.3 Instrumentation

The Visible Broadband Imager (VBI) procurement, fabrication, assembly, and successful lab testing was completed in the Boulder NSO lab. Subsequently, the system was disassembled, packaged, and transported to the construction site, where it was unboxed and initial installation work in the Coudé lab was started.

The Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP) project with the University of Hawaiʻi (UH) Institute for Astronomy (IfA) progressed through the majority of its procurement and fabrication work. A major update to the contract was undertaken in early 2019, with the DKIST project taking on a more prominent role in overseeing technical completion of the instrument. An updated schedule was produced, with delivery to the summit of the instrument expected to take place in late CY 2019.

The Diffraction-Limited Near-IR Spectropolarimeter (DL-NIRSP) procurement and fabrication effort with the UH/IfA is successfully concluding, and initial lab assembly work underway. Final technical issues associated with this challenging instrument are being worked and it is expected that delivery to the summit for IT&C will take place in the fall of 2019.

The Visible Spectropolarimeter (ViSP) project with the University Corporation for Atmospheric Research (UCAR) High Altitude Observatory (HAO) has made good progress this year, with nearly all procurement and fabrication work completed, and some initial assembly and testing work completed. Formal Lab Acceptance Testing (LAT) work is expected to be completed by mid-summer of 2019, with delivery to Maui occurring in fall 2019.

The Visible Tunable Filter (VTF) project with the Kiepenheuer Institute for Solar Physics (KIS) in Freiburg, Germany continued in its procurement and fabrication phase, with some initial lab assembly work undertaken (e.g., installation of the large VTF frame into the KIS lab). Delivery of the instrument to the construction site is expected to occur in late FY 2020.

The United Kingdom (UK) Consortium completed development of the cameras, including a successful factory acceptance test (FAT). Subsequently, five of the nine cameras have been delivered to DKIST, with the remaining four cameras expected to be delivered by mid-2019.

Finally, procurement, fabrication, assembly and successful test of the Polarization, Analysis and Calibration (PA&C) system was completed in early 2019. Following this, the two major PA&C assemblies (Upper and Lower Gregorian Optic Station (GOS)) were packaged and shipped to the construction site on Maui for integration into the TMA.

4.1.1.4 High-Level Software

The Observatory Control System (OCS) passed its lab acceptance test (LAT) and is now undergoing initial user acceptance testing. The Data Handling System (DHS) also successfully passed its LAT process and has been installed in the observatory. The computer network (IT) infrastructure hardware for the summit was also procured and successfully installed on the summit into the observatory. The Global Interlock System (GIS) local interlock controllers (LICs) for the telescope mount assembly, enclosure, and a subset of the facility have been verified for use on the summit; these are now integral to ensuring safety of the on-going IT&C efforts.

4.1.1.5 Site, Buildings and Enclosure

Recent site construction activities have been focused on completion of exterior work, including the installation of the underground water collection system, the concrete roadway, and the parking lot. In addition, the concrete apron that surrounds the south and east side of the facility was completed. Exterior painting is underway as time and weather permits.

Inside the facility, a number of individual rooms were completed sufficiently for the site construction crews to use as offices. Additionally, the instrument prep lab, was fully outfitted and is now in use for supporting IT&C work. The machine shop was also completed, furnished with machine tools, and is now in regular use.

The enclosure retrofits on the rear door, aperture cover, and vent gates were completed this year and the Site Acceptance Testing (SAT) was successfully completed.

4.1.1.6 Facility Thermal Systems (FTS)

Significant progress was made on the FTS system this year. Chief among the accomplishments was the completion of the primary coolant supply and return loops, including connections to the fluid cooler system and the exterior ice tanks. Start-up of this system is expected in mid-2019. Secondary loops are also nearing completion, with start-up of these systems expected by late summer 2019.

Installation of the Coudé Environmental System (CES), including ceiling plenums, supply ducts, and lighting system was completed this past year, and the system is now being operated at a nominal continuous flow to clean the Coudé lab air. Additionally, the Air Knife system successfully passed its factory acceptance testing and was delivered to the site and installed in the telescope.

The enclosure cooling system also made good progress this past year, with the execution of a major contract for procurement of the platecoil systems; we expect delivery of these units by fall of 2019.

4.1.1.7 Integration, Test & Commissioning (IT&C)

As stated above, the M1 received its science coating of aluminum and was installed into the M1 Cell Assembly (M1CA). This unit was then installed into the TMA. Balancing and servo tuning operations were completed, after which the initial pointing tests on nighttime stars were performed (Figure 4-3). These tests showed that the TMA is pointing within its required specifications. Additionally, wavefront measurements at prime focus were performed on the M1; again, the requirements of the system were demonstrated, which allowed the IT&C team to progress onto the installation of the next mirror assembly, M2, which in turn is part of the TEOA assembly.

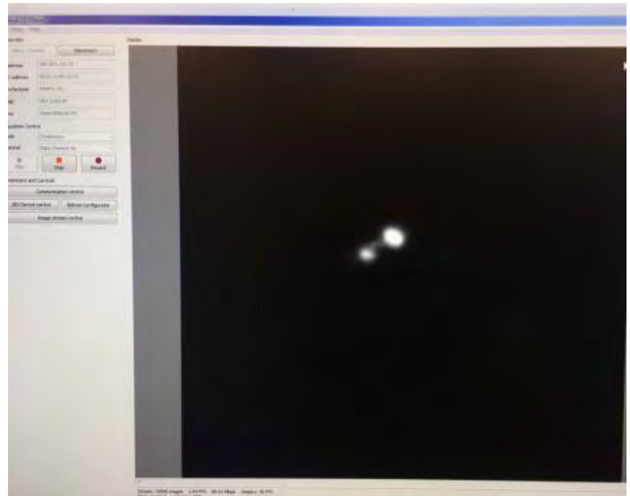


Figure 4-3. One of the first starlight images taken at prime focus with the M1 installed. This image shows the binary star system Castor. Photo by Predrag Sekulic.

Testing of the combined M1+M2 system was performed in early 2019, and initial testing indicates that both pointing and wavefront performance are within required specifications. This will allow the IT&C team to move onto the integration and test of the remaining assemblies in the optical train (i.e., M3-M9).

Recent successful IT&C accomplishments include installation of the Coudé rotator mechanical interface (CRIM) plates and the installation and alignment of the VBI and WFC optics tables. Additionally, the IT&C team also completed the first CO_2 “snow” cleaning of the primary mirror.

4.1.1.8 Schedule Status

A subsystem view of intermediate milestone highlights is shown in Table 4-1 and in Figure 4-4. Current planning targets calendar year 2019 for obtaining the first scientific data with a DKIST instrument. At the end of the commissioning phase, each instrument will be tested for compliance with the science performance specifications (e.g., spatial, spectral resolution, polarimetric sensitivity, as appropriate).

Table 4-1. DKIST Upcoming Major Milestones (2019-2020)		
Site Construction & Support Facilities	2020-Jan 2020-Feb 2020-Mar	Tenant Improvement-Fit & Finish Complete Facility Thermal Systems (FTS) Complete Site Closeout Complete
Subsystem Development	2019-Apr 2019-Apr 2019-May 2019-May	M7-M9 Delivered to Site Wavefront Correction System (WFC) Delivered to Site High-Level Software (HLS) Systems Ready for Site Testing and IT&C Facility Instrument Distribution Optics (FIDO) Delivered to Site (FLI)
Instruments	2019-Feb 2019-Mar 2019-Sep 2019-Oct 2019-Oct	Visible Broadband Imager (VBI) Delivered to Site Polarization Calibration & Analysis (PA&C) System Delivered to Site Visible Spectro-Polarimeter (ViSP) Delivered to Site Cryogenic Near-IR Spectro-Polarimeter (Cryo-NIRSP) Delivered to Site Diffraction-Limited Near-IR Spectro-Polarimeter (DL-NIRSP) Delivered to Site
Integration, Test & Commissioning (IT&C)	2019-Jan 2019-Mar 2019-May 2019-Jun 2019-Nov 2020-Apr	M1 Integration into Telescope Complete M1-M2 Integration Complete M1-M6 Integration Complete Coudè Optics Integration Complete DKIST First Light (VBI Red) Achieved Observatory Commissioning & Verification Complete

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

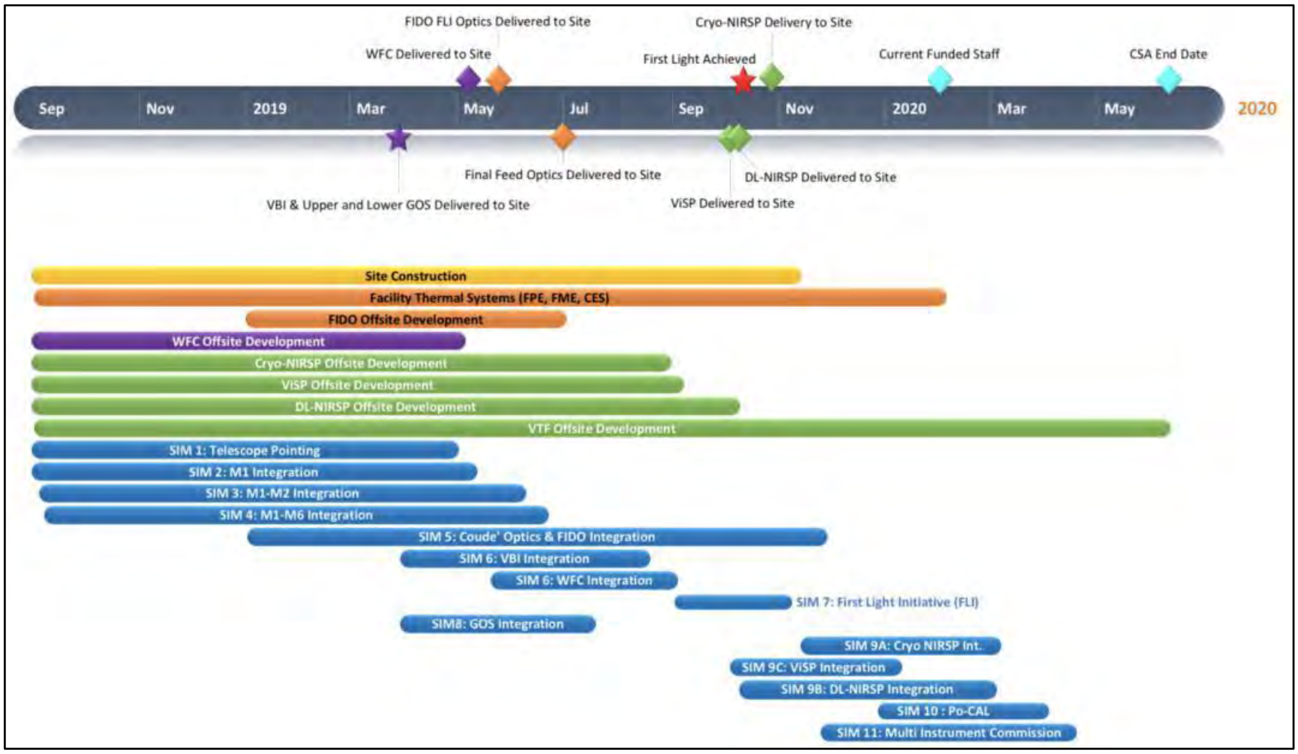


Figure 4-4. DKIST Milestone Time Line (2019-2029).

4.1.1.9 DKIST Financial Status

Following the Project Re-baseline, the Total Project Cost was established as $344.1M. To date, the project has received $324.5M; $146M from the American Recovery and Reinvestment Act (ARRA) of 2009 and the remainder from the Major Research Equipment and Facilities Construction (MREFC) Program. The ARRA funding was provided in January 2010 and expired at the end of FY 2015. The MREFC funding is provided annually, based on supporting the planned spending and commitments through January 2020; there is one remaining funding action that will occur in 2019. Further financial details and project performance, including earned value metrics, are shown in Table 4-2, Table 4-3, Table 4-4, Table 4-5, and Figure 4-5.

Table 4-2. DKIST Financial Summary

Forecast		
Estimate at Completion (EAC - $M)		
EAC_1: AC+(BAC-EV)	$323.1	Latest updated budget estimate
EAC_2: AC+(BAC-EV)/(CPI*SPI)	$323.2	
Date of last EAC update	Jan-19	Date of last update of the EAC
Unencumbered Funds	$14.9	TPC-BAC
Liens		Known costs, variances not in BAC
Budget Contingency	$14.9	Unencumbered Funds - Liens
Estimate to Complete (ETC)	32.7	EAC_1-AC
	32.7	EAC_2-AC
% Budget Contingency of ETC	45.6%	(BC/ETC_1)*100%
	45.6%	(BC/ETC_2)*100%
Risk Exposure		
Risk Confidence Level	80%	Confidence level of Risk Exposure
Critical Milestone Planned Date	Apr-20	IPS Planned Project End Date
Critical Milestone Forecast Date	Jun-20	Baseline Project End Date
Schedule Contingency	2	Amount of float/contingency

Table 4-3. DKIST Earned Value Management System (EVMS) Status		
EVM Status Report	$M	Description
EVM Reporting Date	Jan-19	Date of the report
Total Project Cost (TPC)	$344.1	Performance Baseline+Contingency
NSF Funding To-Date	$324.5	Amount of funding received to date
Budget at Completion (BAC)	$329.2	Approved Budget
Planned Value ($M)	$303.0	
Earned Value ($M)	$296.6	
Actual Costs ($M)	$290.5	
% Complete (Planned)	92%	PV/BAC*100%
% Complete (Actual)	90%	EV/BAC*100%
% Complete (Spent)	88%	AC/BAC*100%
Cost Variance (CV)	$6.1	EV-AC
Schedule Variance (SV)	-$6.4	EV-PV

Table 4-4. DKIST Cost Performance Report (CPR) for January 2019

	CPR REPORT MONTH ENDING JANUARY 2019 (ALL VALUES IN $K)												
	CURRENT PERIOD					CUMULATIVE TO DATE							
WBS	PLANNED	EARNED	ACTUAL	SV	CV	PLANNED	EARNED	ACTUAL	SV	CV	BAC	ESTIMATED	VARIANCE
1.2.1 Project Management	773	750	299	-24	451	42,644	42,467	41,482	-177	985	49,292	48,308	985
1.2.2 Systems Engineering	71	71	52	0	19	4,636	4,636	4,633	0	3	5,478	5,474	3
1.2.3 Telescope Systems	670	1,102	658	432	444	229,910	224,464	219,235	-5,446	5,229	237,282	232,053	5,229
1.2.4 Integration, Test, and Commissioning	603	-15	331	-618	-346	10,923	10,111	10,416	-812	-304	19,973	20,277	-304
1.2.5 Science Support	80	80	45	0	34	5,170	5,170	4,951	0	219	6,316	6,097	219
1.2.8 Support Services	110	110	81	0	29	9,730	9,730	9,768	0	-38	10,893	10,931	-38
SUBTOTAL	2,306	2,097	1,466	-209	631	303,013	296,579	290,485	-6,435	6,094	329,233	323,140	6,094
RISK ADJUSTED TOTAL COST	2,306	2,097	1,466	-209	631	303,013	296,579	290,485	-6,435	6,094	344,129	344,129	

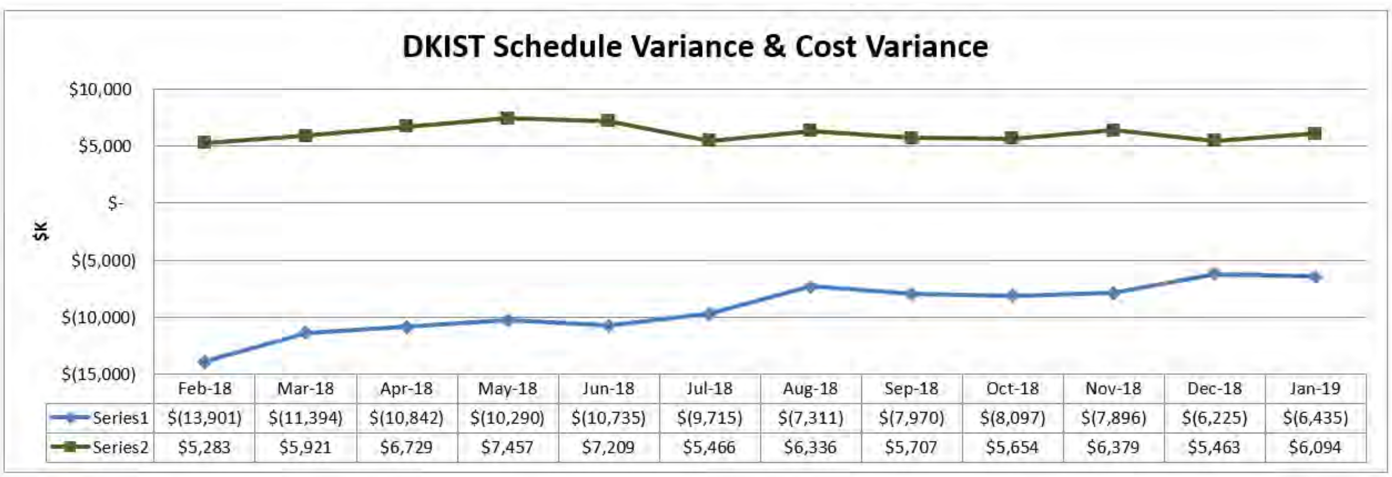


Figure 4-5. DKIST Schedule and Cost Variance.

Table 4-5. DKIST EVMS Variance for January 2019

	BUDGET	PERFORMED	ACTUAL	SV	CV	TOTAL BUDGET	SPI	CPI	% COMPLETE PLANNED (PV/BAC)	% COMPLETE EARNED (EV/BAC)	% COMPLETE SPENT (AC/BAC)
PREVIOUS CUM TO DATE	300,707	294,482	289,019	-6,225	5,463	329,233	0.98	1.02	91%	89%	88%
CURRENT PERIOD	2,306	2,097	1,466	-209	631		0.91	1.43			
CUMULATIVE TO DATE	303,013	296,579	290,485	-6,435	6,094	329,233	0.98	1.02	92%	90%	88%
RISK ADJUSTED TOTAL COST	303,013	296,579	290,485	-6,435	6,093	344,129	0.98	1.02	88%	86%	84%

4.2 Headquarters Relocation

The construction of a world-class facility such as the Daniel K. Inouye Solar Telescope (DKIST) on the island of Maui in Hawaiʻi and the distribution of data to the solar community demanded a significant restructuring of the National Solar Observatory (NSO). The Observatory was traditionally based at two operating locations, Sacramento Peak in Sunspot, New Mexico—site of the Dunn Solar Telescope (DST)—and in Arizona, with NSO Headquarters in downtown Tucson and the McMath-Pierce Solar Telescope (McMP) at Kitt Peak. During the first five years of the current Cooperative Agreement, the NSO experienced a significant transformation, including the relocation to two new sites in Colorado and Hawaiʻi. On the one hand, for efficient operations of the DKIST facility, NSO constructed the operations facility in Maui, the DKIST Science Support Center (DSSC), and is consolidating an operations team on the island. On the other, the data acquired with DKIST, at a rate of 10 TB/day, require complex analysis pipelines and easy access by the community. To maximize interactions with the community, NSO relocated its HQ from Tucson to the campus of the University of Colorado in Boulder (CU) from where we are forging closer links with other solar related labs in the area. The campus-based location also enables venues for NSO participation in academic activities that extend beyond CU Boulder and ensure proximity with the new generation of astronomers.

FY 2017 marked the completion of NSO's Headquarters transition to CU Boulder. A total of 70 employees are currently based in Colorado. The group includes a mixture of DKIST construction and NSO operations staff. NSO-Maui ranks second with 69 employees on-site, mostly all involved in DKIST construction but with a growing operations crew. In Sunspot, four employees run the site, with telescope operations under the leadership of New Mexico State University (NMSU). Except for a small DKIST construction group, all NSO presence in the Tucson offices ended in FY 2017.

NSO established a transition plan that was described and updated in the Annual Progress Report and Program Plans (APRPP) and regularly communicated to the staff at bi-annual all-hands meetings. A core component of the transition plan was a series of milestones (see Table 4-6). The various APRPP documents described progress according to the plan and the cost impact of each of these milestones. Table 4-6 shows the milestones in green and the year of completion. Two milestones that are not yet finalized are in orange under FY 2017. The transfer of Sac Peak operations to NMSU has been only partially achieved as the scope of the transfer itself has changed over the years. While initially we planned a transfer of the entire Sac Peak Observatory to the consortium, site operations required expertise that was considered impractical by NMSU. In the current concept, the consortium leads only the scientific operations of the DST and the Visitor Center. The other unfinished milestone corresponds to the SOLIS relocation. The suite of instruments is currently at Big Bear Solar Observatory (BBSO) but not yet operational. The main reason for this delay has been the State of California permitting process for building the new SOLIS site—a much more complex process than initially planned by the NISP team. At the time of this writing, the expected start date of SOLIS operations at BBSO is in early FY 2020. We refer to the past years' APRPPs[2] for a detail description of progress during the transition. Here we describe only the major milestones and the incurred cost during the transition.

[2] A complete chapter on the transition can be found in the Program Plans for years FY 2014 through FY 2017, available at *https://www.nso.edu/about/reports/*.

Table 4-6. NSO Transition Milestones				
	2014	**2015**	**2016**	**2017**
NSO HQ	• Lease with CU Boulder signed (LoI). • NSB Action Item • Director is Boulder-based • Sac Peak Site Leader • Transition Plan Draft	• New CA starts • Tucson Site Leader • Update Transition Plan • 3rd-floor remodeling starts • 3rd-floor inauguration • NSO Sac Peak moves	• Update Transition Plan • Continue moves from NSO sites • Library relocation • CA signed with CU • Decision on NMSU consortium	• Update Transition Plan • Continue moves from NSO sites • Decision on McMath • NSO base-funded presence in Tucson ends • Transfer of Sac Peak operations to NMSU
DKIST	• DCPM hired • DKIST AD is Boulder-based	• Operations funding wedge • DC core team formed • First science position, Maui • WFC team relocated to Boulder	• Support & operation teams in Boulder/Maui build up • Continue moves of science team to Boulder/Maui • DSSC construction approved • DSSC construction starts	• Support & operation teams in Maui build up • Continue hires in Maui • Boulder-based DKIST ops relocation ends • DSSC available
NISP	• SOLIS relocates from KP to Tucson • SOLIS overhaul starts	• SOLIS RFP announcement • NISP scientific staff relocation starts • NISP AD relocates to Boulder	• Relocation of NISP DC starts • SOLIS site selection • NISP scientific staff relocation • Relocation of GONG engineering unit starts	• SOLIS relocates to its final site • NISP DC in Boulder • Relocation of GONG engineering units • NISP is Boulder-based

4.2.1 The NSO HQ at the University of Colorado Boulder

On February 9, 2015, AURA and CU Boulder signed a 10-year lease agreement for the third-floor occupancy of the east campus Space Science Center (SPSC) building. NSO shares the SPSC with the Laboratory for Atmospheric and Space Physics (LASP), a research institution affiliated with the Departments of Astrophysical and Planetary Sciences (APS), Physics, and Aerospace. LASP was the PI institution of the CU Boulder proposal submitted during the AURA-led process to host NSO Headquarters. Remodeling of the SPSC third floor started on January 1, 2015, soon after the previous tenants vacated the space. On May 11, 2015, NSO occupied the remodeled third floor, formally establishing the site of the new NSO HQ. The remodeling cost was folded into the lease and will be repaid by NSO over the ten years of the current Cooperative Agreement. AURA Central Administrative Services (CAS) and the CU Research Property Services prepared the 10-year lease agreement with a start date of January 1, 2015. The signing of this lease took place after the NSF formally vetted the document in December 2014.

On the first floor of the SPSC, NSO uses an optical laboratory that occupies a total of 2275 square feet. This laboratory serves as a site for testing and calibrating optical equipment for DKIST and NISP. The DKIST and NISP Data Centers both use space located in the room provided by the CU Boulder Office of Information Technology (IT) in the SPSC Data Center. This room is also located on the first floor and across the hall from the NSO optical laboratory. While the NISP Data Center is already serving data from Boulder Headquarters, the DKIST Data Center currently uses only prototyping equipment but is ramping up its presence after a successful Critical Design Review in FY 2019.

The relocation of NISP from Tucson to Boulder also included the GONG engineering units. Site preparations at the CU Boulder east campus for the two GONG engineering shelters started in early

September 2017, and the final relocation occurred on October 17. A third shelter serves as an additional storage site. Completion of the project occurred during the second quarter of FY 2018. A first-light image was acquired in March of 2018 (see Figure 4-6), and a formal dedication ceremony was held in August. The engineering site is now being used regularly for supporting remote site operations, new initiatives, and the GONG refurbishment project. The GONG shelters are located within walking distance of NSO HQ on campus. This accessibility of the GONG engineering units offers a unique outreach opportunity, from VIP visits to student training.

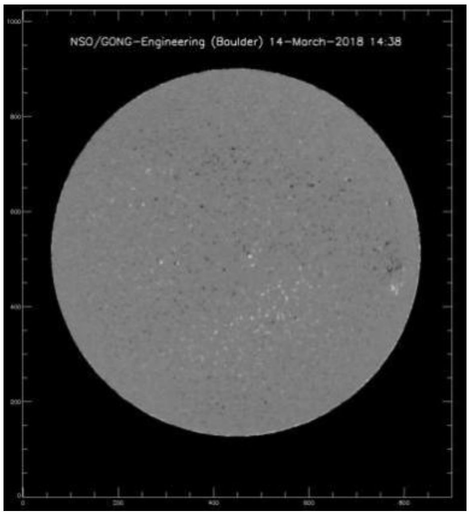


Figure 4-6. First greyscale longitudinal magnetogram taken with the GONG engineering unit in Boulder.

In FY 2017, NSO relocated the machine shop from Sunspot to a Boulder off-campus location. Early in the transition, NSO initiated discussions with LASP about co-locating our machines at their facilities in the LASP engineering building. Because of prevailing International Traffic in Arms Regulations (ITAR) at LASP and complex liability concerns, NSO decided to search for a new off-campus machine shop location. NSO/AURA has leased 2757 square feet of usable space at an industrial warehouse on Longbow Drive in Boulder, and the machines from Sunspot arrived on September 1, 2017. NISP has relocated some equipment from Tucson that is used for various GONG refurbishment tasks. Currently, DKIST construction support is given priority by the machine shop. After completion of DKIST, the machine shop will be an Observatory-wide service.

In September 2016, the AURA President and CU Boulder Provost signed the Cooperative Agreement (CA) that outlines the integration of NSO in the University framework and venues to further collaborations with the research institutions. This CA replaced the previous Memorandum of Intent (MoI) dated September 2012 and is a significant milestone for the transformation of the Observatory. The purpose of the Agreement is to provide a framework within which both parties advance, through mutually beneficial cooperative endeavors, the respective research missions as related to solar research and educational and public outreach. It is also intended to expand and complement each party's research, education, and service activities, through the promotion of faculty and staff exchanges and the formation of collaborative teams to address specific research and opportunities. The CA states that the NSO is considered an independent research organization rostered under the University Vice Chancellor for Research. The CA consolidates the NSO/CU Boulder collaboration through the various joint and visiting faculty positions, George Ellery Hale (GEH) postdoctoral and graduate fellowships, and the appointments of NSO scientists within the University system. Particularly relevant is the status of Assistant Professor Adjoint, to which selected NSO scientists may be nominated, making them eligible for support of activities that are directly pertinent to the research and teaching mission of CU Departments. The expectations are that these Adjoint Professors will become engaged in graduate-student advising and mentoring as appropriate. Currently, two NSO scientists hold this status (Drs. Kevin Reardon and David Harrington) as mentors of PhD students at the APS Department. The CA also details the benefits that NSO employees receive, including tuition discounts, as part of their appointments as Professional Research Assistants at CU Boulder.

During the first half of the Cooperative Agreement, CU Boulder has continued moving forward with the George Ellery Hale Program as detailed in the original bid to host the NSO HQ. As a critical component of the GEH Program, CU provides funding for two three-year graduate student fellowships and one two-year postdoctoral fellowship each year (six graduate-student fellows and two postdoctoral fellows in residence at any one time). These fellowships are intended to support solar and space physics research and stimulate collaborative activities between CU and the NSO. FY 2016 saw the successful filling of the first 50% NSO-CU shared tenure-track faculty position. Dr. Adam Kowalski, a graduate of the University of Washington, was selected from a pool of 35 applicants and joined CU Boulder and NSO in August 2016. The principal employer for this position is CU Boulder, which provides salary and benefits. NSO contributes half of all the necessary funds for this position, including the startup package. A specific Memorandum of Understanding (MOU) between LASP and AURA/NSO describes the obligations and expectations of the two parties and details the procedure for annual merit review and tenure promotion at both institutions. The second joint faculty position was successfully filled in FY 2017. The selected candidate, Dr. Maria Kazachenko, brings to NSO a wealth of knowledge in coronal modeling based on novel applications of first principles that can quickly adapt to the high-resolution observations that DKIST will provide. Six GEH graduate students currently use LASP or NSO as their research center. A student rotation element, which started in FY 2017, exposes them to a diverse pool of research topics that they then select for a PhD. Currently, four PhD students have mentors from NSO and two additional graduate students are permanently collocated in the student area at NSO HQ.

4.2.2 The NSO DKIST Science Support Center in Maui

The NSF approved in July 2015 the acquisition by AURA of the land in Pukalani, where the DKIST Science Support Center was erected. The site is contiguous to the University of Hawaiʻi (UH) Institute for Astronomy (IfA) Advanced Technology Research Center (ATRC) building that hosts the teams that are building two of the DKIST first-light instruments. Being collocated with our UH colleagues ensures a synergistic environment (as found at the Astronomy Campus in Hilo) that will help maximize the efficiency of the operations efforts. Another benefit of this proximity stems from the fact that the UH data-handling system brings raw observational data down from the summit and has a terminus at the IfA building. NSO has linked to that terminus for data to be directed to the DSSC for processing and analysis by the on-site staff at no additional cost. In steady operations, the number of employees in Maui will be about 40.

Construction of the DSSC building started in the second quarter of FY 2017 and lasted less than a year. During that period, the building was known as the Remote Office Building (ROB), and after completion was renamed the DKIST Science Support Center and officially inaugurated on October 26, 2018. The ramp up for operations moved at a slower pace than the staffing plan presented in the original Cooperative Agreement proposal due to delays in the availability of the DSSC. DKIST is adjusting its transition from construction to operations in a cost-effective manner and minimizing the impact of the delays in hiring the workforce on the island. FY 2019 will see the first wave of relocations of operations personnel from Boulder to Maui. Transfers from construction to operations will occur at the end of the MREFC project.

4.2.3 Transition Cost

The NSF/AST solicitation considered the possibility of using a portion of the DKIST funding wedge expected during the first five years of the CA to cover the expenses of the transition. The NSF solicitation explicitly stated that AURA/NSO should address “prospects for utilizing a portion of the DKIST operations funding wedge, and/or potential savings elsewhere within the budget that might offset the costs of the move." The transition budget included four components:

- The relocation expenses for personnel who moved to Boulder or Maui and for those who decided to retire or leave.
- The cost of moving equipment and goods to Boulder and Maui.
- The Boulder HQ furniture and IT equipment costs.
- The Boulder HQ lease costs (3rd floor and lab space on the first floor) during FY 2015 and FY 2016.

FY 2015 utilized $797K to cover the cost of the first three bullets. Expenses included the cost of relocating staff to Boulder, recruitments at the new NSO sites, charges for moving equipment to Boulder (such as the Sunspot library), vacation accrual and severance packages, HQ furniture, and renovation of the first-floor laboratory. It also covered the cost of specific IT infrastructure needed to host new services such as Web servers and a consolidated e-mail system for NSO (now fully implemented using Google services). These expenditures also included the minimum scientific support equipment needed for the first scientists that relocated to Boulder. Additionally, $825K was budgeted to cover the cost of the SPSC lease, including new furniture and the first-floor laboratory space. The equivalent budgets for FY 2016 were $931K (HQ development) and $802K (HQ lease). We allocated in FY 2017 an additional $489K to transition costs for HQ development which corresponded to the last portion of the DKIST funding wedge utilized for this purpose. Expenses incurred in FY 2017 corresponded to additional moves of equipment from Sunspot and Tucson to Boulder, such as the Sunspot machine shop; the GONG engineering units; optical hardware from Sunspot and Tucson, including reference flat mirrors and optical tables; IT and AV equipment; and documentation from the offices at both sites. As in the previous year, this package included the benefits offered to those employees going into retirement or being terminated.

For the HQ lease in FY 2017, we implemented a new accounting structure that allocated the cost of office, cubicle, lab space, and a share of the common spaces to each of the programs, including the DKIST construction project. FY 2018 was the first year when the NSO transition did not utilize any portion of the DKIST funding wedge as proposed in the original CA proposal. The total budget used for transition purposes that came from the DKIST funding wedge over the three years was $3.8M. Of these funds, the Director's budget still carries forward unexpended funds for relocating equipment from the DST to Boulder and Maui once the telescope is no longer operational.

4.3 NSO Integrated Synoptic Program (NISP) Partial Divestment

Following the 2102 recommendation of the NSF/AST Astronomy Portfolio Review Committee (PRC), the NSF solicitation requested that the budget allocation for NISP should decrease from $4M/year to $2M/year by FY 2016. This reduction occurred during the first half of the current CA and coincided with the peak of activities of NSO's transition to Boulder. During this same period, the DKIST Operations budget saw a steady budget increase in preparations for operations of the Maui facility. Thus, under this period the two programs, DKIST and NISP, faced very different challenges that resulted in a much higher level of attrition for the latter.

FY 2017 was the second year when the NISP budget remained at the $2M level. In late FY 2016, however, the program was provided with a one-off contribution of $2.5M from the NSF to refurbish the GONG network. FY 2016 also saw the consolidation of the NOAA Space Weather Prediction Center (SWPC) contribution for GONG operations at a level of $800K/year. These two additional funding sources were agreed to as part of the National Space Weather Strategy and Action Plan and allowed for a softer adaptation to the budget reductions. The scope of the GONG refurbishment is explained in Section 6.2. The NSO transition impacted this activity, which was not included in the original plans for relocation. Personnel dedicated to GONG refurbishment and new hires needed for this activity were distributed between the Boulder and Tucson sites. This separation of workforce slowed the progress in some areas of the refurbishment project that will likely extend well into FY 2019, with the corresponding funds providing a temporary alleviation of the budget constraints. Starting in FY 2020, however, NISP base funding will remain at the $2M/year level, supplemented only by the $800K/year for GONG operations from NOAA /SWPC that need to be renegotiated by FY 2021.

To demonstrate how NISP has adapted to the new reduced budget, we provide in Table 4-7 a comparison of the NISP FTE allocations and the corresponding budgets for FY 2014 and FY 2019. An exact comparison is difficult as the precise meaning of some of the expenditures has changed over the years. The AURA indirect cost model is different and does not include the same items in both years, with some of the benefits charged using different assumptions. Additionally, the cost of the office space was charged differently in Tucson —in an AURA building— than in Boulder, where each program is charged a portion of the lease depending on square footage use and an FTE-prorated scale for common spaces.

NISP traditionally has shared FTEs between the base funding and external grants. These grants also help to relieve budget shortfalls, but the number of grants changes from year to year and makes planning difficult. It also complicates the comparison process of widely separated years. For this reason, in the comparison provided below, we have decided to exclude all external grant funding or any supplemental funding such as that for the GONG refurbishment program. Also, to facilitate the comparison, the numbers on the table have been rounded and do not use fractional FTEs. In FY 2014, we added to the NSF base funds of $4M a contribution from the Air Force that year of $400K that the program received for GONG operations. For FY 2019, we use the $2M base budget plus a NOAA contribution of $800K.

TABLE 4-7. NISP Base Funding + GONG

NISP Base Funding + GONG	2014		2019	
	FTEs	Total Budget	FTEs	Total Budget
Science Support	10	$1,300K	5	$657K
Technical Support	7	$1,096K	4	$998K
Data Center	10	$1,144K	5	$799K
Administrative Support	2	$279	1	$90K
AURA Indirect Costs	n/a	$560K	n/a	$224K
Total	29	$4,379K	14	$2,786K

With the above caveats in mind, Table 4-7 demonstrates the significant changes that have occurred within the program. NISP has reduced by half the number of FTEs allocated to the base. The reduction has been even among all areas. However, in FY 2019, the amounts allocated for technical support (SOLIS and GONG operations) and for data distribution do not approach a 50% reduction. This lack of cost savings should not be a surprise as the program is running the same two facilities. The budget for technical support in FY 2019 includes several one-off expenditures for the new site at BBSO that will not be present in FY 2020. While this will help reduce the cost of the telescope operations in future years, starting in FY 2020, the NISP budget will incur the full operational fee included in the BBSO MOU, offsetting any potential savings. Table 4-7 clearly shows that the cost of operating the two facilities—especially SOLIS, as GONG is funded by the NOAA contribution—is what puts pressure on the NISP budget and demands a higher allocation of scientists to non-base funding sources.

4.4 Kitt Peak and Sacramento Peak Divestment

As mandated in the NSF solicitation for the renewal of NSO's Cooperative Agreement, the major historical telescope facilities managed by NSO needed to be closed or divested after 2017. With mid-2020 as the expected date for DKIST first light, we faced a two-year gap during which NSO would have no observing time to offer to the community for high-spatial resolution investigations. For this reason, NSO is collaborating to ensure that the Dunn Solar Telescope (DST) remains operational under the Sunspot Solar Observatory Consortium (SSOC) led by New Mexico State University (NMSU). The consortium runs a synoptic program at the DST and also provides some limited telescope time for target-of-opportunity scientific observations. NSO participates in this effort by continuing to manage the Sunspot site, including housing and facilities, and by providing the telescope Chief Observer responsible for DST operations. SSOC responsibilities include scientific planning for the DST and management of the Visitor Center. FY 2019 is the first year when NSO and SSOC are functioning under this division of responsibilities. We currently plan to operate the site under this scheme for two additional years, subject to the availability of funds from the various stakeholders. The feasibility of the model is evaluated on a yearly basis.

NSF finalized the Environmental Impact Statement (EIS) required by the substantial change in the operations model of the site that includes new partners and funding streams. The Final Environmental Impact Statement (FEIS) is available at *https://www.nsf.gov/mps/ast/env_impact_reviews/sacpeak/-sacpeak_feis.jsp*. Of the various alternatives studied, Option 2: "Transition to partial operations by interested parties with reduced NSF funding" was selected as the agency's preferred alternative. The EIS states that:

> "This Alternative would meet the purpose and need of reducing the funding required from NSF. It would also allow continued benefits to the scientific and educational communities. However, Alternative 2 can be implemented only if the collaborating parties associated with the university-based consortium, led by NMSU, have viable plans to provide additional non-NSF funding in support of their scientific-focused operations or if new stakeholders come forward to participate as collaborating parties. If implemented, the duration of this Alternative would be contingent on the ability of interested parties to provide funding for operations over time."

The EIS also identifies a second alternative in case the SSOC consolidation fails:

> "NSF has identified a Secondary Agency-Preferred Alternative, Alternative 4, Demolition and Site Restoration, which would meet the purpose and need of the Proposed Action in the event that non-NSF-funding is insufficient in the future for continued operations."

This second alternative might require continued NSO presence on-site during the demolition and restoration activities.

4.4.1 Divestiture Planning: The Memorandum of Understanding between AURA and New Mexico State University (NMSU)

The National Solar Observatory operated the Dunn Solar Telescope and its full complement of instruments until FY 2017. During FY 2018, NSO trained the NMSU staff on-site to operate the instrument set-up necessary for the synoptic programs as determined by the SSOC. The consortium synoptic science plans cover various topics that benefit from a relatively large-aperture telescope feeding sensitive instrumentation and a very capable adaptive optics system. The science topics are filament vector magnetic fields, flare patrol, prominence instabilities, and the chromospheric canopy. A description of the scientific objectives and the consortium structure are available at *http://astronomy.nmsu.edu/ssoc/docs/TheTransitionToSSOC_ProjectDescriptionV3.0.pdf*.

NSO continues to provide support for data reduction pipelines, which are available on the website (*https://www.nso.edu/telescopes/dunn-solar-telescope/dst-pipelines/*) to the community in general and SSOC scientists in particular. During FY 2018, the combined NSO and SSOC operations crew performed DST observations aimed at testing the synoptic program instruments' setup. Preliminary Level-1 and Level-2 data from these runs are available at the consortium website (*http://solardisk.nmsu.edu/).* The SSOC welcomes solicitations to use the DST for target-of-opportunity observations such as coordination with space missions or rocket experiments from the nearby White-Sands facility.

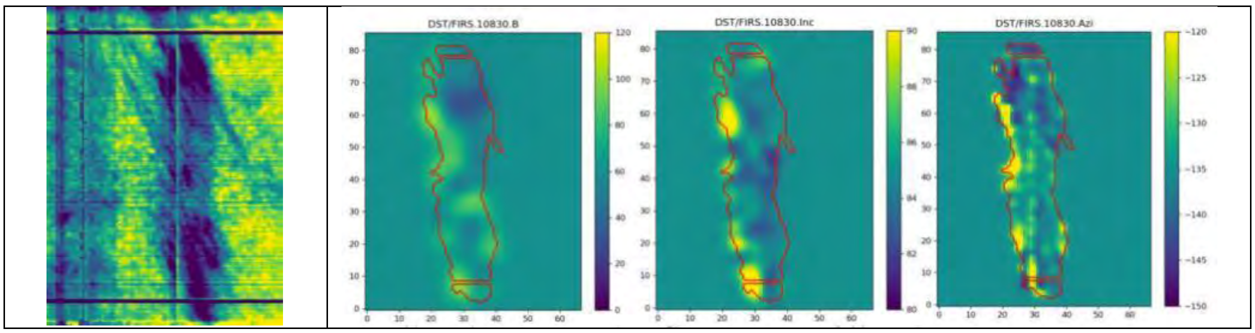


Figure 4-7. Example of Level-2 data obtained as part of the filament vector magnetic field synoptic program. The observations were taken with the FIRS instrument using the He I 1083 nm line. The HAZEL (A. Ramos, 2008) inversion code was used to infer the magnetic field parameters (from left to right on the last three images: field strength, inclination, and azimuth).

In Sunspot, NSO maintains support of the DST Chief Observer (CO), two facilities maintenance staff, one part-time administrative person, and a site manager. In FY 2019, the site manager and the DST CO started reporting directly to the NSO Director, who is also the point of contact with the SSOC leadership. For their part, the SSOC has three employees on-site: a telescope observer, an IT person, and a manager for the Visitor Center and outreach activities. The consortium is in the process of re-hiring a telescope engineer, at which point they will complete their staffing plans. The combined total of NSO and SSOC staff is 8.5 FTEs.

In FY 2018, the State of New Mexico Higher Education Department approved, for the first time, the SSOC proposal to support operations in Sunspot at a level of $273K. The funding from the State of New Mexico will support the consortium's entire program at the Visitor Center and some of the activities at the DST. In FY 2019, the State approved a second proposal at a similar level but with recurrent support, providing long-term stability for this funding line.

In October 2018, AURA and NMSU signed the MOU that describes the responsibilities of the two parties for continued operations of the site. The SSOC will manage the scientific research conducted with the DST and the collection and analysis of all data. NSO operates the DST via the Chief Observer, who will provide oversight and management of all operations at the DST, including NMSU personnel. The CO will be responsible for physically operating the telescope, planning and executing all observing routines and all maintenance activities at the DST. The DST will only operate in the presence of the Chief Observer. NMSU employees are not allowed to operate the DST. The CO has the authority to direct all operations at the DST and to remove from the DST any person who fails to follow instructions or, at the sole discretion of the Chief Observer, presents a risk to the DST or to any personnel. The CO's instructions are meant to ensure safe operation and acquisition of scientific data at the DST. The CO maintains regular contact with the SSOC lead scientist to coordinate DST activities, including scheduling of telescope time. These planning discussions include the NSO Director as needed.

As it appears in the MOU, NSO bills NMSU $10K per month to offset the DST operating costs. NSO also charges NMSU for the cost of Visitor Center and NMSU housing utilities.

NSO scope of work in Sunspot continues to include:

- Provision of site utilities, including water, electricity, and propane.
- Internet and telephone connectivity.
- Metering and billing of these utility items for the telescope, the Visitor Center, and housing.
- Provision of site maintenance, including roads, trees, and houses related to day-to-day operations and all safety aspects of working on site.
- Rubbish removal.
- Coordination with NSF on the removal of site items not required for day-to-day operations of telescope and Visitor Center.
- Training of new personnel.
- Two houses guaranteed for NMSU personnel, including maintenance and safety items.
- Two houses available for NMSU personnel as needed as for the summer NMSU students.
- One house for the NSO site manager.
- Administrative management.
- Site security.

In FY 2019, NSO started some site improvements and reparations. These include roof repairs of various buildings including the Hilltop Dome, replacement of the site septic system, and enhancing the safety of the DST elevator platform. NSO will negotiate with NSF, as a CA Supplemental Funding Request, the funding necessary for these activities and other future repairs.

Given the much-reduced number of staff living in Sunspot, the SSOC and NSO personnel have expressed concerns about security at the site. To mitigate these legitimate concerns, NSO relocated Geoff Roberts from Headquarters in Colorado to be the site manager in Sunspot. The site manager is responsible for all site activities outside of the DST and the Visitor Center. Additionally, NSO has contracted a local security firm that has regular presence on site. These additional security measures have increased the cost of keeping the observatory operational.

4.4.2 Dunn Solar Telescope (DST)

The 76-cm Richard B. Dunn Solar Telescope, located on Sacramento Peak, is a diffraction-limited solar telescope with strong user demand and excellent scientific output. The DST has five exit ports, one of which feeds a well-established AO system that is well matched to seeing conditions. This port accommodates a variety of diffraction-limited, facility-class instrumentation, including the Spectro-Polarimeter for Infrared and Optical Regions (SPINOR), the Interferometric BIdimensional Spectrometer (IBIS), the Facility Infrared Spectrograph (FIRS), and the Rapid Oscillations of the Solar Atmosphere (ROSA). This suite of instruments and matched AO system have made the DST one of the most powerful facilities available in terms of post-focus instrumentation.

The DST supports the US and international high-resolution and polarimetry communities and is often used in collaboration with space missions, including the recently launched NASA Parker Solar Probe, to develop global pictures of magnetic field structure and evolution. While competing European and privately funded US telescopes have emerged, they have not supplanted the need for the DST. Many Europeans still use the DST and provide instruments, such as IBIS (Italy) and ROSA (Northern Ireland, UK), that are available as facility instruments. The DST will continue to play the major role in supporting US high-resolution spectro-polarimetry and the development of instruments needed for progress in this important field.

IBIS, the Italian designed and built instrument, may be sent back to Italy for repurposing at a training facility for younger generations and in preparation for the 4-m European Solar Telescope (EST). If this occurs, NSO and its Italian partners have negotiated an arrangement whereby IBIS components that are the property of NSO or other US institutions will remain at the DST. NSO and the SSOC are considering implementing an alternative to IBIS that will use a single chromospheric-imaging channel.

4.5 Divestiture of Kitt Peak Facilities

The NSO has been operating the McMath-Pierce Solar Telescope (McMP) and the Kitt Peak Vacuum Tower (KPVT) at Kitt Peak in Tucson, Arizona. The National Optical Astronomy Observatory (NOAO) has been recently awarded a new $4.5M grant from the National Science Foundation for the development of the "Windows on the Universe Center for Astronomy Outreach" at Kitt Peak National Observatory (KPNO). Located in the McMP facility, the Center will provide the public with a new way of experiencing the cutting-edge research being carried out at Kitt Peak and NSF's other astronomy facilities around the globe, including ground-based optical, radio, solar, and gravitational wave facilities. The grant will fund the renovation and transformation of the McMP into an astronomy visualization center. To highlight its location in the McMP facility, the Center will also feature special exhibits on the history of solar astronomy.

The Kitt Peak Vacuum Telescope (aka Kitt Peak SOLIS Tower (KPST)) is extraneous to the needs of the NSF and NSO, as the SOLIS instrument has been relocated to Big Bear Solar Observatory (BBSO). Thus, NSF is proceeding with the complete demolition of the tower, without impacting the McMP. In collaboration with AURA Central Administrative Services (CAS) and with NOAO, NSO provides support to the demolition program on an as needed basis. A recently selected contractor will finalize demolition of the tower by early Spring 2019.

As part of the divestiture of the McMP, NSO has arranged the long-term loan of the 1024 × 1024 NSO Array Camera (NAC) to the New Jersey Institute of Technology/Big Bear Solar Observatory (NJIT/BBSO), where it will be used in conjunction with the Cryogenic Infrared Spectrograph (Cyra) to do spectropolarimetry in the 1–5 μm range, a pathfinder to the on-disk observations that the DKIST and Cryo-NIRSP combination will perform starting in 2020. The loan agreement was signed by NSO and NJIT in March 2019; the agreement includes the Celeste 12-μm spectrometer, a Tribodyn vacuum pump, and various electronic components. As part of the agreement, BBSO will send NSO their AO-76 equipment, a replica of what's currently used at the DST, that can be used for spare components.

NSO has also reached an agreement with the Pisgah Astronomical Research Institute (PARI) in Rosman, North Carolina, to transfer from the McMP the US Naval Observatory (USNO) white-light, full-disk plates for addition to the PARI Astronomical Photographic Data Archives (APDA). The USNO program began in 1898, then was transferred to Mt. Wilson in 1930. The collection of about 29,000 plates was sent to NSO in the 1990s.

4.6 Budget Expenditures

Over the past five years, the NSO has detailed yearly expenditures, new funds and carry-forward budget planning, and external grant support in the corresponding APRPP documents[3]. Appendix A provides budgetary expenditure information on the most significant cost of the accomplishments of the program over the first five years of the current CA underlying all areas of activity.

[3] https://www.nso.edu/about/reports/

5 DANIEL K. INOUYE SOLAR TELESCOPE (DKIST)

This Chapter addresses all Goals described in Section 2.2 and Activities 1, 2, 3, 7, 9, 10 and 15.

5.1 DKIST Construction Final Phase

5.1.1 Integration, Test & Commissioning (IT&C) of DKIST

The planning and execution of the project is based around the classic systems engineering "V"-diagram approach to design, fabricate, assemble and test the telescope (Figure 5-1).

As the project enters its final full-year, we are ensconced as planned in the upper-right hand phases of the V-diagram (Level-2 Subsystem Testing; Level-1 Integration, Test and Commissioning (IT&C); and Level-0 Science Verification & Closeout).

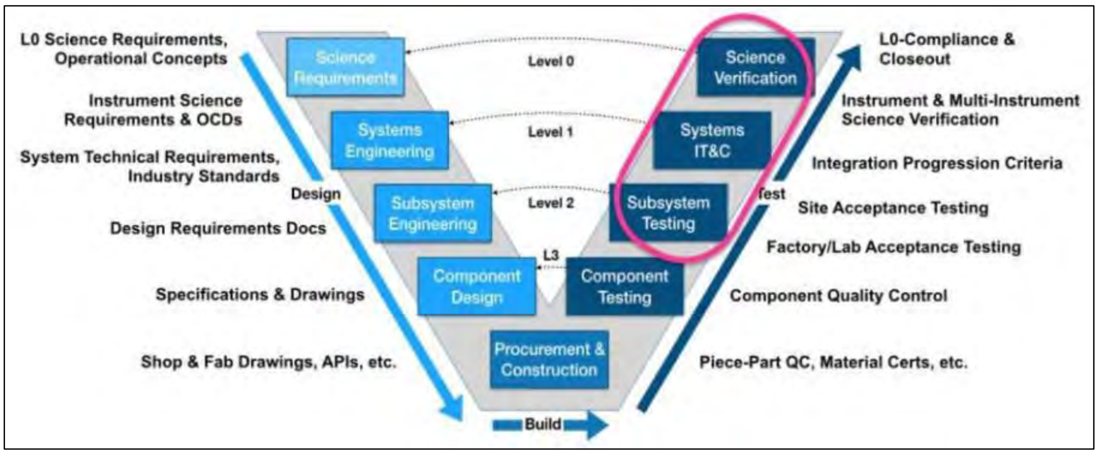


Figure 5-1. Classic systems engineering "V"-diagram approach to design, fabricate, assemble and test the telescope.

There are a number of remaining subsystems that have yet to be delivered to the site. These include the Facility Instrument Distribution Optics (FIDO), the Wavefront Correct System (WFC), four of the remaining nine visible cameras, and the four partner instruments (Cryo-NIRSP, DL-NIRSP, ViSP, and VTF). We expect all of these systems to be delivered within the project schedule.

The IT&C effort is subdivided into eleven key System Integration Modules (SIMs) packages. These SIMs are not entirely serial in nature. Some SIMs can be carried out in parallel with other SIMs and some activities captured in higher numbered SIMs can occur earlier than lower numbered SIMs. Regardless, it is convenient to think of the SIMs as sequential work used to plan and orchestrate the IT&C effort. Each SIM includes a flow chart that describes the logical flow of the work and includes a number of pre-conditions. For each SIM, the project has established Integration Progression Criteria (IPC), which are essentially go/no-go criteria for completion of the SIMs. In many cases, these IPCs serve as formal acceptance criteria for SRD, ICD and OCD requirements, i.e., the SIM process facilitates populating the top-level compliance matrix needed for the close out of the project.

The current status of the SIMs is as follows:

- **IT&C SIM 1 - Telescope Pointing Map**. The bulk of this work is complete, with demonstration of the pointing of the telescope within its required IPC specification.
- **IT&C SIM 2 - M1 Integration**. This SIM includes: aluminum coating of the primary mirror; integration of the mirror into its cell assembly; integration of mirror and cell assembly into the

telescope optical support system (OSS), and measurements of pointing and prime focus image quality. The bulk of this work is complete, with satisfactory demonstration of its required IPCs.

- **IT&C SIM 3 - M1 and M2 Integration**. This SIM entails installation of the top end optical assembly (TEOA; including secondary mirror) onto the OSS and performing measurements of telescope pointing and image quality at Gregorian focus. The bulk of this work is complete, with satisfactory demonstration of its required IPCs.
- **IT&C SIM 4 - M1-M6 Integration**. The next SIM that the IT&C team is focusing on is the installation and integration of the remaining optics to be installed on the OSS. The implementation of this SIM is just now starting.
- **IT&C SIM 5 - Coudé Optics + FIDO Integration**. This SIM entails installation and alignment of the M7-M9 mirror assemblies and the FIDO optics onto the Coudé rotator. This SIM is just starting up.
- **IT&C SIM 6a - VBI Integration**. The first light initiative (FLI) instrument is the Visible Broadband Imager (VBI), which is installed and commissioned as part of this SIM. Planning for this SIM is complete and will be implemented in summer of 2019.
- **IT&C SIM 6b - WFC Integration**. To support FLI, the WFC system is required to be installed, aligned, and operating, which is the focus of this SIM. Planning for this SIM is complete and the execution of the SIM will be implemented in summer 2019.
- **IT&C SIM 7 - First Light Initiative**. Completion of this SIM represents the penultimate "Level-1" reportable milestone to the National Science Foundation (NSF). IPCs associated with this SIM include the first Sun-based observations of the observatory with fully functioning wavefront correction. Planning for this SIM is complete and the SIM will be executed in late summer and early fall of 2019.
- **IT&C SIM 8 - GOS Integration**. The execution of this SIM is starting up now, with the installation of the Gregorian Optics Station (upper and lower) into the OSS.
- **IT&C SIM 9a - Cryo-NIRSP Integration**. This SIM entails installation, alignment and commissioning of the Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP) instrument onto the Coudé rotator, including on-Sun observations and initial science verification of the instrument. Initial planning for this SIM has taken place and will be finalized in the coming months.
- **IT&C SIM 9b - DL-NIRSP Integration**. This SIM entails installation, alignment and commissioning of the Diffraction-Limited Near-IR Spectro-Polarimeter (DL-NIRSP) instrument onto the Coudé rotator, including on-Sun observations and initial science verification of the instrument. Initial planning for this SIM has taken place and will be finalized in the coming months.
- **IT&C SIM 9c - ViSP Integration**. This SIM entails installation, alignment and commissioning of the Visible Spectro-Polarimeter (ViSP) instrument onto the Coudé rotator, including on-Sun observations and initial science verification of the instrument. Initial planning for this SIM has taken place and will be finalized in the coming months.
- **IT&C SIM 9d - VTF Integration**. This SIM entails installation, alignment and commissioning of the Visible Tunable Filter (VTF) instrument onto the Coudé rotator, including on-Sun observations and initial science verification of the instrument. Initial planning for this SIM has taken place and will be finalized in the coming months.

- **IT&C SIM 10 - Polarization Calibration**. Initial planning for this SIM has taken place and will be finalized in the coming months.
- **IT&C SIM 11 - Observatory Commissioning & Verification**. Initial planning for this SIM is underway.

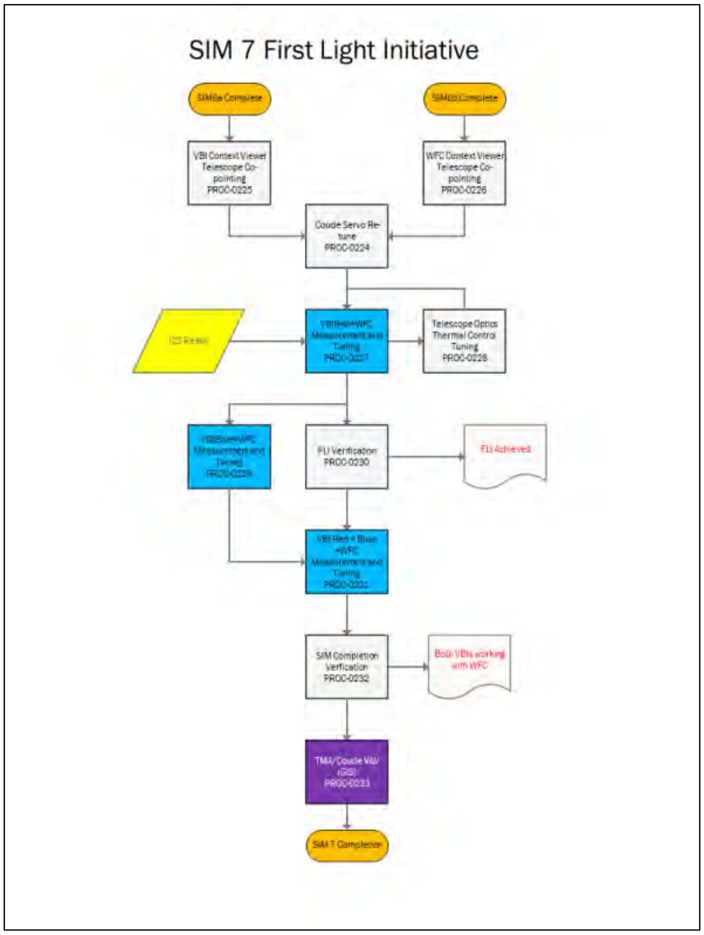


Figure 5-2. SIM7 (FLI) flow diagram. This chart is an example of the detailed planning that has occurred for SIM1-7 and is in progress for SIM8-11. Procedures are executed and lead to "progression criteria met" milestones, such as FLI achieved.

Figure 5-2 shows as an example the flow chart of SIM7 – First Light Initiative. The First Light Initiative (FLI) is the centerpiece of SIM 7. The statement of work of SIM7 defines verifiable Integration Progression Criteria (IPCs), which is generally achieved through a detailed and formally documented agreement between Systems Engineering, Project Management and Science on the definition of FLI. The work itself is detailed in procedures. A pre-condition is that SIM6a and SIM6b must be complete before SIM7 can be executed, i.e., the wavefront correction system, in particular, the high-order adaptive optics system must be functional and the VBI integration and functional testing must be complete (Figure 5-3).

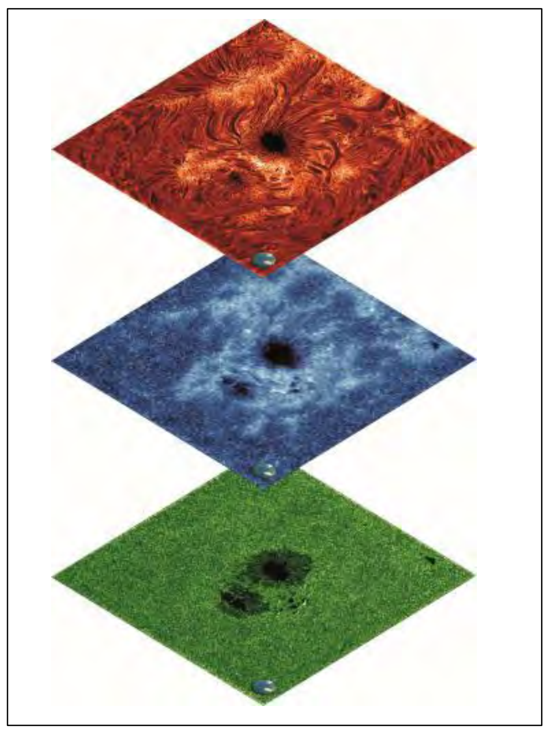


Figure 5-3. The First Light Initiative will produce a first and limited set of images and movie(s) from the VBI similar to the images shown here taken at the DST but with much higher resolution.

FLI completion is a Level-1 Milestones in the IPS, and as such is reportable to the NSF. FLI is one of only three remaining Level-1 Milestones. The FLI constitutes a major milestone since it will demonstrate the functionality of the entire optical system, including the main telescope, all transfer and feed optics, wavefront correction and one of the first-light instruments. In addition, a number of supporting systems including many software and control systems as well as the all-important thermal systems will be tested and demonstrated. The expectation is to record first diffraction-limited images and movies. FLI is scheduled to be completed in fall 2019.

5.1.2 DKIST Project Closeout

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

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

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

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

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

5.2.1 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 PI's (Current membership Table 5-1).

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

Table 5-1. 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 5-4. The DKIST Critical Science Plan website with links to documentation and tools.

capabilities and includes links to the documentation and tools required to construct a CSP Science Use Case (SUC) (Figure 5-4.) and https://nso-atst.atlassian.net/, a collaborative site for the development of Science Use Cases by the community. These Science Use Cases not only serve as the basis for the critical science describes in the CSP document, but also as first drafts of the Observing Proposals users of the DKIST will be required to submit to the DKIST Time Allocation Committee (TAC) to acquire observing time on the telescope. The JIRA DKIST Community development site is password protected, and there are currently 387 members and 260 Use Cases in various stages of development. Of these Science Use Cases, 97 are assessed to be well developed by their PI's, ready to be converted into Observing Proposals in response to early calls for proposals by the project. The completion of remaining Science Use Cases and their conversion to DKIST Proposals will be essential to meet the broad early critical science goals.

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

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

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

The DKIST SWG is now nearing completion of a draft Critical Science Plan document. 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:

<u>Magnetoconvection and Dynamo Processes</u>

- 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.

<u>Flares and Eruptive Activity</u>

- 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.

<u>Magnetic Connectivity through the Non-Eruptive Solar Atmosphere</u>

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

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

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

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

During the first year of operations, it is anticipated that DKIST calls for observing proposals will define an Observatory Commissioning Phase (see Section 5.5.5 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 likely 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. The NSO/DKIST will inform the SWG and community about the capabilities available at different stages of the Operations Commissioning Phase (OCP) (see Section 5.5.5 Operations Commissioning) with the aim of maintaining community engagement throughout the OCP.

5.3 DKIST Operations

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

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

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

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

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

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

This LRP provides a summary overview of all DKIST Operations activities. 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.

It is beyond the scope of this document to coalesce and compile all of the existing information into one document. The LRP summarizes concepts with references to the aforementioned concepts and procedures documents.

5.3.2 Deliverables and Objectives

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

1. Development and implementation of Science Operations concepts and procedures, including service and access mode operations, TAC procedures, proposal and experiment cycle. (Preliminary versions in June 2020; full implementation at the end of OCP).
2. Implementation of Science Operations, including supporting tools, staffing plans, shift schedules and budgets. This includes the Science Operations Specialists (SOSs), Resident Scientists, the Operations Tools, and the Help Desk. (Preliminary versions in June 2020; full implementation at the end of OCP).
3. Development and operations of infrastructure, such as the DKIST Science Support Center (DSSC) on Maui, office, lab and shop space in Boulder. (DSSC, lab and machine shop were completed during the first half of the CSA. Solution for long-term equipment storage space on Maui, rent or build, at the end of CSA).
4. Concepts, plans and implementation of Technical Operations of the DKIST facilities on Maui, including staffing plans, shift schedules and budgets. This includes the engineering support and maintenance activities involved in operating the Maui facilities, including the summit facilities and the DSSC. (Initial planning complete; full implementation at the end of OCP).
5. The development and operations of the DKIST Data Center (DC), which will handle processing, archiving, and distribution to the community of calibrated DKIST data. (DC infrastructure implemented at the beginning of the OCP. First iteration of instrument calibration pipelines implemented at the end of OCP. Calibration pipelines for additional instrument modes and some Level-2 products developed at the end of the CSA).
6. Development and integration into DKIST of new instrumentation or capabilities, such as MCAO, instrument upgrades and enhancements to be implemented during operations in FY 2020 – FY 2024. (Major components manufactured by the end of FY 2021. Lab integration and testing in FY 2022 – FY 2024.)
7. Support of the community in order to prepare for DKIST science by developing a Critical Science Plan (CSP). (Ongoing effort. CSP document complete by FY 2020).
8. NSO Research – NSO science staff will participate in CSP science activities and scientific publications, including NSO staff led CSPs. NSO science staff will serve as the PI of individual DKIST Proposals. NSO science staff will continue to play a leading role in working with the community to develop new instrument capabilities. Science staff document their research with publications and presentations. (Ongoing effort).
9. For operations the DKIST will adapt the safety program developed during DKIST construction. (Adaptation to operations phase complete by the end of OCP).
10. Development and implementation of an effective organizational structure, including staffing plans, schedules and budgets. (Complete by the end of OCP).

We emphasize that operations planning and ramp up to operations, including the implementation of the DSSC and the Data Center are outside the scope of the DKIST MREFC construction project. The initial DKIST Data Center will deliver calibrated data for all first-light instruments. Enhanced capabilities, such as higher-level data products and inversions, will be developed initially through recently awarded supplemental NSF funding (Section 7.1 DKIST Level-2 Data Efforts) and, as funding and available resources allow, during operations. Distribution of Level-2 data products has been added to the DKIST Data Center scope and is funded through the Level-2 effort.

The planning and implementation of DKIST Operations began at significant levels with the approval of the current CA in 2015 and subsequent funding. During FY15 and FY19 significant progress has been made in all areas listed above. Milestones achieved as well as milestones to be achieved in the second half of the CA are addressed in the individual sections below.

The team involved in the operations planning and ramp up consists of staff dedicated to the operations effort and small fractions of full-time equivalents (FTEs) from construction staff. The team covers all areas of relevant expertise needed to plan and implement the DKIST Operations. Obviously, at this phase of the DKIST project resource contention exists, in particular, for contributions of members of the construction engineering team. The top priority remains the completion of the construction of DKIST on schedule. Hence, construction staff availability for operations planning is very limited, which affects primarily the planning of technical operations on summit. An example of where additional planning effort is needed and would be helpful for defining resource requirements is the detailed planning of maintenance of the complex summit facility. However, detailed documented procedures including maintenance procedures and manuals are being developed as part of the construction effort. Procedures and manuals will be handed over to DKIST Operations at the end of construction. We also expect a large fraction of the construction engineering staff to transfer to operations, essentially transferring the required expertise and experience to operate and maintain DKIST systems. The lack of very detailed planning of the summit technical operations introduces uncertainty and risk in the resource estimates in this area.

5.3.3 Background and Assumptions

The level-0 Science Requirements Document, SPEC-0001 of the construction project, has guided the design and implementation of the facility. This document has been in stable and revision controlled form for at least a decade. Additional guidance concerning the science objectives is provided by the Instrument Science Requirements for the five first light instruments. As DKIST Operations approaches the community has engaged in an effort to develop the critical science plan (CSP, *https://www.nso.edu/telescopes/dkist/csp/*). The CSP is a document that describes the science objectives of DKIST from today's perspective and taking into account the progress that has been made since the SRD was developed. Progress has been made in all areas but, in particular, in the area of modeling and simulations, which provide detailed guidance and motivation for verifying observations. The CSP is a community driven effort to define scientific use cases, i.e. observations using the available instrument suite and data processing capabilities of DKIST.

It is important to note that DKIST and, in particular, DKIST Operations have been designed as a proposal driven facility that is expected to operate for about two magnetic cycles. Over this period science goals will continue to evolve. The evolving science goals of a broad community are best served and supported by a facility that responds to community needs with an efficient bottom-up proposal process and cycle and by facilitating self-organization of the community through, e.g., the CSP effort. NSO facilities have operated in a proposal driven manner for decades. We note that with DKIST we are moving into a new era where NSO does not just enable science through providing PI's with access to telescope facilities but enable a much broader user base with science opportunities by providing access to data products.

The collection of CSP use cases is expected to be processed into DKIST Proposals. The intention is to execute approved CSP proposals along with approved solicited proposals during the first one-to-two years of operations. Review and ranking of proposals will be performed by a Time Allocation Committee (TAC). The process is described in Section 5.5.2.11 Proposal Process and Telescope Allocation Committee.

The DKIST Operations Plan is based on the following assumptions and expectations for the start of operations in 2020.

The well-documented construction scope defines the state in which the DKIST facility is handed over to operations. The DKIST facility will be delivered to operations in the following state:

- The facility has successfully passed all IT&C steps and associated verification tests. Verification results are fully documented.
- SRD, Instrument Science Requirement Document (ISRD) and OCD requirements have been verified and documented.
- A complete set of documentation, including users and maintenance manuals, has been handed to operations.
- Instruments, including wavefront correction and the polarization analysis and calibration (PA&C) system have passed all acceptance tests and are science ready. Science verification results have been documented.

A number of key parameters and expectations drive the operations planning, including staffing and budget. Those operations parameters include:

- Based on the DST operations model the expectation is that the DKIST facility will operate (science and technical) seven days per week and with a very limited number of scheduled holiday closures.
- The facility will be operated in service mode for a significant fraction of the observing time. As a target for stable, full-up operations 75% service mode and 25% access time are envisioned. The fraction of access time is envisioned to be larger during early operations.
- The core operations time is sunrise+1.5h to sunset-1.5h (set by the minimum elevation the off-axis telescope can point to) with a few hours of pre-sunrise prep time and a few hours of after sunset follow up and maintenance activity.
- A typical observing day will combine high resolution on-disk observations and coronal observations. The two main science objectives can broadly be summarized as 1) high-resolution observation of the solar disk; and 2) off-limb coronal observations. Objective 1) requires good to excellent seeing conditions (large r0), while Objective 2) requires coronal sky conditions. At Haleakalā, good seeing conditions occur in the morning hours and sometimes in the late afternoon (Rimmele et al., 2005). The best coronal conditions occur with the Sun near zenith. To achieve optimal operational efficiency, it is therefore planned to sequence high resolution disk and coronal observations on a daily basis in a manner that makes optimal use of seeing and sky conditions. The DKIST instrument system has been designed to allow fast switch over from adaptive optics assisted on disk observations to seeing limited coronal

observations. An added challenge is obtaining the required and sometimes time consuming calibration measurements.
- Daily planning or pre-planning will eventually (long-term goal) be assisted by weather forecast, experience base folding in the site survey results, and sophisticated models, including seeing forecasting (Numerical Weather Model, MM5).
- Occasional significant nighttime activities, such as calibration activity requiring night time objects and conditions, are envisioned.

Other assumptions:

The following assumptions drive how smoothly the transition from construction to operations occurs and how efficient early operations can be conducted:

- A significant fraction of the construction staff will transfer to operations.
- In areas where staff retention was not possible cross-training of newly hired operations staff has occurred.
- Operations manuals and procedures, e.g., for opening and closing the facility, operation of instruments and wavefront correction, operation of thermal systems, and shutdown due to weather conditions are provided to the operations team at the end of construction.
- Maintenance plans and manuals are provided to operations by the construction project.
- The core Science Operations Specialists team has been hired and trained on DKIST systems using simulators and directly at the facility during IT&C activities.
- The core Science Team is in place and has been trained to assume the roles of Resident Scientist and/or Instrument Scientist.
- Development and implementation of the Data Center infrastructure (not part of construction project) has been completed during the operations ramp up phase and staffing of DC is sufficient to support early operations.
- At the start of early operations the data center has implemented the required infrastructure, and has tested, and verified the ability to ingest data from the summit. Initial calibration pipelines based on science verification data for at least two of the instruments (VBI and VISP) have been implemented and undergone initial testing. The Data Center is ready to distribute data to users.
- Concept development and design activities for second generation instrumentation and MCAO are ongoing.

5.3.4 Early Operations/Transition

5.3.4.1 Introduction

This section discusses the challenges involved with the transition from construction to operations from the technical operations perspective. Several telescopes have experienced significant difficulties with the transition from Construction to Operations. It is unrealistic to expect the facility to work out of the box and that the construction team will deliver as such. However, it is inevitable that in early operations there will be more technical down time and inefficiency as compared to steady-state operations. The need for additional (compared to steady-state operations) engineering support in early operations is a direct consequence of these challenges. Similarly, science operations commissioning challenges exist and are discussed in one of the following sections.

5.3.4.2 Technical Support during Early Operations

This section describes the early operation with DKIST as differentiated from steady-state operations and with focus on technical maturity of summit systems. Most of the complex systems in DKIST (instruments, active optics (aO), thermal systems) arrive, or are on sky, late in the construction schedule. This means there will be significant work required to get these systems to peak operating performance levels, support integrated and working together optimally. This work requires additional staffing to provide technical during the transition to steady-state operations.

5.3.4.3 SubSystem Maturity Versus Time

In developing the plan for transition, it is important to try and quantify the stage of development of each subsystem at the time of handover. To quantify this, we introduce the concept of subsystem maturity. In Section 8 of Reflecting Telescope Optics II[4], Wilson introduces the model of 'Development-maintenance relationship' using data from the European Southern Observatory New Technology Telescope (ESO NTT) commissioning. With a bit of manipulation, we use this to develop a maturity/time curve for a DKIST subsystem as shown in Figure 5-5.

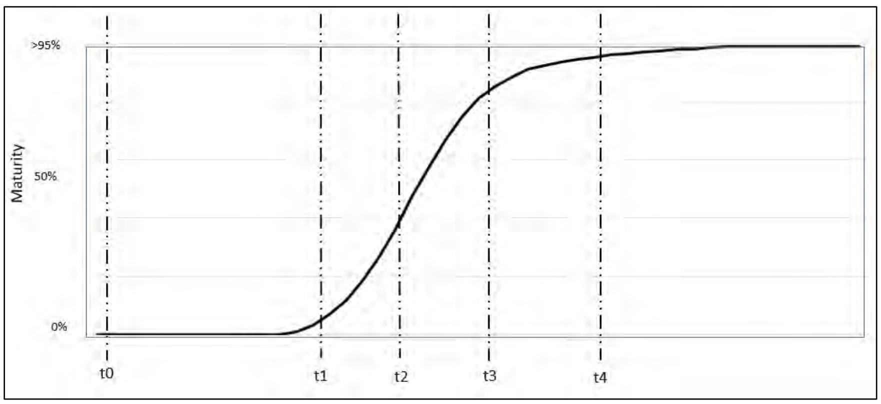


Figure 5-5. Maturity versus time for DKIST subsystem.

Table 5-2. Time Phase Definition for Instruments	
Time Stamp	Instrument Definition
t0	Instrument Arrives on Site.
t1	Site acceptance testing complete.
t2	Science verification complete.
t3	All major science cases demonstrated.
t4	Instrument fully integrated into operations.

Table 5-2 defines the time stamps in Figure 5-5. All subsystems will follow a similar curve, but we have represented instrumentation here as the key subsystems for transition. The time intervals will be highly dependent on the complexity of the subsystem(s) involved.

5.3.4.4 Maturity of DKIST at Handover

If we follow the Maturity curve, it is inevitable that some of the instruments will not be operating at high levels of efficiency in early operations. The expected order of arrival of the Coudé systems are: VBI, aO, VISP, CryoNIRSP then DLNIRSP.[5] While schedule constraints and delivery delays may juggle the order

[4]Reflecting Telescope Optics II, R.N.Wilson; ISBN 978-3-642-08223-8

[5] Note: VTF is not considered for the early transition phase, as it will be delivered too late in the process to change the outcome.

of the three spectro-polarimeters this document will assume the above sequence. Given integration is scheduled sequentially there is an anticipated two-month delay between each instrument (including aO). Using this scheduling assumption, we can create a snapshot of the instrument maturity at handover as shown in Figure 5-6.

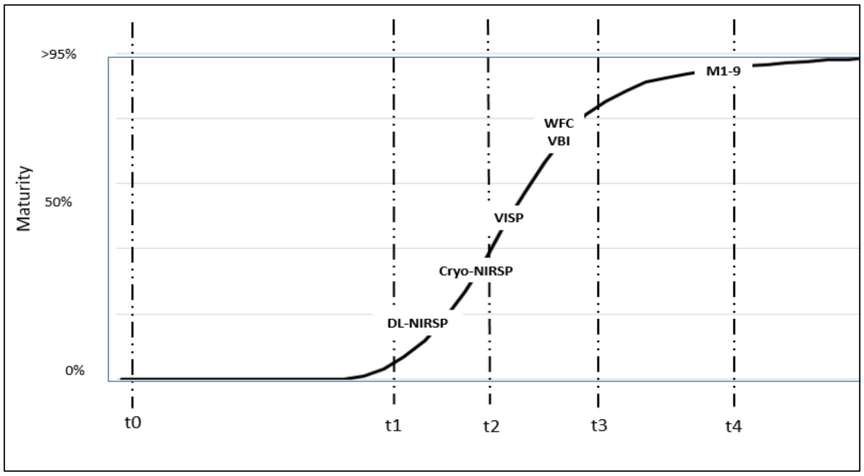


Figure 5-6. Snapshot of instrument maturity at operational handover.

As can be seen, all instruments are expected to have a level of maturity directly in relation to the period of deployment. VBI is a simpler instrument than DL-NIRSP so it should go up the maturity curve faster. Its perceived maturity, however, will be entirely based on WFC maturity curve which has a similar level of complexity to DL-NIRSP.

5.3.4.5 DKIST Capability as a Function of Time

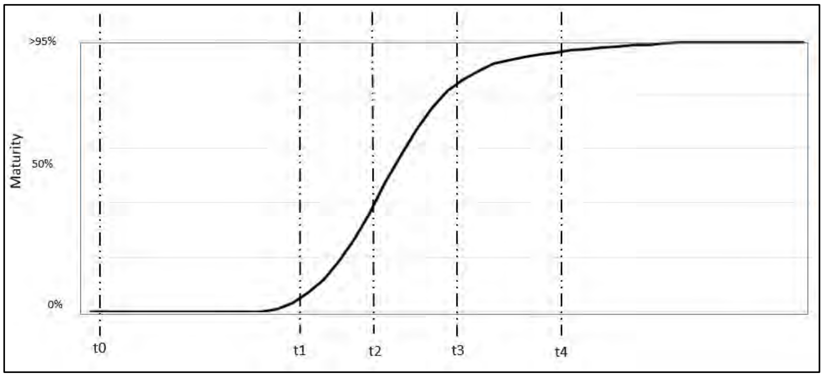
In a similar manner, we can look at the overall facility capability against time. Table 5-3 shows some of the key functionality required of DKIST to meet the science use cases. For example, to demonstrate diffraction-limited performance, we need the optics to be fully functional from M1 through M9, the aO system and VBI all working. In comparison, two-instrument science operations is dependent on VBI and VISP operating reliably enough that meaningful commissioning of this functionality can be conducted. This inevitably means it is very late in the project schedule.

Note that the VTF has been added to Table 5-3 for informational purposes only. The VTF will be delivered to the site during the transition phase.

Table 5-3. Maturity of DKIST Capability from Six Months Prior to Twenty-Four Months after Handover

Functionality	ID #	Description	Subsystems	-6m	0	+6m	+12m	+18m	+24m
Fore Optics Operational	1	All equipment required to get the light to M10, LUTS and active optics	Enclosure, TMA, M1-9, TCS (and sub-system controllers)	t_3	t_4	t_4	t_4	t_4	t_4
Diffraction-Limited Performance	2	Additional equipment required to verify the diffraction-limited adaptive optics performance	#1,+WFC, VBI (at least one channel), FIDO, Lower GOS, OCS, DHS	t_2	t_3	t_3	t_4	t_4	t_4
IR Seeing-Limited Performance	3	Additional equipment required for CryoNISRP	#1 +CryoNISRP, Upper GOS, M9a, OCS, DHS	t_0	t_1	t_2	t_3	t_4	t_4
Diffraction-Limited Polarization	4	Additional equipment required for diffraction-limited polarimetry	#2+DL-NIRSP or VISP, Upper GOS, OCS, DHS	t_1	t_2	t_3	t_3	t_4	t_4
Multi-Instrument Performance	5	Two instrument operation, ideally two spectro-polarimeters	#4 +Other instrument	t_0	t_1	t_2	t_3	t_3	t_4
VTF Functional	6	VTF late integration	#2 + VTF Upper GOS, OCS, DHS			t_0	t_1	t_1	t_2

Table 5-4. Capability as a Function of the Maturity Curve



Time Stamp	Instrument Definition
t0	Last required sub-assembly on site
t1	Capability testing complete
t2	Capability Science verification complete
t3	All major science cases demonstrated
t4	Capability fully integrated into operations

5.3.4.6 Technical Staffing Levels during the Transition Phase

Technical staff will be responsible for many additional activities during transition and will require training to acquire supplemental skill sets to accomplish these tasks. In addition to the day-to-day operational and maintenance activities, the lack of maturity of the instruments will require extra support if they are to progress through to fully functional and optimized facility instruments. Looking at the maturity chart (Table 5-3) there is significant work required to achieve the full science capability.

The need for engineering intervention time over and above the steady state will follow the inverse of the Maturity Curve. At the outset of operations ~30% of observing time over and above steady state will be required by engineering to improve the reliability and efficiency of the facility; this is reduced to ~10% by the end of transition (24 months after handover).

Shift patterns will likely be very different at the onset of the transition with the emphasis to keep the facility operational requiring intervention at any time during the operation envelop. Staff will operate on a similar shift pattern to the construction project. As time progresses and reliability improves this will evolve into the final steady-state shift pattern.

5.3.4.7 Science Operations Efficiency

As many of the instruments will be in an early stage of maturity, there will be a significant efficiency hit in execution of Observing Programs. Simple things like premature loss of AO lock, software glitches or non-automated procedures could cost significant operational time. The correct level of technical staffing and training of SOSs will go a long way to minimize the loss, but we do stress that operation time loss will be significant during the transition period. This will be exacerbated when VTF begins its on-sky commissioning.

5.3.4.8 The Final Projection

All of the above discussion on the maturation transition from the start of operations to a steady-state operational facility points to an early operational model which will necessarily be flexible. The optimization of the use of time, shared risk observing, scientist on site, prescheduled downtime and other techniques will maximize the experience of observers and operations staff. The project must provide realistic expectation of the status and performance of the facility to the community well ahead of the handover to full operations. Properly implemented, the change over the first two years will show a positive and continuous improvement until DKIST realizes the full potential.

5.4 Management Structure and Staffing

During the first half of the CA, operations staffing was ramped up and a number of key positions were defined and filed. As of FY19 the operations team is approximately 25 FTE. The Data Center, including operations tool development, experienced the most aggressive ramp up followed by the science operations specialists' group and science support. Steady-state operations staffing levels and additional transition staffing requirements are discussed later in this section. Here we discuss the organizational structure of the DKIST Program. Figure 5-7 shows the top-level organizational chart (org-chart) for the DKIST Program in operations.

DKIST is organized into functional areas including:

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

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

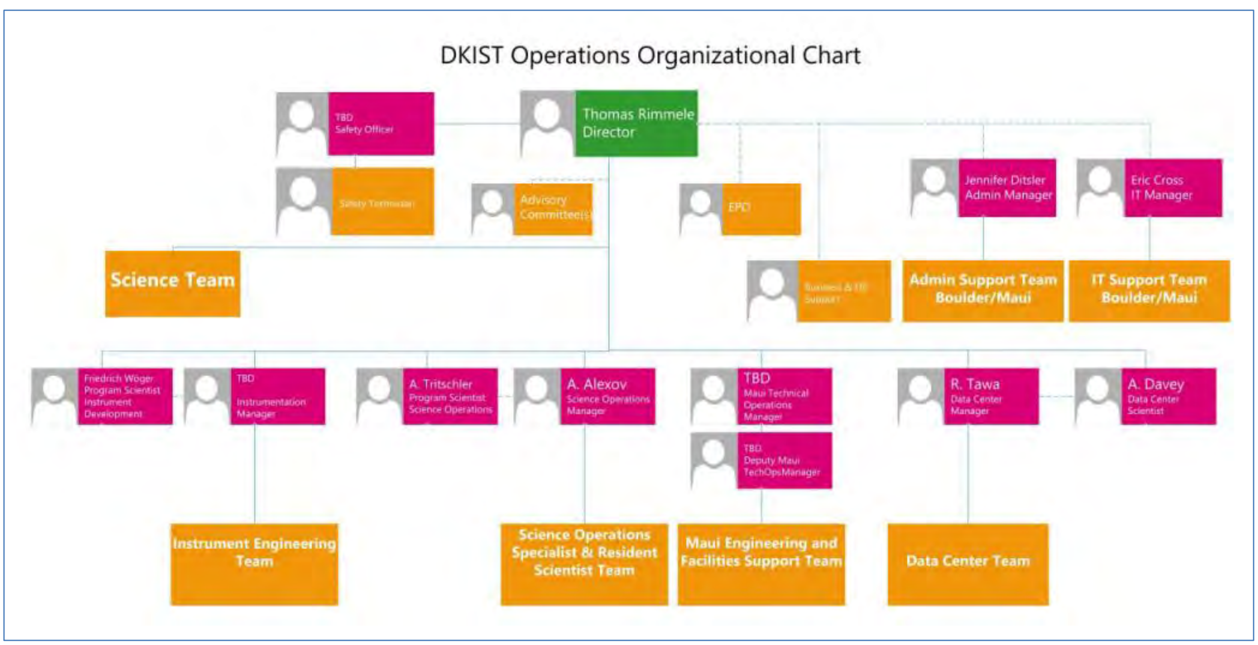


Figure 5-7. DKIST top-level organizational chart.

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.

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 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 Science Operations Manager works and coordinates closely with the Operations Scientist, Maui Technical Operations Manager, Data Center Scientist and Data Center Manager, the Chief Science Operations Specialist and Science Team members, while on duty as Resident Scientists, report to the Science Operations Manager. The position is located in Boulder.

   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 position is located on Maui.

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

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

4. **Maui Site Technical and Facilities Operations**

The Maui **Technical Operations Manager** supports the DKIST Director in the development and efficient site and technical operation of the DKIST facility. This position is responsible for the development and execution of technical, engineering, and maintenance operations plans, management of staff supporting the technical operations, communication with the observatory science and engineering community on DKIST capabilities and planning. Responsibility for management of buildings and facilities on Maui is included in this position. The position will interact and coordinate closely with the Boulder-based science and engineering leadership, the Science Operations Manager, Resident Scientist(s), Chief Science Operations Specialist, and Data Center Manager.

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. In collaboration with the Technical Operations Manager and Science Operations Manager, coordinate day-to-day Haleakalā summit work, in particular, maintenance activity prioritization. This position regularly reviews observatory performance and problems, and coordinate and assign teams to assure timely repairs, and develops operations procedures and policies for approval by the Director. 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. This position prepares technical operations staff shift patterns, coordinates with discipline leads to make assignments, and oversees technical staff training and development. This position is located on Maui.

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. In steady-state operations this group includes 24 FTEs of optical, mechanical, electrical engineering, systems engineering aspects and minimal facilities support personnel. Facilities support will be contracted to the extent possible. Even though major new developments are planned to be pursued by the Boulder instrument development team using the Boulder facilities, the combined pool of Boulder and Maui engineering resources will participate in new developments and upgrades to existing instrument and telescope systems, including software. Similarly, the Boulder instrument engineering team will contribute remotely and via campaigns to the operations and maintenance of summit systems. In particular, instrument systems, such as PA&C, WFC and software systems, including the Camera software (CSS) that during construction were developed by the Boulder instrument team can be effectively supported with participation by Boulder-based personnel that are expected to transition to operations.

The intent is that the vast majority of the **Maui Site Technical and Facilities Operations Group** will be transfers from the construction project staff.

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. Following successful NSO tradition, the Program Scientist will contribute to the systems and other engineering effort and organize similar contributions from other scientists. The position is located in Boulder.

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

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

5.4.1 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). In the current phase of the project, the SWG is developing the Critical Science Plan that will define the majority of observing programs for the approximately first two years DKIST full operation (following the operations commissioning). We anticipate that with the start of full operations, the SWG will cease to exist or merge into the long standing NSO Users' Committee.

5.4.2 DKIST Staffing Summary FY 2020 – FY 2024

The staffing plan for FY 2020 - 2024 is summarized in Figure 5-8. The figure shows staffing numbers (FTEs) as a function of WBS element and fiscal year. Where staffing numbers are stable for most WBS elements, the WBS Summit Engineering profile reflects the transition or early-operations engineering team and ramp-down to steady-state operations.

5.5 DKIST Science Operations

5.5.1 Scope Summary

The deliverables and objectives, i.e., the program scope of DKIST Operations was summarized in Section 5.3.2 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

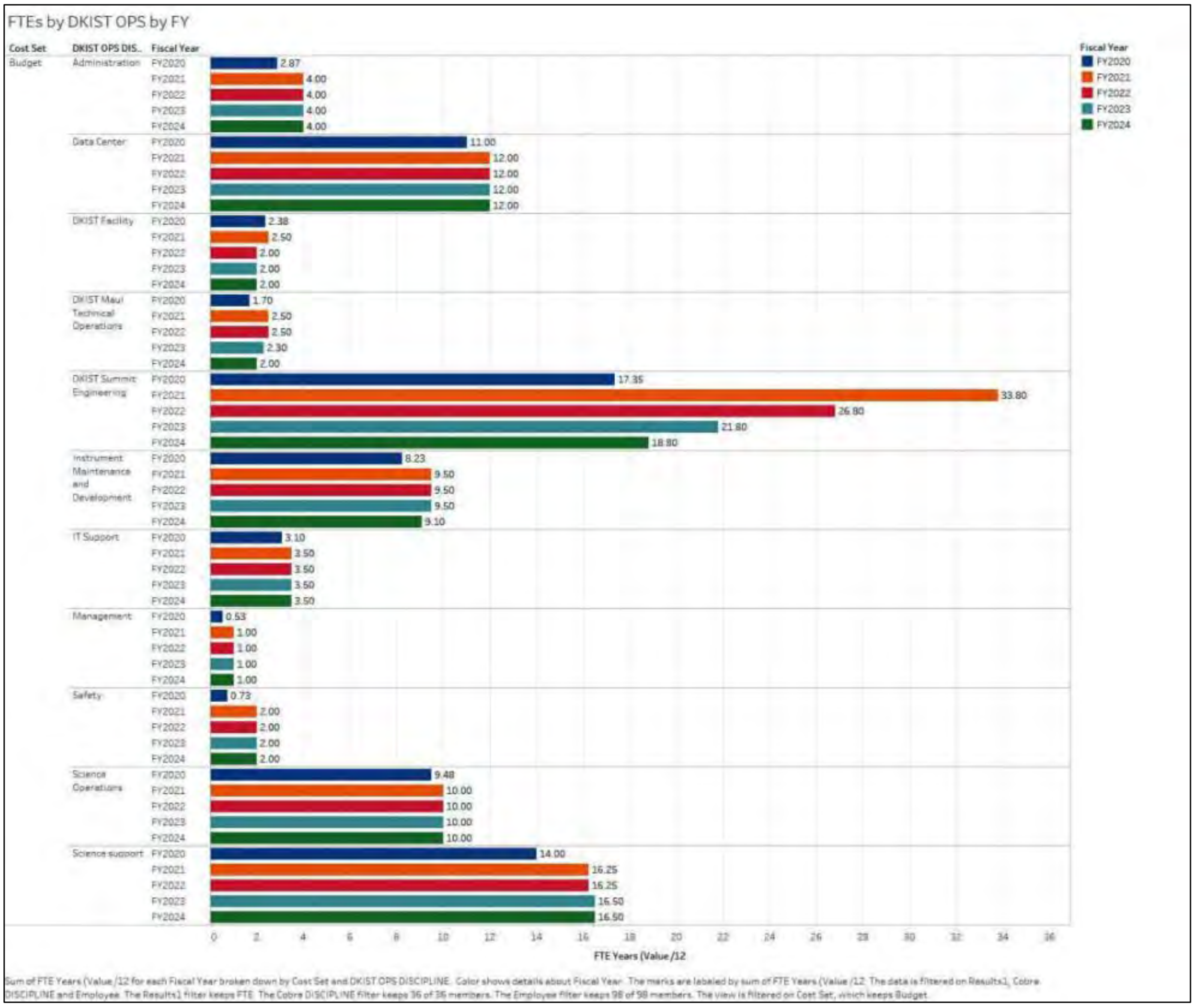


Figure 5-8. DKIST Operations staffing plan for FY 2020 – FY 2024.

Operations is collection of science, meta- and calibration data and delivery to the Data Center. Science Operations will be performed in either service mode via dynamic scheduling or access mode via fixed-block scheduling.

At the front end, Science Operations supports the user community in their efforts to generate and submit DKIST Proposals. Science Operations manages the proposal review process by the TAC, including the scientific merit and technical reviews. Approved proposals are translated to experiments using software tools, such as the Experiment Architect. Science Operations staff tests, verifies experiments, plans and supports execution of daily observations in either service mode or directly supporting a PI on site. Science Operations is also responsible for obtaining all required calibrations for each science observation. Science Operations develops and maintains software tools that support users and staff in performing the required functions. DKIST Science Operations includes an Operations Scientist, 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 5.6 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. For example, close collaboration between science and technical operations groups is required for scheduling sufficient maintenance time. 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. It is important that DKIST preventive maintenance is done in accordance with recommended manufacturer/hardware guidelines.

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 serves as the basis for developing all the science operational concepts, procedures, tools, workflows and paths forward to running the DKIST. The DIL document outlines the details of day-to-day operations for observing typical experiments, which fulfill proposals. The DIL is based on well-established solar observing techniques and expertise established by the NSO through its operations of daytime observatories, as well as from processes provided by, as well as lessons learned from, the IT&C phase of the DKIST project.

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 Science Operations commissioning or shared-risk phase of DKIST. The goal is to fine tune and perfect all the DIL procedures in order to optimize efficiency prior to steady-state operations.

The IT&C phase of DKIST construction will produce vital data towards the Data Center's development effort. These first raw data from actual DKIST instruments will be vital for testing the end-to-end data flows, processing, archiving and distribution. Data taken at the DKIST during IT&C testing of instruments will flow through the DHS into the Data Center. The delivery of all raw data to the Data Center falls within the scope of Science Operations. The Data Center will be able to test all aspects using the test data through the system. It will help with calibration pipeline development, with calibration pipeline workflows and with all aspects of end-to-end processing, archiving and distribution.

5.5.2 Summary of Operational Concepts

5.5.2.1 General Guidelines and Considerations

- Science: The DKIST will adopt a fixed-length Proposal Cycle with cyclical solicitation for Proposals (Proposal Call) governing science operations.
- Operational Model: The DKIST will offer two different observing modes for Investigators: Service Mode Observing (SMO) and Access Mode Observing (AMO). Observing modes specify how observations are scheduled.
- Proposals and Experiments: All Science Operations and their related observations are based on and directly traceable back to an approved DKIST Proposal. Proposals provide enough detail to allow a science merit review and a technical feasibility review. Proposals also specify which instruments in what configurations or modes are requested for the observations. Proposals will be implemented through Experiments. Exactly one Experiment is generated per Proposal (i.e., translated into

instructions that can be automatically executed). An Experiment contains a sequence of Observing Programs (OPs). Each OP fulfills an Observing Program Task and defines what the telescope, its subsystems and individual instruments have to do when the Observing Programs script is executed at the summit to acquire data.
- Synergies: The DKIST allows and supports co-observing efforts. Current solar ground-based observatories regularly support and co-observe with other observatories and missions, often referred to as coordinated observations. These co-observing efforts benefit the science goals, specifically if additional wavelength information and/or time coverage is needed. It is expected that the DKIST will be requested to co-observe with other observatories or missions on a regular basis.
- Multi-Instrument Operations: The DKIST supports the parallel operation of multiple instruments to obtain larger wavelength coverage and/or make use of different instrument capabilities. The Proposal and its respective Experiment define which instruments in what configurations are participating during an observation and the data acquisition process.
- Standard Calibrations: The DKIST complements each Experiment with calibrations. Each instrument participating in the Experiments observation will be supported by standard calibration measurements. Instruments are combined during those calibrations measurements as much as possible.
- The software systems on DKIST are designed to be extensible and scalable. All DKIST software control systems build on the same common software framework (called the Common Services Framework, CSF).
- The DKIST supports instrument development as well as visitor instruments.

5.5.2.2 Access-Mode and Service-Mode Observing

The DKIST Observatory is offered in two different observing modes: Service-Mode Observing (SMO) and Access-Mode Observing (AMO). SMO observations are planned and executed by DKIST Operations staff on behalf of a Proposal PI when observing and solar conditions are suitable, and technical readiness is assured. AMO is performed when the PI is present at the DSSC, overviewing and guiding the observing process.

For efficient Science Operations, the DKIST will implement service-mode observing. This is a major paradigm shift which essentially moves away from the traditional model of fixed scheduling where only one Principal Investigator (PI) has exclusive access to the observatory during a block of observing time. Instead, by adopting a flexible service model, observations are efficiently planned and executed only when solar conditions (target availability) and observing conditions (weather, seeing, etc.) are suitable, and when technical readiness of all systems is assured. SMO takes place without the PI being physically present due to the very dynamic planning and execution of the observations. 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 in deciding what experiments out of a queue 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. Service mode does not preclude joint/coordinated (campaign) programs or other programs where special time constraints are given (e.g., rocket launch, balloon or space experiment). 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 from the DSSC or may be granted physical access to the summit facility. During AMO the DKIST offers regular/standard and Target of Opportunity (ToO).

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 during a number of service-mode campaigns, the implementation of service mode at DKIST will require a commissioning and test phase in early operations. All DKIST science staff or potentially NSO science staff in general are expected to serve as Resident Scientists. Training of scientists in the use of operations tools, DKIST instrumentation and calibration procedures will accelerate until the start of operations in mid-2020 and continue into the second half of the CA. Resident Scientists support is also an area where international partner contributions, financial or in-kind, could be integrated into the DKIST Operations effort and thus help alleviate resource constraints. Discussions with a few potential contributors are ongoing.

5.5.2.3 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 5-9) was developed, embracing and incorporating many of the important operational concepts that most modern large facilities share and from which the DKIST will benefit. On the overall scale, the DKIST Science Operations Lifecycle decomposes into a Proposal and an Experiment Lifecycle during which either Proposal- or Experiment-related tasks are performed (Experiments for the most part are the implementation of Proposals, i.e., their executable counterpart).

Figure 5-9. *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 Time Allocation Committee reviews and scores submitted DKIST Proposals.
- Finalization: The TAC finalizes Proposals by amending them with approved TAC changes.
- 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.
- 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.

5.5.2.4 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 5-10. Principal Investigators will 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 allowing reviewing and scoring of submitted Proposals. The tool also has the capability to assist in creating a ranked list of approved Proposals which is reconciled with the available observing time for the upcoming cycle. DKIST Scientists will use an Experiment Generation Tool (called the Experiment Architect) to generate Experiments, Observing Programs, and their Observing Program scripts which control the telescope and its subsystems during an observation. DKIST Scientists will subject each Experiment and its Observing Programs to a quality-assurance process using an End-to-End testbed and the summits' Observatory Control System. DKIST Scientists will use an Operations Planning and Monitoring Tool to plan, and dynamically schedule Experiments and their Observing Programs for execution at the summit to obtain data. The same tool also allows assessing the Observing Programs that have been run at the summit and tag them and their Experiments as successful (i.e., status = completed). Science Operations Specialists will execute Observing Programs at the summit using the Observatory Control System.

Figure 5-10. Science Operations Lifecycle phases; tools which support the phases are indicated in the small bubbles.

In summary, the main Science Operations support 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, allowing for the creation of 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. While some of the tools are DKIST Higher Level Software (HLS) deliverables (i.e., End-to-End Testbed, Observatory Control System, OCS) and reliant on the software infrastructure at the summit, the majority of the tools 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 tools utilizing AWS are the Proposal Architect, Proposal Review Tool, Experiment Architect, Operations Planning and Monitoring Tool.

Proposal Architect Tool

The Proposal Architect Tool will allow Principal Investigators to generate, edit, save, and submit DKIST Proposals. The Proposal Architect will facilitate 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 will make available templates to provide guidance and support for the preparation of a science justification, an observing strategy, and a data-analysis plan. In more detail, this tool will allow 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 5-11).

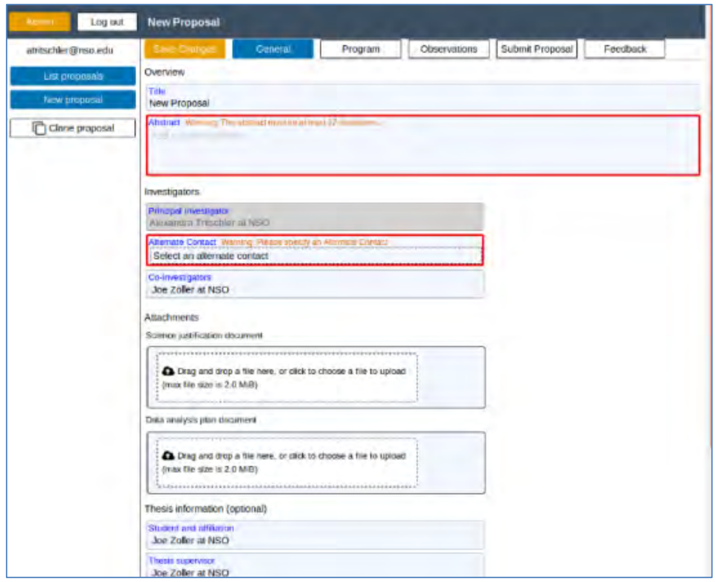


Figure 5-11. Proposal Architect GUI.

Proposal Review Tool

The Proposal Review Tool will support TAC members to review, comment and individually score submitted DKIST Proposals. The tool will allow approving and rejecting submitted proposals. Additionally, the tool will assist with generating a ranked list of approved Proposals that is reconciled with the available observing time for the upcoming Proposal Cycle. The Proposal Review Tool will allow finalizing Proposals, which involves amending the Proposal with TAC approved changes and notifying PI's about the status of their Proposal.

Experiment Architect Tool

The Experiment Architect Tool will allow DKIST Scientists to automatically generate Experiments from approved Proposals. More specifically, the tool will facilitate the generation of Experiments' Observing Programs and Instrument Programs (Figure 5-12). Observing Programs define the configuration of the telescope (pointing, Coudé orientation, etc.), the Gregorian Optic Station (GOS) (which FOV, dark, pinhole, target, etc.), and WFC (mode, offsetting and lockpoint details). Instrument Programs define the configuration of the instruments specified by the PI in the Proposal. Instrument Programs are part of the Observing Program. The Experiment Architect will

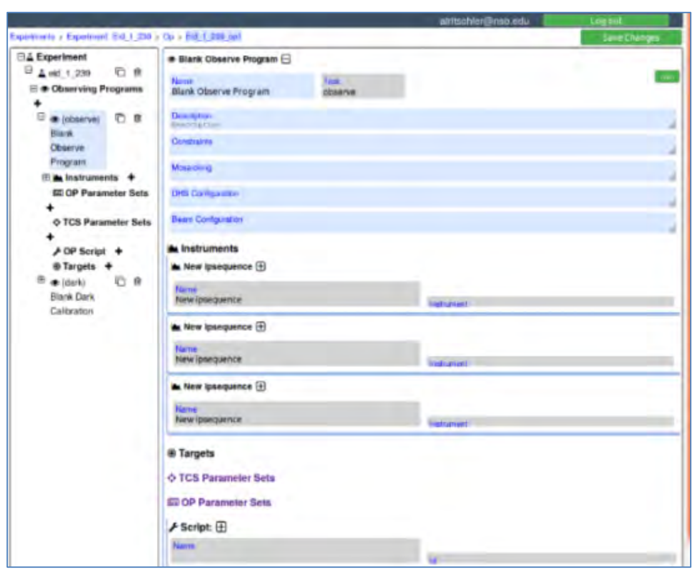


Figure 5-12. Experiment Architect GUI.

support DKIST Scientists in creating Observing Program scripts for each Observing Program. All science observations are obtained through the OCS by executing an Observing Program script. Only data that are obtained during the execution of an Experiments' Observing Program are transferred to the Data Center for calibration and distributed to the end-user. Script generation will be automated as much as possible, alleviating the need for handwritten scripts. These scripts will be tested against the (Boulder) End-to-End Testbed prior to being forwarded for execution against real hardware.

Operations Planning and Monitoring Tool

The Operations Planning and Monitoring Tool will allow planning and monitoring of the daily activities at the summit through communication with the OCS. The tool will allow DKIST Scientists to generate Experiment Lists (aka priority lists) and potentially exact time lines (which is an eventual tool functionality goal). This input information is then made available for ingestion by the OCS. The monitoring of Experiment and Observing Program execution is performed and percent complete statuses are noted. Additional information is monitored in order to assess the exact status of Observing Programs reported by the OCS, and flag the completion of Experiments and Observing Programs. Moreover, the tool will facilitate in associating calibration measurements with science measurements which is crucial information for the DKIST Data Center.

Background and Status of the Operations Tools

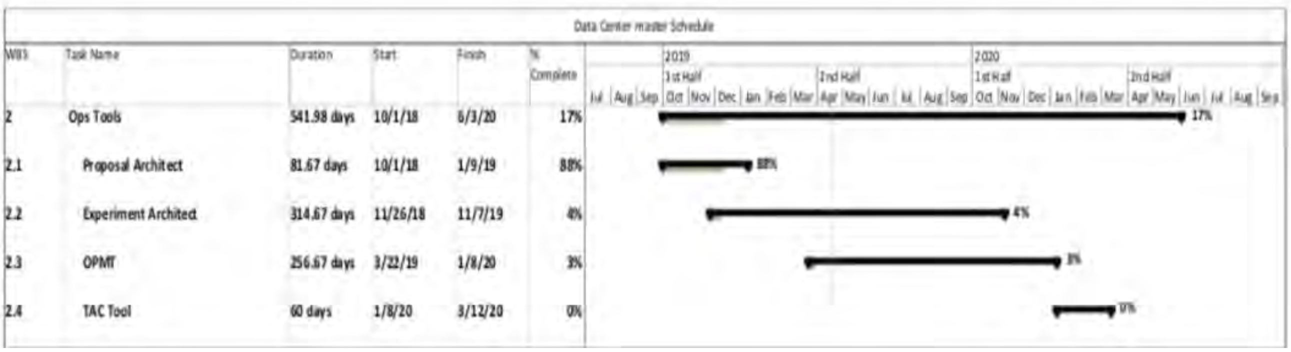
Early concepts for the Operations Tool were explored in the context of the development of the DKIST *Operational Concepts Definition* (SPEC-0036). DST Service-Mode Observing experiments were performed in 2013-2014. These exercises heavily corroborated the OCD concepts and confirmed the needs for the individual Operations Tools; many operational lessons were learned first-hand. In addition, Operations Tools openly made available by other large facilities like Hubble Space Telescope's (HST), European Southern Observaotry's (ESO) and Gemini's Phase 1 and Phase 2 tools were studied. These studies were expanded with visits to the McDonald Observatory's Hobby-Eberly Telescope, to Gemini North, and to NRAO's Science Operations Center in Socorro. During all those multi-day visits, conversations and discussion with operations staff (resident astronomers, software engineers and operators) provided additional lessons about observatory operations which were folded into the development of the DKIST Operations Tools. The development effort for the DKIST Operations Tools started with the hiring of the first Project Manager for the Operations Tools, followed by the specification of detailed operational concepts based on use cases, along with the specification of science requirements (in 2016), and with the subsequent hiring of two software engineers (in 2017).

As already mentioned, all Operations Tools are being developed as web-based tools and are serverless (use "native architecture of the cloud"). The back-end architecture is in place, heavily relying on the use of Amazon Web Services.

All Operations Tools are connected with a Help Desk service shared with the Data Center. A Graphical User Interface for the Proposal Architect and the Experiment Architect has been proto-typed and first user input has been gathered from DKIST scientists. The development for the Proposal Review Tool's and the Operations Planning and Monitoring Tool's Graphical User Interface has not started as of spring 2019.

The Operations Tools development schedule is presented in Table 5-5. The Operations Tools are well along the development path. The first tool which will be completed is the Proposal Architect Tool which will allow for PI's to convert their Critical Science Plan "proposals" to be written as official DKIST proposals. This same tool will then be used in the standard proposal preparation process during the call for DKIST proposals. The TAC tool to assist with the Time Allocation Committee has been specified but is not yet under development. It is anticipated that during the early operations phase some aspects of the TAC process will need to be done manually and via procedures if the TAC tool is not available in time. These processes and procedures will be written in advance and will be supported by the DKIST Science Operations staff in helping the TAC perform its' duties. The Experiment Architect Tool is also under development and will be tested prior to and during the translation of CSP proposals to experiments. The Monitoring Tool will be tested during IT&C and during Operations Commissioning.

Table 5-5. Operations Tools Development Schedule


Data Center master Schedule

WBS	Task Name	Duration	Start	Finish	% Complete
2	Ops Tools	541.98 days	10/1/18	6/3/20	17%
2.1	Proposal Architect	81.67 days	10/1/18	1/9/19	88%
2.2	Experiment Architect	314.67 days	11/26/18	11/7/19	4%
2.3	OPMT	256.67 days	3/22/19	1/8/20	3%
2.4	TAC Tool	60 days	1/8/20	3/12/20	0%

5.5.2.5 Operations Tools during DKIST Operations

As the DKIST Operations Tools (Ops Tools) transition into operations, which under the current Cooperative Agreement with NSF extends until FY 2024, the focus will shift from development of the Ops Tools suite towards maintenance of the infrastructure and software developed during the previous years. In general, the operations of the Ops Tools can be broken into several functions as defined and described in the following paragraphs.

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

In addition, it is expected that Ops Tools staff will be performing debugging and manual manipulations (movement, retrieval, posting, etc.) of entered data until the suite of applications is mature enough that human intervention is reduced. These manual interventions will likely result in code modifications to implement functionality that may not have been correctly implemented or to add necessary functionality that may not have previous been envisioned. As this type of operational model has not been used in previous observatories, it is unlikely that all possible requirements of science operations staff have been thought of and implemented. These new but necessary utilities will be developed by the Ops Tools staff during operations.

During Operations, the DKIST project will solicit input from the community via a Help Desk and dedicated workshops. The workshops enable the community to learn about the user facing operations tools, such as the Proposal Tool, provided by the DKIST suite. These allow the DKIST project to gather feedback form the users about how to best serve the needs of the community.

5.5.2.6 Operations Tools Maintenance

Technical Operations, which is described in this section, relates to all the tasking that the Operations Tools systems and software personnel will undertake in order to maintain the infrastructure necessary to facilitate the daily routine o science operations, from the ingest of proposals to the monitoring of operations.

Operations Tools System Maintenance

The Operations Tools staff will be responsible for maintaining the virtualized computing infrastructure that the Ops Tools depend on. The maintenance activities include monitoring the Amazon Web Services (AWS) storage and service infrastructure is running as within expected parameters and that the AWS capabilities purchased are commensurate with the AWS capabilities needed to achieve the Science Operations mission.

The staff will be responsible for monitoring and maintaining the interfaces to the Operations Control System (OCS), the Data Center (DC), as well as the general public. The two former systems rely on data generated by the Ops Tools in order to meet their own mission requirements, and the Ops Tools staff will monitor incoming and outgoing traffic to assure that data is being sent and received and delivered without loss. In addition, the staff will monitor the AWS web servers to assure that no security related events are occurring on the web portals that would adversely affect the capability to serve users. In the event that such an occurrence is detected, the Ops Tools staff 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 AWS and software updates may take place without disruption to the normal activities of Science Operations. These maintenance downtimes will be coordinated with DKIST telescope maintenance downtimes so as to minimize impact to DKIST Operations as a whole.

Operations Tools Software Maintenance

The Ops Tools staff will be responsible for maintaining the Ops Tools software infrastructure. 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 or through Help-Desk activities, whereby a user of the Ops Tools suite submitted a ticket for a perceived issue.

The Ops Tools staff will be responsible for vetting application logs to assure that services developed by the team are behaving in a manner consistent with their design. Staff will submit work tickets for any perceived issue and run those tickets to ground to keep the system functioning at the level necessary to allow the science operations team to discharge its mission.

Operations Tools Software Improvement/Upgrade

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

Operations Tools System Help Desk Support

The Ops Tools staff will be responsible for assisting in the triage, prioritizing, allocation, and resolution of tickets generated though the Operations Help Desk function.

Ops Tools Exploratory Development

The Ops Tools staff will be responsible for maintaining currencies in the technologies relevant to their fields. Maintaining currency in this context requires that 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 Ops Tools staff to propose new technologies and/or systems that will elevate the productivity of the Science Operations as well as improve quality of the services the Ops Tools provide in terms of responsiveness to Science Operations staff and community needs.

5.5.2.7 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.

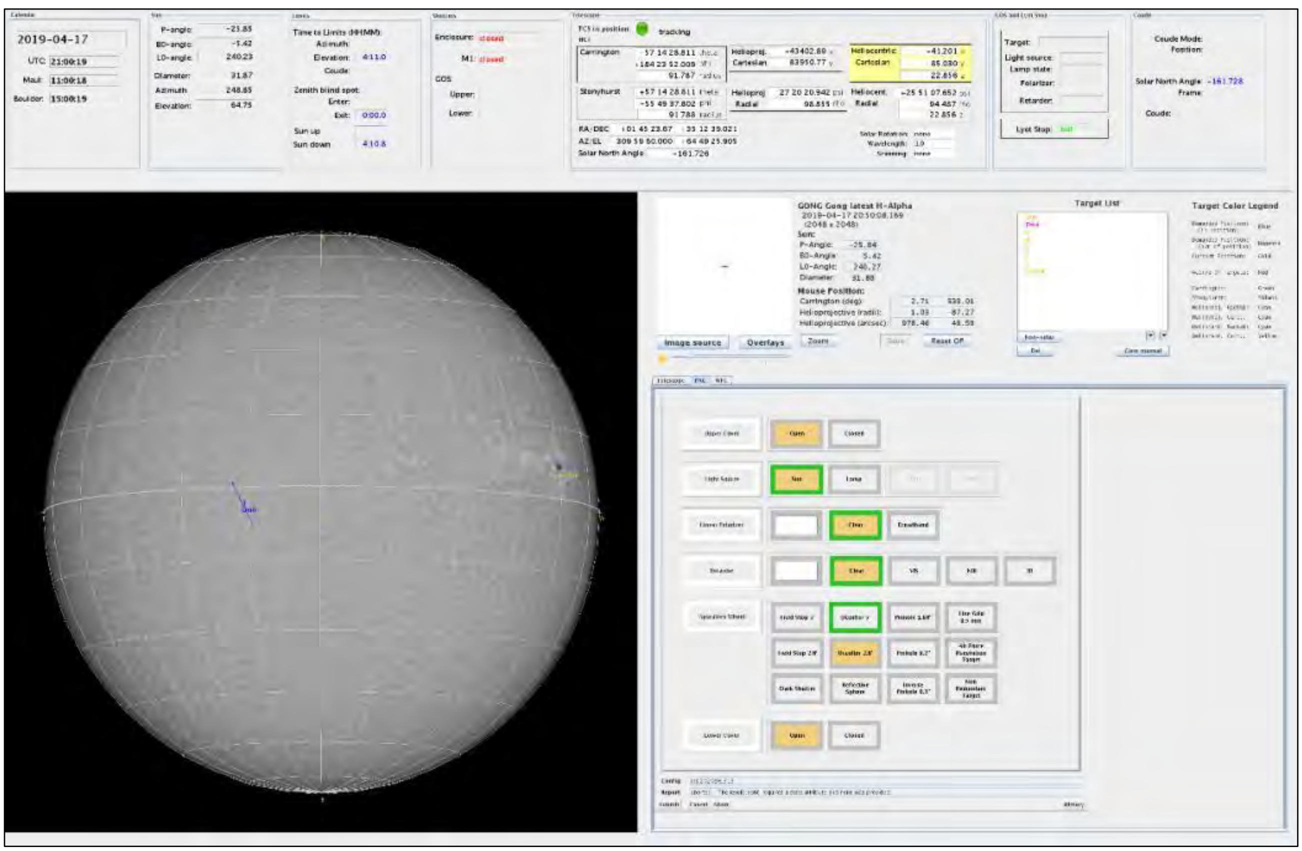


Figure 5-13. OCS screen.

The OCS provides for direct control of these systems as needed while still supporting automatic performance of rou-tine tasks. The OCS also manages the Common Services Framework (CSF), its services (e.g., event, alarm, log) and its summit data stores. The OCS provides tools to examine system diagnostic information, handles alarm conditions, monitors safety systems, and supports routine engineering tasks.

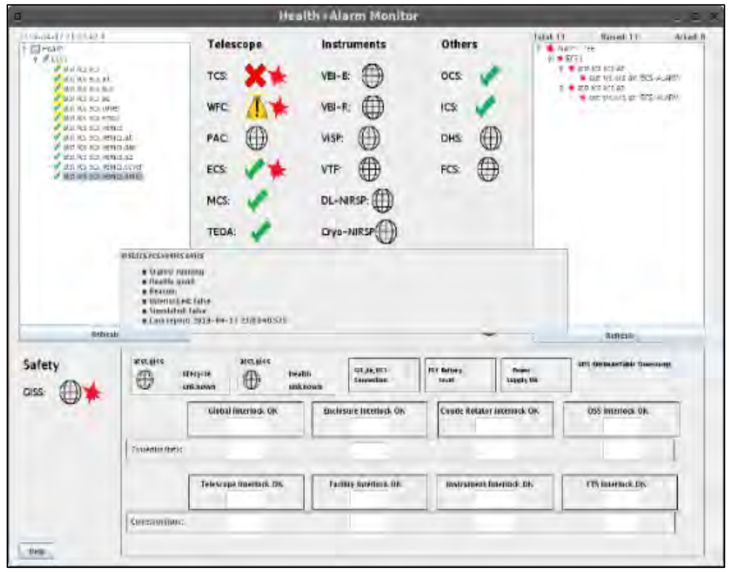


Figure 5-14. OCS Screen - Observing Control.

The OCS acts as the primary interface and tool for DKIST control during normal oper-ations. 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 has extensive functionality, including allowing the operations staff to view lists of Experiments, select Experiments and Observing Programs and Instrument Programs, execute Instrument Programs and monitor their execution, update targets associated with Observing Programs, execute Observing Programs, and monitor Observing Programs during their 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 5-13, Figure 5-14, and Figure 5-15. Specifically, the OCS supports multi-instrument operations. To guarantee traceability of all science observations, the OCS provides and ensures a unique and unambiguous association between an Experiment, its Observing Programs, and all products of the observation. In other words, all data that are produced during an Observing Program execution, are associated with its source Proposal. The Boulder End-To-End (BE2E) simulator is a full test bed for the Observatory Control System and its functionality. The BE2E integrates and incorporates all DKIST control systems ranging from the enclosure and mount, through the Gregorian Optical System and Wave-Front Correction system down 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

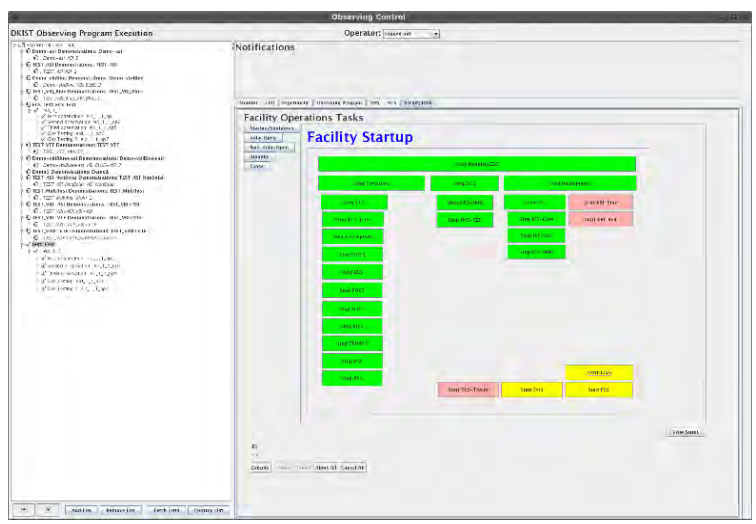


Figure 5-15. OCS screen - Heath Alarm Monitor.

allows for the testing of up-dates and new releases to software prior to integration at the summit. Most importantly, it allows for the testing of workflows through the systems using its graphical user interfaces, and as such, provides unique training opportunities for the operations staff.

5.5.2.8 Help Desk

Science operations is in the process of evaluating Help Desk software tool options. The DKIST project has been using the issue/bug tracking Atlassian product called Jira for several years. This Jira software tool can be used to track project management items, software bugs/tasks, project review material, test procedures, as well as to run a Help Desk. The Jira Service Desk software tool suite is specifically geared for Help Desk request tracking and is an expansion to the Jira product already used by most staff. The DKIST project will be performing an evaluation of Jira Service Desk and other similar products, and will purchase, implement and configure a tool set in 2019. The Help Desk configuration will encompass all the entities, which need to work through items via the Help Desk: the SOSs, Scientists, Data Center, NSO IT, and Technical Operations. The workflow of tickets will be 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. There are many off the shelf software solutions which perform Help Desk functionality; the project will choose the best option within its budget and train its staff to configure and support the Help Desk workflow. The advantage of using Jira Service Desk is that the NSO staff have been using it for a number of years and are already well versed with configuring and using it. NSO IT will be instrumental in helping setup and configure the DKIST Help Desk. If DKIST chooses Jira Service Desk, having the experience and inhouse knowledgebase of Jira Service Desk will be vital to assisting science operations staff in setting up Jira Service Desk and in assisting with training of staff.

DKIST Help Desk will need to address documentation and support to assist the DKIST community, especially the new users, with proposal planning and data analysis.

5.5.2.9 Proposal Process and Telescope Allocation Committee (TAC)

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, PI's) at least on a biannual basis via a Proposal Call. It is likely that the solicitation cycle will be six months. Investigators will use an integrated Proposal Tool (called the Proposal Architect, see earlier sections) consisting of a graphical user interface facilitating proposal preparation and submission.

The DKIST will accept Proposals during a defined submission window. All submitted Proposals are subjected to a competitive peer review for scientific merit and technical feasibility to assure that the DKIST is exploited to its best potential. The outcome of this review will be a ranked list of approved and finalized DKIST Proposals that is reconciled with the estimated available observing time for the upcoming execution cycle.

The DKIST Proposal Cycle will be composed of the following time line windows, as depicted in Figure 5-16.

1. 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.
2. Proposal Review Window: two months; opens when submission window ends, and closes two months later. In this review window, the TAC has performed all science and technical feasibility assessment, the TAC has convened, the TAC has resolved all potential conflicts, the TAC has generated the final approved and ranked Proposal Queue, PI's of submitted Proposals have been notified of the results of the Proposal Review process, and all approved Proposals are finalized.
3. 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).
4. 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 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.

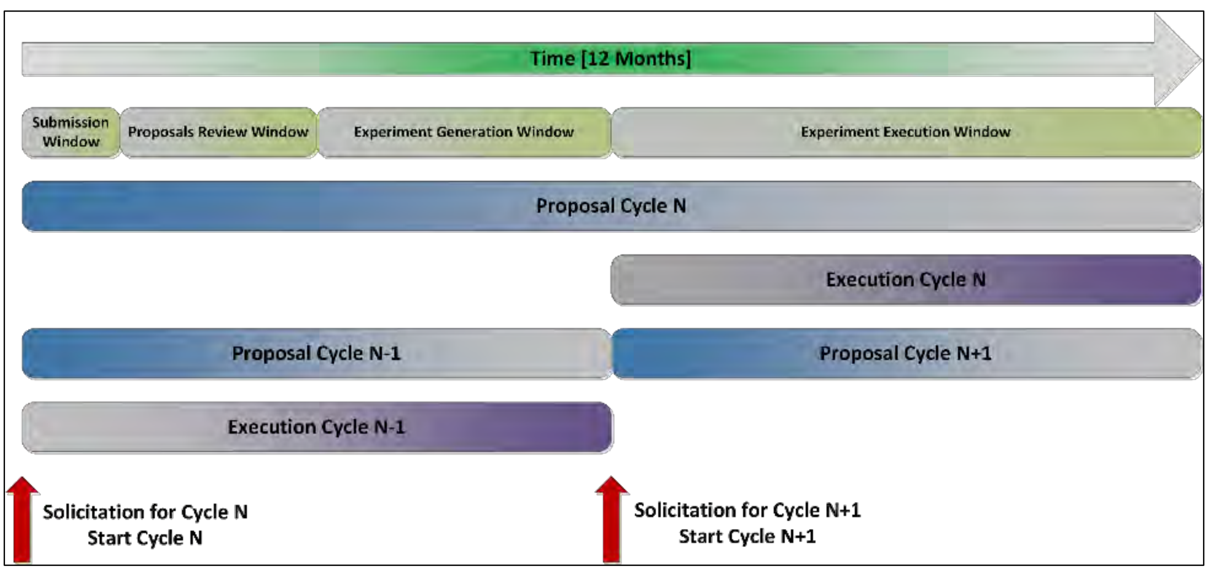


Figure 5-16. The DKIST proposal cycle time line.

The time line allows for enough time to set up the DKIST TAC, send Proposals for review, organize a TAC meeting, 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.

5.5.2.10 Science Operations Planning Time Line

The DKIST plans Science Operations on a long-term (six months), medium-term (one-to-three months), and short term (days to week(s)) basis. The long-term planning is driven by the length of the solicitation cycle. The medium-term planning is driven by co-observing (see Synergies in Section 5.5.2.1 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.

Long-Term Planning

On a time scale of six months, it is planned for and known what needs to be executed during the upcoming Experiment Execution cycle, i.e., all approved Proposals and their Experiments. This time scale is determined by the fixed length of the solicitation cycle. It is currently planned to ask the community for input and solicit for proposals every six months.

Medium-Term Planning

On a time scale of one-to-three months, changes of the optical configuration of the Coudé laboratory are planned. These changes take about one day at a maximum and need access to the Coudé laboratory. A change of the Coudé laboratory configuration allows only a subset of the approved Proposals and their Experiments to be planned for and executed, i.e., those Experiments that requested Coudé configuration to begin with. Proposal PI's will be notified when the Coudé laboratory configuration is changed to the exact configuration so that they know in advance whether they can expect that their Experiment is potentially executed in the upcoming month(s). On the time scale of one-to-three months, the details of co-observing efforts and visits of PI's that have been granted AMO time are fine-tuned and prepared. Some facility calibration efforts are likely planned on this time scale as well (e.g., telescope polarization calibrations for M1 and M2, polarization calibrations for M3 through M6).

Short-Term Planning

On a time scale of one day to one week, it is planned what exact Experiments are scheduled for execution based on solar conditions, observing and weather conditions in general, and on technical readiness. Proposals and their Experiments request specific targets on the Sun (e.g., sunspots, filaments, prominences) and can only be planned if those targets are present on the Sun. Proposals and their Experiments also request a combination of different instruments observing in specific wavelength regimes. Hence, they can only be planned for if the current Coudé laboratory configuration does support this wavelength and instrument combination. Weather forecasts will determine whether science operations can commence on the next or current day, or technical operations are performed. As the best seeing conditions are prevailing during the morning hours, on-disk observations in the visible will be planned during these hours while coronal observations in the infrared will be planned for later in the day.

5.5.2.11 Actors and Roles

In order to optimize its scientific capabilities, the DKIST requires a dedicated DKIST Operations staff. The primary function of that team is to operate and maintain the DKIST and support its use by the solar physics community in a way that conforms to the science requirements outlined in the DKIST SRD (SPEC-0001). The members of this team consist of scientists, specialists, technicians and engineers.

Scientists

Resident Scientist

The *Resident Scientist* is a solar scientist with strong expertise in observational solar physics. The Resident Scientist supports the design, generation and quality assurance effort of Experiments and Observing Programs derived from approved and finalized DKIST Proposals. The Resident Scientist supports the planning and execution effort of daily science operations and performs the completion confirmation of Experiments and Observing Programs. The Resident Scientist is an integral part of the proposal review process, specifically the technical feasibility assessment of submitted DKIST Proposals. The Resident Scientist assists visiting investigators during their access mode time. The Resident Scientist is likely a member of the TAC.

Instrument Scientist

The *Instrument Scientist* is a solar scientist with strong expertise in observational solar physics. An Instrument Scientist is responsible for and is an expert user of at least one DKIST facility instrument. The Instrument Scientist is potentially involved in and supports science and calibration data quality assurance, if warranted, through the capabilities provided by the DHS. The Instrument Scientist is likely to supports the design, generation and quality assurance effort of Experiments and Observing Programs derived from approved and finalized DKIST Proposals. The Instrument Scientist is involved in the technical assessment of submitted proposals during the proposal review process. The instrument scientist will also be responsible for the preparation and maintenance of manuals and other documents that describe in detail the capabilities of particular DKIST facility instrumentation. The Instrument Scientist is likely involved in user support and is the primary contact person for instrument specific data related questions.

Specialists

Science Operations Specialist

The *Science Operations Specialist* (SOS) has a scientific and/or engineering background and has gone through special training on solar observatory operations. The Science Operations Specialist is executing daily observatory science operations tasks. Specifically, the Science Operations Specialist is operating the telescope and instruments, and executing observations as guided by the Resident Scientist. At other ground-based facilities, these staff are synonymous with Telescope Operators.

Subsystem Specialist

The Subsystem Specialist has an engineering and/or scientific educational background in important supporting subsystems such as, adaptive optics systems, polarimetry systems or other systems that most directly impact the scientific "value" of the raw data, including calibration data, produced at the DKIST facility. The Subsystem Specialist is responsible for the performance of the subsystem and directly supports science staff who have ultimate responsibility for the scientific validity and "scientific value" of the observations performed. The Subsystem Specialist is an expert and an expert user of specific DKIST subsystem(s). During regular operations the Specialist supports the SOS staff ensuring optimal performance of the subsystem. The Specialist supports the scientist(s) in analyzing data (e.g., telemetry data, calibration data) to evaluate performance parameters.

Safety Officer

The *Safety Officer* is responsible for site safety.

Engineer
The *Engineer* has specific engineering knowledge of DKIST components. The Engineer has the responsibility for maintaining, repairing, or improving the DKIST. There will be Engineers with expertise in each of the following disciplines: electrical, mechanical, optical and software.

Technician
The *Technician* has specific technical knowledge of DKIST components to support engineering activities. There will be Technicians with expertise in each of the following disciplines: electrician, electronics, and mechanical.

Time Allocation Committee

TAC Chair
The *TAC Chair* presides over the TAC. He/she is monitoring incoming DKIST Proposals submitted to the upcoming proposal cycle. The TAC Chair assigns a proposal first to TRC members or a group of TRC members for a technical feasibility assessment and after that assigns the proposal to SRC members or a group of SRC members for a scientific merit assessment. The TAC Chair as guided by the TAC and on behalf of the TAC approves and rejects proposals. The TAC Chair also augments individual proposals with TAC approved changes. The TAC Chair may communicate with proposal PI's during the review period. The TAC Chair generates preliminary proposal queues and the final ranked proposal queue. The TAC Chair as guided by the TAC prepares review reports for the PI's (as guided by policy).

Science Review Committee
The members of the *Science Review Committee* (SRC) perform a scientific merit assessment of those DKIST Proposals that have been assigned to them. Members of the SRC comment on proposals, score individual proposals, and give recommendations for approval or rejection of the proposal. The SRC members provide feed-back on issues and problems and suggestions on how to resolve those if possible.

Technical Review Committee (TRC)
The members of the *Technical Review Committee* perform a technical feasibility assessment of those DKIST Proposals that have been assigned to them. Members of the TRC verify proposal input and the consistency of proposal input. Members of the TRC comment on proposals, score individual proposals and give recommendations. The TRC members provide feed-back on issues and problems and suggestions on how to resolve those, if possible, to the TAC Chair.

5.5.2.12 (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 which are being developed during Integration, Testing & Commissioning, and possibly by the available bandwidth to the summit.

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

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

DKIST Science Operations embeds into the larger context of daily observatory operations. This involves procedures and activities that are performed every day, just as at every optical ground-based facility, allowing the observatory to transition from a high-level Housekeeping state (for the DKIST this is its Nighttime state) into other high-level states like Open or Closed or possibly Standing-By. Figure 5-17 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.

Results from the Haleakalā site survey clearly show that the highest probability for excellent observing conditions characterized by the percentage of the Fried parameter larger than 12 cm occurs when the Sun is only 15 degrees above the horizon (see Rimmele et al., 2005, Figure 4). The site survey also indicates that on average this corresponds to about 1h 25 min after sunrise (see TN-0094, Figure 2.1). Constraints on the telescope mount assembly and enclosure, however, combined with low light levels, will not allow opening the observatory until the Sun is 7 to 10 degrees above the local horizon (corresponding to about 30 minutes after sunrise). Consequently, there is little time available after opening but prior to observing for pre-observational preparations or calibration measurements, which require sunlight. Therefore, the DKIST will attempt to perform most preparations for as many Experiments planned for execution (i.e., focus, alignment, and possibly some calibration tasks) without direct sunlight using artificial light sources when possible.

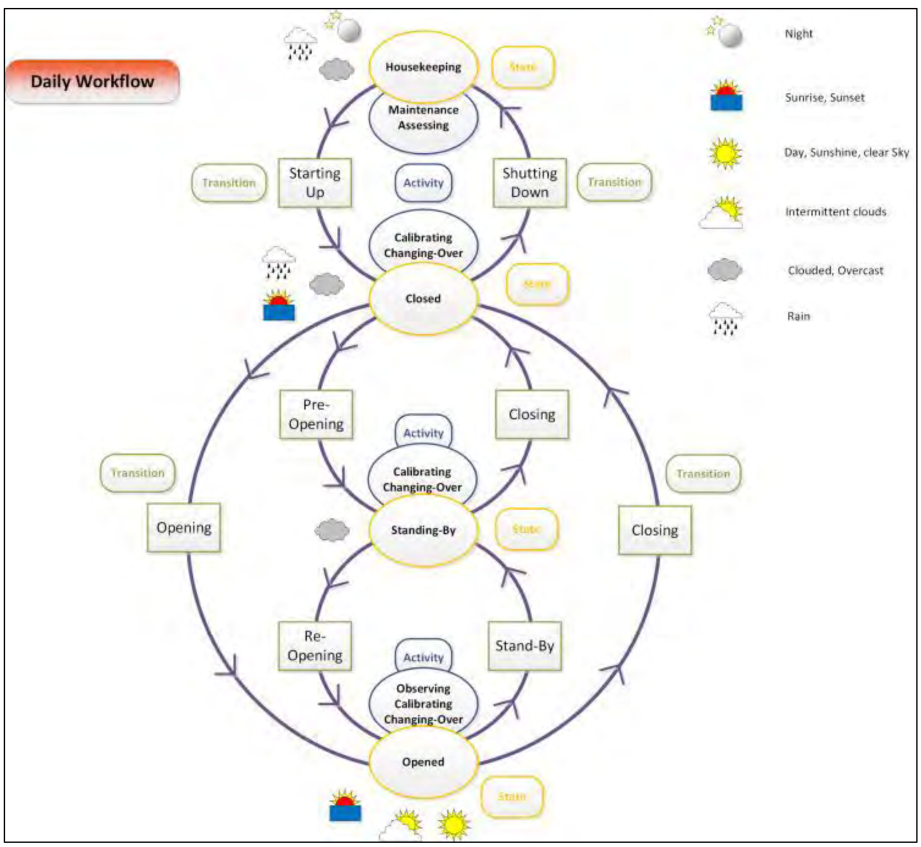


Figure 5-17. DKIST Daily Workflow, depicting the observatory to transition from a high-level Housekeeping state into other high-level states like Open or Closed or possibly Standing-By.

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 5-17 describes a daily workflow scenario, outlining what work is accomplished to transition the observatory and what work is performed when in a specific high-level state. In particular, the latter is kept generic and not tied to the specific details of an Experiment or the context within which it is executed. Most activities are executed from the Summit Control Room (SUCR) with a few exceptions where procedurally it is disallowed.

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

A typical work day starts officially when the duty staff arrives at the workplace at least one hour and 30 minutes before sunrise. Summit support for operations will be provided by two groups, a Technical Operations group ("TOPs") and the Science Operations group (SOPs). The TOPs group includes technicians and engineers with different backgrounds, working in two shifts for morning activities (AM) and afternoon activities (PM), covering almost the entire day supporting operations. The Science Operations group ("SOPs") provides at least two Science Operations Specialists (SOS) who will perform observations in between sunrise +7 degrees and sunset -7 degrees of the position of the sun every day at the summit. In this scenario three SOSs are assigned to the summit every day, the first SOS arrives at the summit 1.5 hours before sunrise with the TOPs crew to perform all morning activities (AM) to prepare the facility and provide observation support in the first part of the day. The second SOS will arrive at the summit to support the opening activities and to mainly support the observations. The third SOS arrives later to (more support observations during the afternoon (PM) and to close/shutdown the telescope at the end of the day details in Section 5.5.4.1 Science Operations Specialist (SOS Schedules).

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

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

The Day is divided into five main Phases: Starting-up, Opening, Observing, Closing and Shutting-down; each are described in detail as follows.

1) **Starting-Up:**

Activities performed with the shutter closed to prepare the facility for operations. This may include a systematic walk through the facility to visually inspect areas like the enclosure and the Coudé laboratory before major equipment is powered up (e.g. major moving parts like the TMA and the enclosure), safety checks, restrict the access to specific areas, power-up of systems and check the plan for observing, etc.

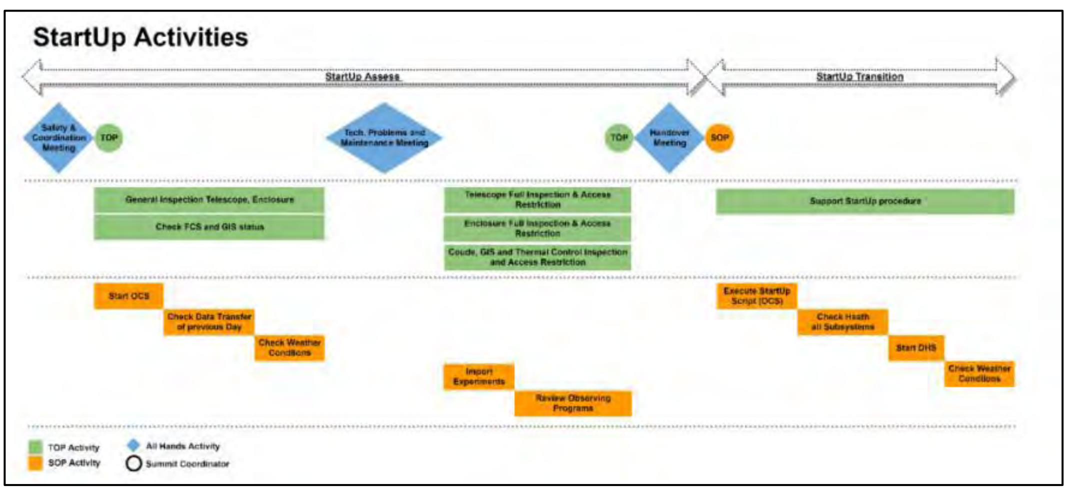
Starting Up is the transition process from Housekeeping state to Closed state.

Starting-up is a two-step process:

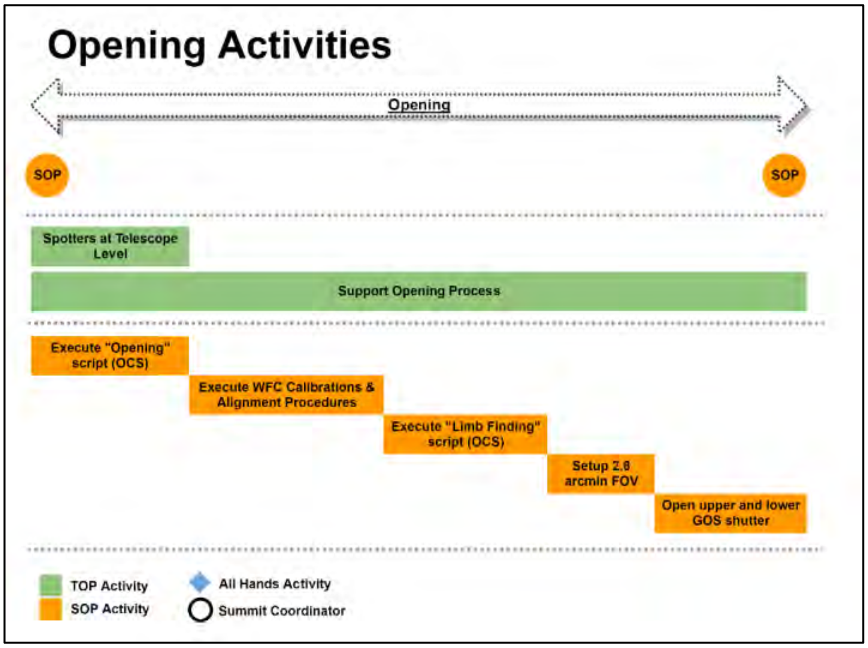
i) **Starting Up –Assess:**
This phase includes all work involved in assessing the state of the facility, all activities previous to energize the systems. This phase is completed when all the DKIST systems have been assessed and any required corrective measures have been taken (if applicable).

ii) **Starting Up – Transition:**
This phase includes all work and activities necessary to transition the facility from its nighttime to daytime status in a Closed Facility State. The activities are mainly to energize the systems and prepare the facility for the opening phase.

2) **Opening**:



Activities to be executed for the transition of the facility from Closed state to being Open to starting to capture sunlight for calibrations or science observations. The most important starting condition is that the environmental conditions at this point are in agreement with the weather constraints defined for operations. Some of the activities are: Enclosure aperture shutter opening, M1 cover opening, WFC calibration, and sending the light in the Coudé laboratory. This is the transition process between Closed or Standby stage to the Opened state.



3) **Observing:**

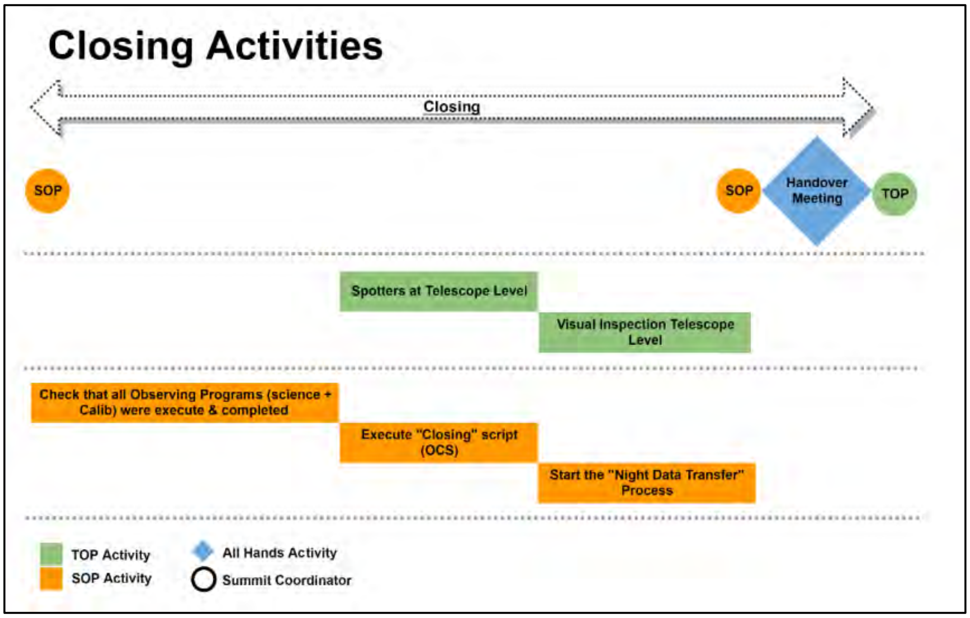
All activities that are preparing for and executing specific (i.e., Experiment and Observing Program related) science observations. The expectation is that in the morning mostly on-disk diffraction limited observations (and their calibrations) are executed, while later during the day mostly seeing limited observations are addressed.

4) **Closing**:

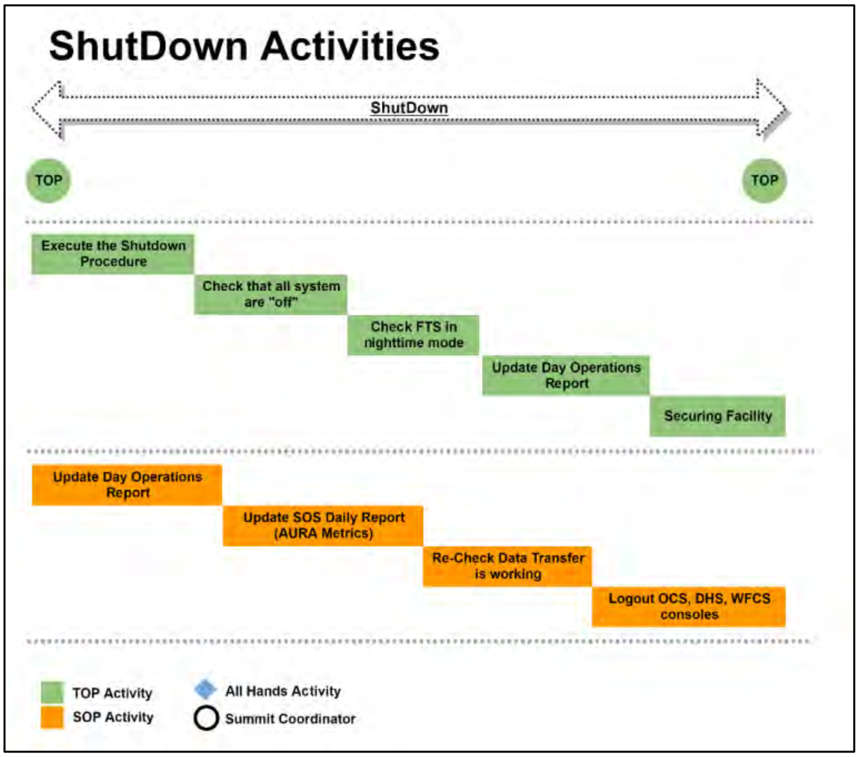
All activities related to close the facility (enclosure and telescope) after a day of observations or due to bad weather. This is the transition between Opening or Standby state to Closed state.

As long as weather conditions allow, science or technical operations will continue until the operator or the Resident Scientist decides otherwise. Similarly, it may be determined that weather conditions are unlikely to improve enough to resume operations out of standby mode within a significant time scale (two hours or more). In that case, the facility is closed and transitions into Maintenance Mode.

5) **Shutting-Down:**



Activities performed to place the facility in a safe condition, power off the required subsystems and begin a maintenance activity or leave the facility for nighttime. This is the transition process from Closed state to Housekeeping state.



5.5.4 Operator and Resident Scientist Schedules & Training

5.5.4.1 Science Operation Specialist (SOS) Schedules

The Science Operation Specialist (SOS) is the person responsible for performing and executing all aspects of science operations at the summit with the support of the Resident Scientists; SOSs work in conjunction with the Technical Operations staff. As such, the SOS is responsible for making sure that all facility systems are functional, they perform regular experiment support and conduct observations.

A day of operation at the summit will include three or four SOSs who will support a phased schedule which includes morning activities (AM), Noon Activities (Mid) and afternoon activities (PM). Each SOS will arrive at the summit at different times to work at the summit for 10 hours. The goal is to maximize support for observing time with at least two SOSs between sunrise +7 degrees and sunset -7 degrees when the sun can be observed with the DKIST.

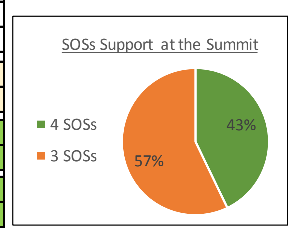
The full staff schedule is shown in the next figure. The schedule includes six SOSs without planned or unplanned leave for a period of time equal to four weeks. There are three or four SOSs scheduled daily at the summit depending on the day in the week. In this schedule, there is full coverage with four SOSs at the summit where two SOSs support morning and two SOSs support afternoon observations, covering 100% of the possible observing time. For the days with three SOSs at the summit, the afternoon observing will be executed by one SOS most of the time. In four weeks (28 days) with all SOS staff available for operations (without leave), we can support operations with four SOSs for 12 days (43%) and with three SOSs for 16 days (57%) at the summit.

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

Working hrs	
Summit	10
OFF Days	
Vacation - leave	

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

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



The main activities defined for each SOS are broken up into three phases:

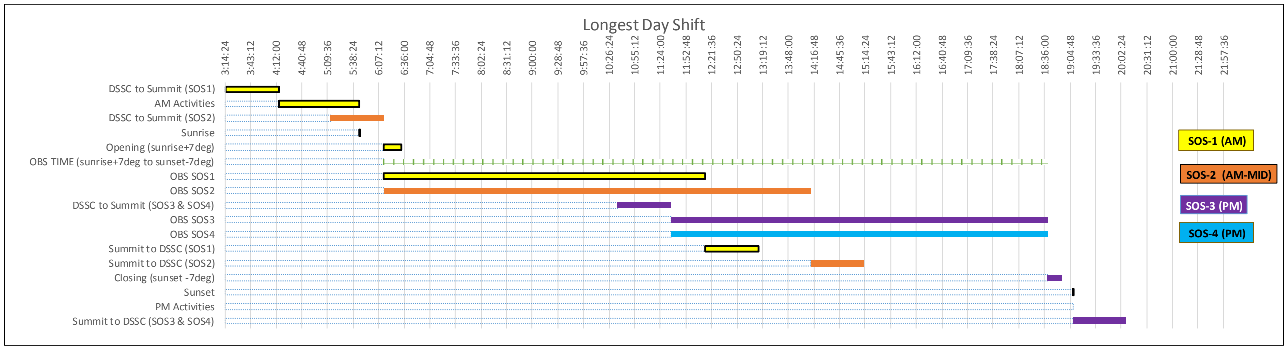
(A) Morning operations (AM) activities:
1) Starting Up – Assess
2) Starting Up - Transition
3) Opening
4) Observations (OBS)

(B) Noon (Mid) activities:
5) Observations (OBS)
6) Closing (depends on the day length during the year)

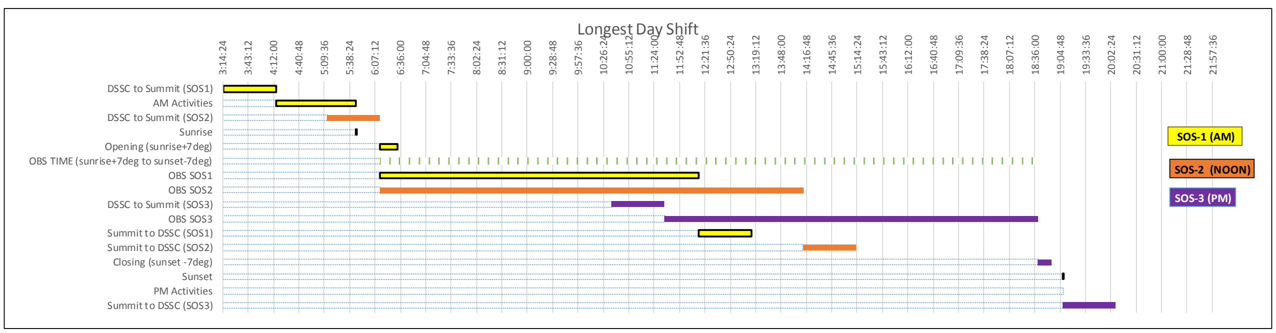
(C) Afternoon operations (PM) activities

7) Observations (OBS)
8) Closing
9) Shutting down

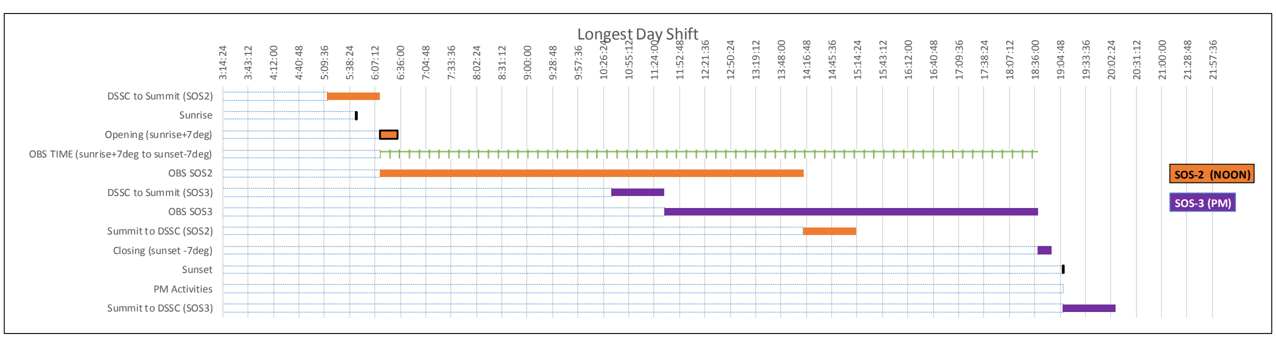
The main activities and the support with 4 SOSs at the summit is displayed in the following figure for the longest day in 2020 as an example.



The main activities and the support with three SOSs at the summit is displayed in the following figure; the change implies only one SOS for afternoon observation (instead of two SOSs).



The main activities and the support with only two SOSs at the summit are displayed in the following figure. This case depicts only PARTIAL summit support; therefore, additional support is needed from the TOPs or from pulling on the reserves of the SOP group in order to cover all activities defined for SOS staff in operations for startup/shutdown procedures. The goal is to prioritize SOSs support in observing/calibration phases (green OBS TIME in the figure below).

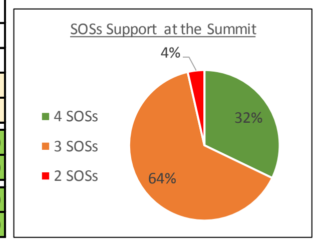


The activities described as "Summit to DSSC" and "DSSC to Summit" refers to the travel that the SOS need to undertake every day; these travel times are not considered as working hours.

In the event that we have one SOS staff member on vacation or leave, the coverage with four SOSs at the summit is reduced. The number of days with only three SOSs supporting the summit is therefore increased to 18 (64%) per month, and the one day with only two SOSs available for support must be managed with PARTIAL support. An example of this is shown in the next figure where one week of leave is indicated in blue.

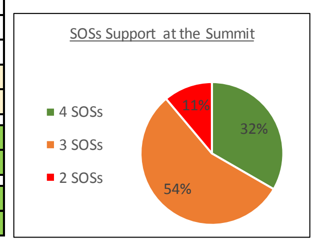
Working hrs	
Summit	10
OFF Days	
Vacation - leave	

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	WEEK1							WEEK 2							WEEK 3							WEEK 4						
	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa
SOS1	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0
SOS2	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0
SOS3	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10
SOS4	10	0	0	0	10	10	10	10	0	0	0	0	0	0	0	0	0	0	10	10	10	10	0	0	0	10	10	10
SOS5	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10
SOS6	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10



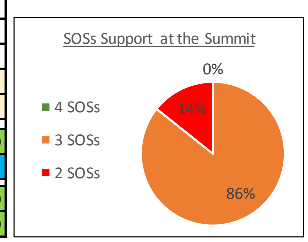
In case we have two SOSs on vacation or leave, the support at the summit is affected by an increment in the number of days with only two SOSs (11%) as PARTIAL support. The following figure shows the schedule changes in the case of two SOSs are on vacation or leave for one week (shift).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	WEEK1							WEEK 2							WEEK 3							WEEK 4						
	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa
SOS1	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0
SOS2	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0
SOS3	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10
SOS4	10	0	0	0	10	10	10	10	0	0	0	0	0	0	0	0	0	0	10	10	10	10	0	0	0	10	10	10
SOS5	10	10	0	0	0	10	10	10	10	0	0	0	0	0	0	0	0	0	0	10	10	10	10	0	0	0	10	10
SOS6	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10



In case of unexpected extended leave for one SOS team member, summit support using four SOSs is no longer feasible. Supporting operations at the summit as shown the following figure and will be done with two or three SOS staff members.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	WEEK1							WEEK 2							WEEK 3							WEEK 4						
	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa
SOS1	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0
SOS2	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0
SOS3	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10
SOS4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SOS5	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10
SOS6	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10	10	10	10	0	0	0	10



In the scenario with one SOS with an extended leave plus another SOS with any leave or vacation, or any scenario with additional leave in the schedule, will produce **degraded** summit support with only one SOS available for the summit for a number of days proportional to the leave period.

Schedule arrangements will be performed in advance and will be worked with the SOS staff when assigning them to the various shifts. The goal is to have an equitable schedule as the base which accommodates the following variables throughout the year:

1. The number of shifts (AM, MID, PM).
2. The number of shifts needed in the season.
3. The number of worked weekends per person.
4. The number of holidays in a year.
5. The known leave/vacation.

The scheduling analysis and planning should be done every month to compensate all these variables in the seasons, as well as for the longer view in a semester and for the entire year with regard to the day-lengths within the year as the starting point.

5.5.4.2 SOS Training

SOS Training: Looking Back

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

For the SOS group the most important systems to interact during operations are:

- Observatory Control System (OCS).
- Data Handling System (DHS).
- Quality Assurance System (QAS).

Because of this, the focus of the training over the years was the Boulder End-To-End (BE2E) Simulator that runs one instance of the OCS, DHS, QAS systems. The SOS group worked mainly on testing these systems and provided feedback regarding improvement of functionality.

Additional details regarding SOS training activities are described in the subsequent paragraphs.

2016 & 2017 SOS Training Activities:

A summary of the training activities from November 2016 through December 2017 are included in the following figure:

The first Orientation and Training workshop for the SOS Group (SOS Workshop 1) took place in November 2016. The main goal of this activity was to show the differences between the actual operations model in the DST and the future operations model for the DKIST.

Other topics reviewed during the workshop were focused on the DKIST:

- High-level concepts for operating the DKIST.
- Telescope Overview.
- Coudé Laboratory and Instruments.
- Wavefront Correction System (WCS).
- Observatory Control System (OCS).
- Data Handling System (DHS).
- Instruments.

At the SOS Workshop I the documentation available for review was the *Operational Concepts Definition* (OCD) which includes specific operational characteristics and procedures substantiated by operational and observational scenarios.

Throughout 2017, five new SOS Workshops took place, four were in Boulder and one was in Maui.
For the Workshops in Boulder, the main goal was to interact with the BE2E system which includes the Observatory Control System (OCS), Data Handling System (DHS) and the Quality Assurance System (QAS). All of these systems were tested by the SOS group, comments and feedback were sent to the software developers to improve all the GUI functionality from the operator's perspective.

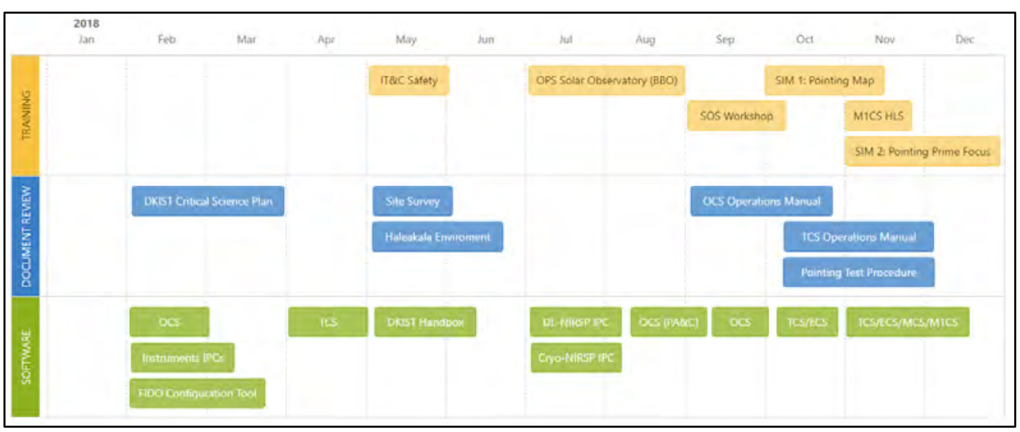
Additionally at the Workshops, the SOS group reviewed documentation received from the IT&C group; the most important documents were:

- Telescope Control System (TCS) Operations Manual.
- Global Interlock System (GIS) Operations Manual.
- Instruments Operational Concept Definition (Instruments OCDs).

During the Workshop in Maui (SOS Workshop 5), the SOS group visited the summit to see the status of the facility. In the same visit, the SOSs had the opportunity to discuss technical details of the systems with the IT&C staff.

<u>2018 SOS Training Activities:</u>

A summary of the main training activities in 2018 is included in the following figure:



A Safety training by IT&C group was given to the new SOS Staff in Maui in May 2018; this is one of the main requirements to have access to the telescope during the construction phase.

An SOS Workshop took place in Boulder in September 2018 for Orientation and Training of new SOS staff. The main topics reviewed at the Workshop were the OCS, WCS and DHS, as well as the Coudé Laboratory and Instruments. The new SOS staff had a training session on the BE2E; the main goal was to review the OCS functionality and a few aspects of the DHS. The documents reviewed and studied for the Workshop were the *OCS Operations Manual* and the *DHS Operations Manual*.

In the summer of 2018, the SOS Lead visited the Big Bear Solar Observatory (BBSO) in Southern California in order to get their first introduction into daily operations of a Solar Observatory. It should be noted though the GST/BBSO is operated very differently than it is planned for the DKIST and also when compared to the operations of NSO's former flagship facility, the Dunn Solar Telescope. During the visit, they witnessed what the challenges are in operating a solar facility, they got a sense of the typical problems which arise and most importantly they got to see how the science is acquired.

The Lead SOS participated in several System Integration Modules (SIMs) at the DKIST which took place at night, to test the pointing of the telescope. At the SIMs the SOS Lead received training in:

- StartUp & ShutDown of the Telescope and Enclosure.
- Procedure to perform a pointing map from the TCS for the Mount.
- Procedure to perform a pointing map with the M1.

In these activities, the SOS interacted with the systems using different Engineering GUIs: the TCS, the Mount Control System (MCS), the Enclosure Control System (ECS) and the M1 Control System (M1CS). Other tests were performed with Wavefront Sensor; these series of tests were also excellent experiences for the SOS Lead to witness in a qualitative way, about how the image quality can be improved with the M1 control system.

The initial SOS training with the M1CS was made by the High-Level Software Group (HLS) in Maui during the night SIMs. This was a first SOS interaction with the system to understand functionality of the M1CS and the controls available from the Engineering GUI.

The SOS group has access to important documentation needed for future operations. One such vital document is the *Site Survey and Environmental Conditions at the Summit* which describes the results of the analysis of the environmental conditions and the constraints for operation.

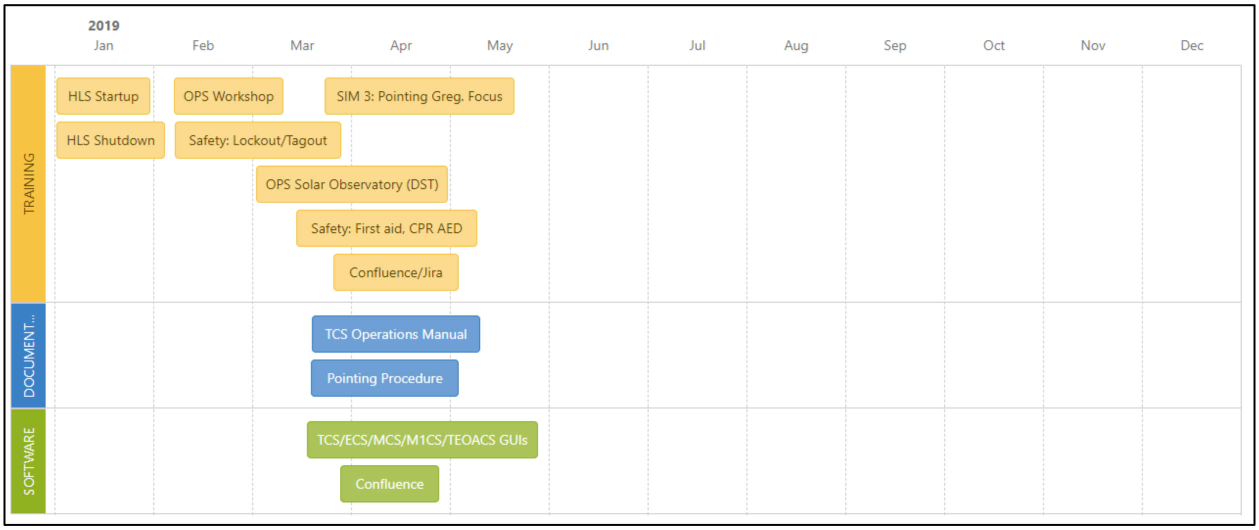
In terms of Software interaction, the SOS group continues to work mainly with the BE2E, following the updates made throughout the year. Most importantly, the BE2E allows testing the operability of and workflow of Experiments using the operational GUI interfaces. This gives the SOS's a unique training opportunity that they would not be able to receive otherwise, since it mimics capabilities currently at the summit. Specifically, the SOS group worked on developing the essential parts of the *OCS User Acceptance Test Plan* which will be used for final acceptance testing of the OCS prior to its delivery to the summit.

The SOSs have reviewed the software for the Instrument Performance Calculators; these tools have helped familiarize the team with the capabilities and functionality of the instruments to be incorporated into the OCS.

A prototype of the Hand Box was received in Boulder for testing and training with the BE2E system. The feedback from the SOS group was sent to the developers (IT&C Software Team) to make improvements from the operations perspective.

2019 SOS Training Activities (April):

A summary of the main training activities to date in 2019 is included in the following figure:



One highlight from the early Spring 2019 training came from the IT&C Software Team who performed an introduction on how to ShutDown <=> StartUp the HLS packages for the different subsystems as TCS, ECS, and M1CS.

The first Operations (OPS) Workshop was held in Maui in February 2019 to review the preliminary plan for daily operations for the DKIST. This was an excellent opportunity for the SOS and Science Team leads to meet with IT&C and Systems Engineering to better understand and work through many technical aspects of the different subsystems that can affect operations in terms of maintenance, safety, stability, as well as others. The workshop event was also used as training for all the Operations Staff on Safety procedures of the Lockout/Tagout systems.

Additionally, the Safety Department held a "First Aid, CPR and AED" training for some personnel of the SOS Group. This is very important training for future operations at the summit where Satefy staff will not always be on site. Emergency activities at the summit that can affect the operations staff on duty will be attended to as quickly as possible for (and by) the same DKIST personnel.

In March 2019 the entire SOS group visited the Dunn Solar Telescope (DTS) for one week of training in the Operations of Solar Telescopes. The training focused on:

- Daily activities to prepare the facility to operations (StartUp).
- Daily activities to finish the day of Observation and prepare the facility for Nighttime (Shutdown).
- Introduction to the instruments in operations, daily calibrations, science calibrations, stability, science images.
- Operators support, observing mode, maintenance plan, safety regulation.

The Lead SOS participated in nighttime tests to perform the Pointing Map for Gregorian Focus (aka SIM3). In principle, the same pointing procedure used in SIM1 & SIM2 was executed in this test, however, TEOA with the M2 was also included in the process. Other tests with Wavefront Sensor measurement were performed during the same nighttime activities, therefore additional experience was acquired on how the image quality is optimized with the M1 and M2.

As part of the plan for Operations, the SOS group has started training in using the software tools called "Confluence" and "Jira". Both are off-the-shelf software products which are intended to be used in the future for operations. The SOS group use Confluence as a WIKI for their content management, a repository of all information needed such as procedures for operations. Jira will be used as the Ticketing System for operations for bug tracking, reports and for the Help Desk.

SOS Training: Looking Forward

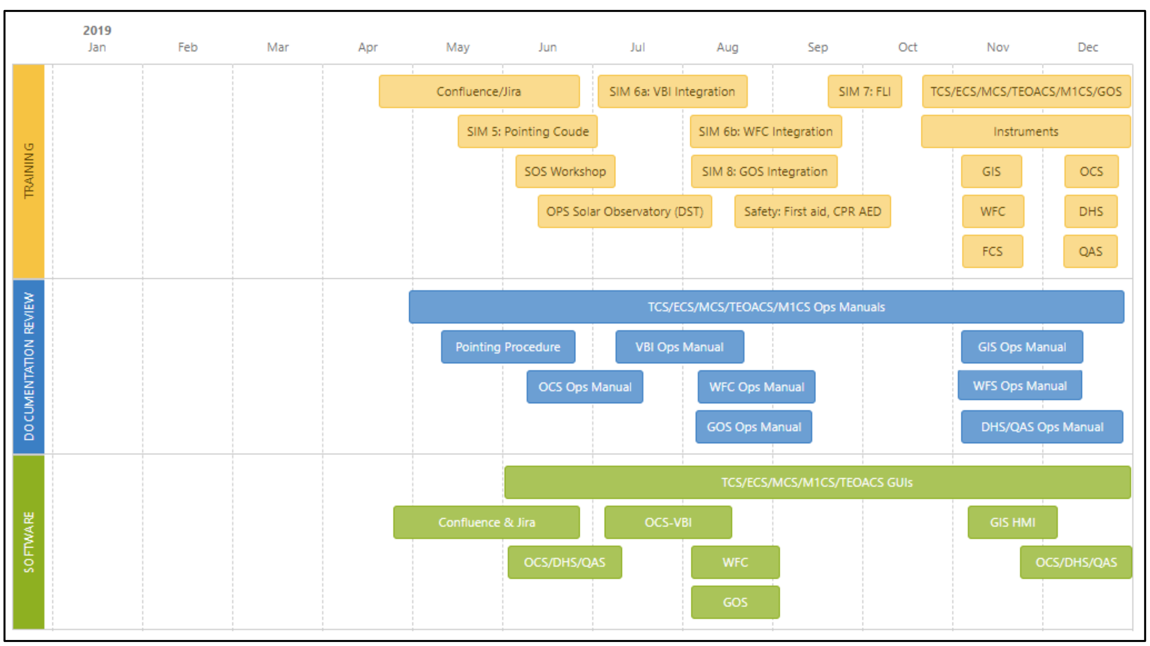
The SOS group is expected to receive all additional training needed for the transition from the Construction phase (IT&C) to Operations in order to:

- Operate the facility in a safe environment for the personnel and the equipment.
- Operate all subsystem needed for the Observing mode.
- Optimize the performance of the telescope to improve efficiency, image quality and in turn, the science.

With the training and experience, the SOS staff will start to create procedures and checklist for operations for the group. These procedures, processes and other documentation will be kept up to date on an "SOS Space" in Confluence. This documentation area will be created for the SOS group to collect all important information for operations.

2019 SOS training activities (April-December):

A summary of the main training activities for the rest of 2019 is included in the following figure:



Safety training is critical for the SOS group. All personnel must be trained to understand safety clothes, the hazard areas in/out of the facility, emergency contacts, special conditions, and regulations during the Construction process. In addition, the SOS group should be prepared in case of emergency situations, the First Aid, CPR AED Training is a high priority for the coming year.

Additional training in the use of Confluence, Jira and Jira Service Desk (aka Help Desk) software tools will be included for the SOS group to learn additional functionality, such as the ability to create templates, and how to create, format and build the documentation site for the group.

There are Construction activities planned to test the different subsystems installed in the facility; the SOSs will closely follow the execution and the results of the SIMs, making sure the following goals are achieved:

- Verify the *Subsystem Operations Manual*.
- Check the Procedures used in the SIMs tests and verify whether these Procedures will be used in operations.
- If Operations Procedures are available; review the documents and check whether the information is complete for future operations (e.g., Pointing Map procedure), if not, create a new complete version of the document and procedure.
- Check the result of the SIMs to understand whether results will imply changes in the operating model; make changes as needed.
- Document relevant aspects of the SIMs for operations.

A visit to the Dunn Solar Telescope will be performed in June by members of the SOS group. This will be one week visit to review details about Solar Observations, science and calibration observations, quality assurance, Wavefront operations, and science images.

An SOS Workshop in Boulder is planned in June 2019 to review a new version of the OCS using the BE2E, QAS functionality as well as to get an introduction to Solar phenomena.

For the end of 2019 it is anticipated that the SOSs will request training from IT&C on each subsystem on the telescope that the SOS group will need to manage in Operations. Specific training sessions with the TCS, ECS, & MCS GUIs will be needed to ensure that any SOS on duty is able to close the facility in any situation (or in the event the automatic scripts to close the facility are not working). The SOS group will also request training on how to close the facility directly from the electrical cabinets in case the software is not working properly. For all these activities the SOSs will receive the operations manuals and procedures for review from IT&C group. In case the information is not complete from the operations perspective, the SOS group will update the documents according to their needs and perspective in preparation for operations.

Another important training is the Global Interlock System (GIS) which will manage the safety system in DKIST. The SOS group will receive complete training in operating the GIS system in correlation with the GIS Operations Manual. The SOS group will review use cases and create documents as procedures and checklists to take action in different emergency/safety situations.

<u>2020 SOS Training Activities</u>

The SOS group will participate in training sessions for all Instruments as they are installed on the DKIST during the year, some of the topics to review during these sessions are as follows:

- Instrument GUI, basic functions.
- Calibration Plan and reference images for QAS.
- Science image products and references for QAS.

All details related to calibrations and science products are important topics to review with respect to procedures for execution and quality assurance.

Facility Instrument Distribution Optics (FIDO) is one important system for the SOSs to be trained in 2020. The FIDO setup itself will be a task for engineers and technicians; the SOS group must be able to perform tests of the new FIDO configuration to make sure that science observations can be executed.

Additional training activities will depend on when the Construction Phase is finished and how the transition phase is planned.

5.5.5 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 to ramp up and transition into full, steady-state operations. At the end of construction, instruments will have been "science ready" by exercising a few select modes of operations for each instrument. However, an advantage of the DKIST instruments is their flexibility to operate in many different modes and in combination with other instruments. The VISP alone can observe more than 300 unique combinations of three different spectral lines. Users will take advantage of the full capability of instruments. It is outside the scope of the construction project to without fully develop, test and verify a sufficient number of key use cases for each instrument or instrument combinations.

Furthermore, due to segregation and timing of construction and operations funding the development of essential operations systems, such as operations tools and procedures, and major infrastructure such as the Data Center has been lagging with respect to the construction schedule. Besides many interface issues, the impacts of segregation into and timing of MREFC and operations funding has contributed to the need for an OCP, maybe most prominently for the Data Center. A significant part of the early, shared-risk commissioning phase therefore is the implementation and verification of calibration pipelines for the various instruments and their key operational modes. Although, the Data Center has proceeded to implement and test with simulated data prototype calibration pipelines, it is only once a sufficient set of real data from the actual instruments is available that calibration pipelines can be fully developed and finalized.

At the end of construction in June 2020, we expect essential DKIST Operations Tools supporting users and staff, such as the Proposal Preparation and Submission Tool (Proposal Architect), the Proposal Review Tool, the Experiment Generation Tool (Experiment Architect), and the Operations Planning and Monitoring Tool to be ready for commissioning and testing by a select group of beta or shared risk users. "Shared Risk Users" are expected to work closely with DKIST staff to commission all DKIST Operations aspects starting with proposal submission and TAC process. Experiment generation and testing with simulators and on the actual hardware will follow for approved proposals. Verified Experiments will be run in service mode including necessary calibrations for instrument and facility. At the end of an Experiment, raw data is transferred to the data center. A representative set of key operational modes will be exercised for each instrument or instrument combination. During OCP DKIST will 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".

In order to efficiently organize the OCP effort we plan to use an approach similar to the System Integration Module (SIM) definition and execution that is being used for the IT&C phase of construction (see Section 5.1.1). Although, during OCP we will not be integrating hardware components but rather software tools, data piplines, and processes the general SIM approach, with well defined Statement of Work, flow charts, procedures and progression criteria for each module is still applicable. A detailed schedule for the effort will flow from the definition of the modules.

Commissioning of these aspects requires considerable effort and time. We plan to invite community members who are willing and able to contribute to the effort to participate, as shared-risk users, in all aspects of the operations commissioning phase.

Operations commissioning is expected to take on the order of 12 months. A balance between achieving high priority OCP objectives and user pressure for regular operations to begin will have to be struck through regular discussions with the community. There may be some overlap possible with the very late phases of construction where activities can happen in parallel with IT&C. During this phase, Science Operations will specifically integrate, test and streamline its procedures by exercising through all steps of the DKIST's Science Operations Lifecycle using scaled down versions of the science use cases developed in the context of the DKIST Critical Science Plan (see Section 5.2 DKIST Science Case: The DKIST Critical Science Plan (CSP)).

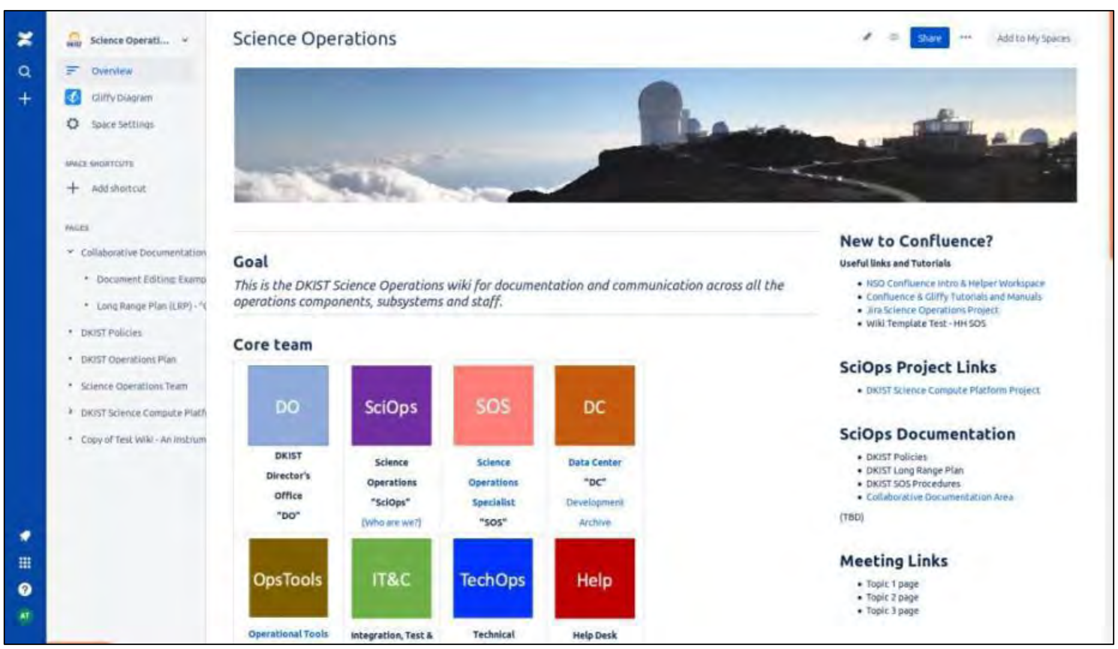


Figure 5-18. Science Operations wiki Confluence site. This portal is for content management of Science Operations internal documentation. The other Confluence team wikis working with Science Operations are easily accessible from the Core Team area.

An early Proposal Call will ensure solar community involvement on a shared risk basis. This Proposal call will likely announce what telescope and instrumentation capabilities are available during this period. One major goal is to build up complexity from simple instrument configurations to full capabilities (i.e., multi-instrument operations) over this period of operations commissioning. All PI's will use the Proposal Architect to prepare and submit proposals. We plan to implement a "prototype" TAC selected by the NSO/DKIST leadership. As the Proposal Review Tool is the last of the Ops Tools to complete development, it may not have full functionality during the very early stages of this operations commissioning phase; therefore, some aspects of the TAC process may be done through manual procedures. The TAC will choose proposals from the submitted proposal pool, score them based on scientific merit taking into account technical feasibility as well as the PI's willingness to assist with early operations, and produce a ranked Proposal list. The approved Proposals on this list will be delegated to DKIST Scientists to generate one Experiment per Proposal using the Experiment Architect tool. Each scientist will be assigned a small number of Experiments to manage and see through from start to finish. Management tools will be used for the tracking, coordination, and monitoring of the work, i.e., all bookkeeping aspects of the process.

Each Experiment and its Observing Programs will be subjected to a quality assurance process. The first step in the process involves testing on the Boulder End-To-End system (BE2E). The second step involves testing on the real hardware at the observatory prior actual execution and data acquisition. Only successfully tested Experiments and Observing Programs will be scheduled for execution and data acquisition. The Operations Planning and Monitoring tool will be used by Resident Scientists to create and exchange lists of Experiments with the observatory ready for either testing or execution through the SOS staff (using the Observatory Control System). As soon as specific Observing Programs have executed and data was acquired, or an entire Experiment has completed, the respective PI's will be notified. It is expected that the science operations staff will be able to fine-tune the workflow based on the lessons learned and that many procedures will be updated during this vetting process.

Figure 5-19. List of future DKIST co-observing solar telescopes and missions.

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.

An important operational requirement for the DKIST is to regularly co-observe with other observatories and missions (coordinated observations). Hence, part of the OCP will be to allow for at least one coordinated observation to test current baseline practices adopted by the DKIST. Proposal PI's will request a coordination and provide relevant details like requested time window, dates, and individual co-observing partners (Figure 5-19) 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.

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. The internal and external Help Desk will be utilized for booking of bug/issues/problems and their resolution.

A good indicator for completion of the Operations Commissioning Phase will be the ability to complete all accepted Proposals and their Experiments. This is not a trivial exercise and will take extensive planning and time to execute at all three DKIST locations – Boulder, DSSC and at the observatory. Although, a large number of staff will transition from Construction into Operations all technical and science staff will need to grow into and understand their new roles and responsibilities, adhere to schedules and processes, while still learning to use the state of the art DKIST telescope.

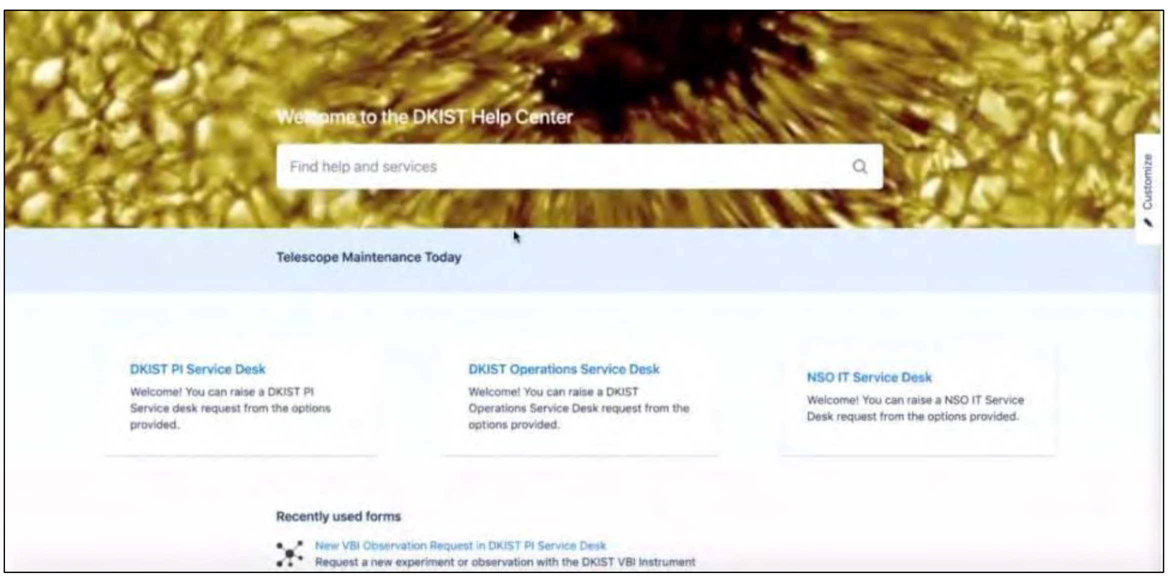


Figure 5-20. Jira Service Desk Example Entry Page. Out of the box, an administrator can easily set up a Jira Service Desk welcome page, where a user can search for help or click on one of the main aspects of DKIST or NSO Help Desks to file a ticket/request/bug.

The plan of this operations commissioning phase is in development. Supporting management software tools (not to be confused with the DKIST Operations Tools, mentioned above and described in Section

5.5.2.4, Science Operations Software Support Tools are being evaluated and purchased for documentation of processes and procedures. The Atlassian Cloud products Confluence and Jira will be used for content management and ticket management, respectively. The Jira Service Desk product will likely be used for the DKIST internal and external Help Desk. Operations staff are being trained in using these tools in order to have a full knowledge in time for the start of the OCP.

5.6 DKIST Technical Summit Operations

5.6.1 Scope Summary

The DKIST Technical Operations Team will be comprised of Maui-based Technical Operations management along with a staff of engineers and technicians to maintain, repair, and upgrade the DKIST Observatory according to NSO overall priorities. Key construction staff will be targeted for retention into the transition period and long-term operations and are already working to gather or develop necessary maintenance documentation and stocking critical spares. The Maui-based staff will require remote support from Boulder-based colleagues, for example specialists in camera or instrument software, and deployments when appropriate to collaborate on major upgrade and repair efforts.

5.6.2 Maintenance Plan

5.6.2.1 Technical Operations and Maintenance Support

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

Daily Startup

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

Daytime Operations Support

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

Maintenance Support Categories at DKIST

Observatory maintenance can be separated into three categories:

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

Planned Concurrent Maintenance

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

Planned Downtime Maintenance

Planned Downtime Maintenance will require immobilization of all or part of the facility by means of equipment shutdown or lockout-tagout procedures. Planned Downtime (or non-concurrent) Maintenance will, as far as possible, be performed during non-observing time, for example during periods of poor weather or very poor seeing. However, cost constraints on overall staff size is likely to result in planned downtime during potential observing periods in order to ensure reliability of different observatory systems and overall lifetime of the observatory.

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

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

strip and recoat process requires a large technical team, but some maintenance may be performed in parallel such as facility cleaning, Coudé Environmental System filter changes, and software updates.

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

Unplanned Downtime

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

Maintenance Strategies for DKIST

Several types of maintenance strategies may be implemented by DKIST technical operations team, dependent upon staffing, budget, and space constraints. The most likely scenario is a mix of all three of the following:

1. Run to Failure.
2. Preventative Maintenance.
3. Predictive.

The relative merits of each are shown in Table 5-6 and described below.

Table 5-6. Types of Maintenance Implemented by DKIST

Strategy	Summary	Cost to Implement	Pros	Cons
Run to Failure	Fix when it breaks	Low	Ideal for low priority equipment	Can lead to runaway repair costs
Preventive	Maintenance on a predetermined schedule	Average	Best strategy to implement without expertise	Inefficient schedules compared to PdM or RCM
Predictive	Condition based monitoring triggering work orders	High	Timely and informed monitoring. More insight into causes of breakdowns	Expensive to set up – only cost effective for critical assets

Run to Failure

While this sounds like a bad strategy, if used correctly it maximizes the lifetime of an item and reduces amount of sparing. A simple example of this is replacing a lightbulb after it burns out. A more complex example might be running a pump until the end of its useful life rather than replacing it when its predicted life is up. This is particularly appropriate if there is redundancy in the system, such as two or more pumps running in parallel. Depending on cost, size, reliability, and redundancy of components operating in this strategy, spares may be stocked so a replacement can be installed as soon as practical after a failure.

Preventive Maintenance

Preventive maintenance is the workhorse of a reasonable maintenance scheme. This is comprised of essential maintenance that is performed on a regular and recurring basis, and minimally ensures that components do not deteriorate or fail due to lack of care. Using the pump above as an example, preventive maintenance tasks would regular inspection for leaks and routine oil changes in gearboxes. A more complex example would be the recurring snow cleaning and wet-washing of the primary mirror to prolong the life of each aluminum coating.

Predictive Maintenance

Predictive maintenance consists of the analysis of engineering and performance data from numerous components looking for deviations from the nominal behaviors. Continuing with the pump example, predictive maintenance tasks could include measurement of vibration modes and amplitudes to ensure proper bearing alignment is maintained, sampling of used oil for wear particles or other contamination, and monitoring current draw over time. Changes in any of these measurements provide warning of an impending failure such that a new pump may be prepared or ordered to have on-hand. Such indicators of trouble will not show up in a preventative maintenance-only strategy. However, deploying predictive maintenance strategies can trigger corrective maintenance tasks and enhance the preventive maintenance routines.

5.7 DKIST Data Center

5.7.1 Introduction and Scope

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

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

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

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

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

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

5.7.2 DKIST Data Center Goals

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

1. Receipt and ingest of summit data.
2. Receipt and ingest of ancillary data.
3. Storage and curation of scientifically relevant data.
   a. Roughly 6 PiB of new science data every year.
4. Science Data Processing.
5. Search and Discovery of DKIST produced data.
6. Data Distribution.
7. Operations Support.

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

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

5.7.3 Design Overview

5.7.3.1 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 5-21 and described in more detail in Table 5-7, has been followed throughout the DC development and will continue to be used during operations whenever new capabilities are to be developed.

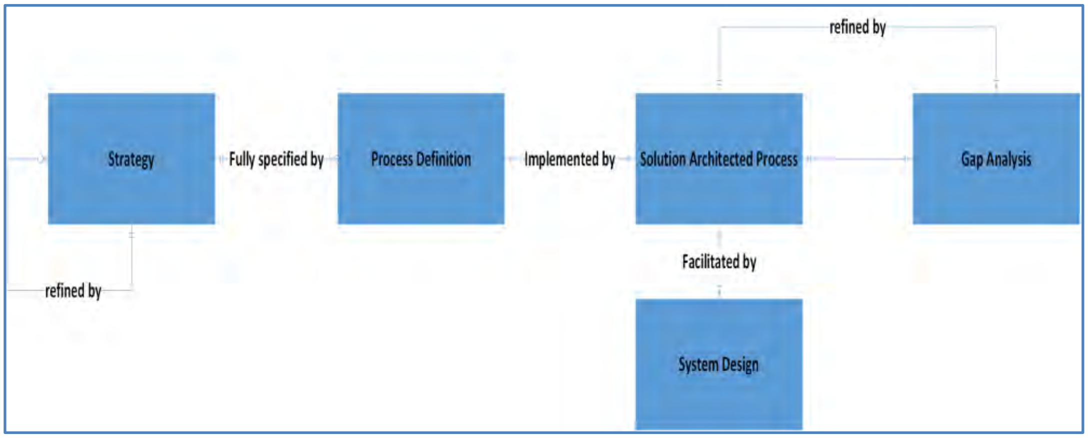


Figure 5-21. Metahow Process.

Table 5-7. Metahow Process Phases		
Phase	Activities	Produced Artifacts
Strategy	• Set Goals • Set Scope • Define Operational Approach	• Goals • Scope Diagram • Process Approaches • Key Performance Indicators • Key Concepts • Sticky Subjects
Process Definition	• Define Processes in Strategy Context • Define Necessary Support Processes • Identify Roles & Responsibilities • Identify Necessary Rules • Identify Necessary Data to Collect	• Processes • Roles & Responsibilities • Rules • Data Dictionary
Solution Architecture + Gap Analysis	• Integrate System Design to Process Definition to Create Solution Architected Processes • Define Necessary Solution Architected Support Processes • Augment Roles & Responsibilities Where Solution Architecture Requires • Augment Rules Where Solution Architecture Requires	• Solution Architected Processes • Augmented Roles & Responsibilities • Augmented Rules
System Design	• Define System Architecture to Support Process Definitions • Define Logical Data Models to Support System Design and Data Dictionary Needs	• System Architecture • Logical Data Models

5.7.3.2 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
  - o from technologies.
  - o between components and services.
- Maintainability.
- Testability.
- Extensibility.
- Scalability.
- Flexibility.

The services within the architecture are organized into Composite Applications (see Figure 5-22).

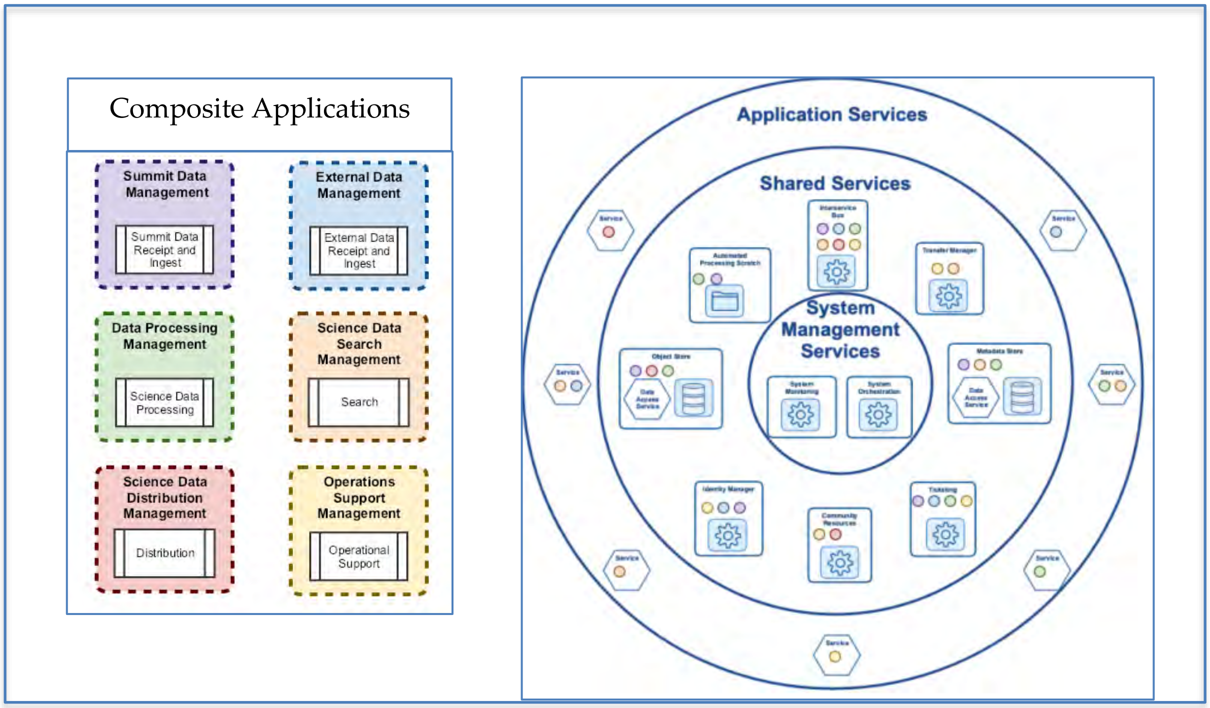


Figure 5-22. DKIST Data Center Architecture.

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.

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.

5.7.3.3 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 5-23). 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.

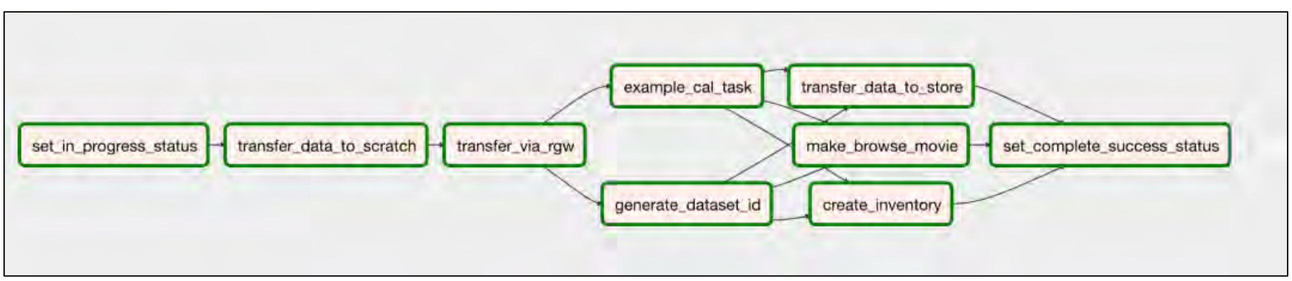


Figure 5-23. Example Direct Acyclic Graph (DAG).

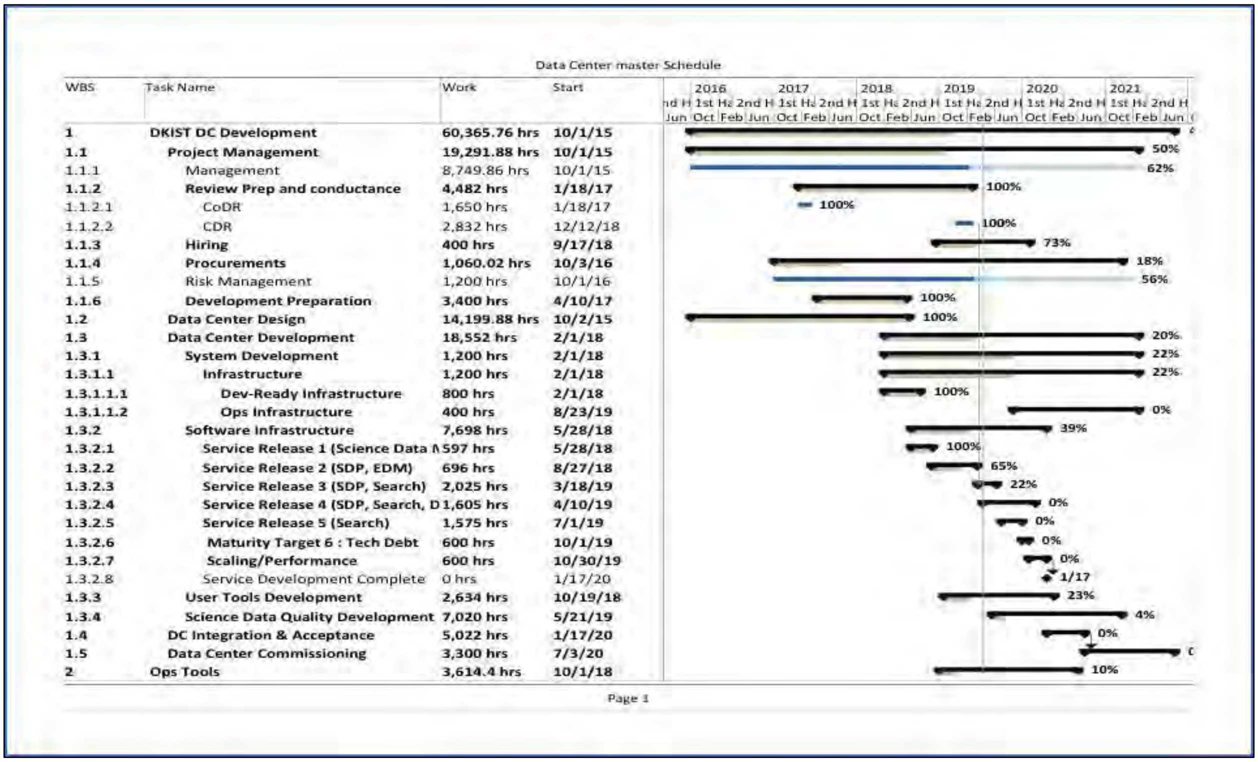
5.7.4 Data Center Schedule and Current Status

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 FY19, the Data Center has passed its Critical Design Review, which will lead to some design augmentation and implementation based on the review committee report. The Data Center has a plan to complete all the requirements on time. There is also a plan to complete technical debt from the upcoming year of development effort. The Data Center will be developing its Commissioning Plan with the rest of the Operations planning and scheduling.

5.7.4.1 Development Schedule

The development phase of the DKIST DC project is shown in Figure 5-24.



WBS	Task Name	Work	Start
1	DKIST DC Development	60,365.76 hrs	10/1/15
1.1	Project Management	19,291.88 hrs	10/1/15
1.1.1	Management	8,749.86 hrs	10/1/15
1.1.2	Review Prep and conductance	4,482 hrs	1/18/17
1.1.2.1	CoDR	1,650 hrs	1/18/17
1.1.2.2	CDR	2,832 hrs	12/12/18
1.1.3	Hiring	400 hrs	9/17/18
1.1.4	Procurements	1,060.02 hrs	10/3/16
1.1.5	Risk Management	1,200 hrs	10/1/16
1.1.6	Development Preparation	3,400 hrs	4/10/17
1.2	Data Center Design	14,199.88 hrs	10/2/15
1.3	Data Center Development	18,552 hrs	2/1/18
1.3.1	System Development	1,200 hrs	2/1/18
1.3.1.1	Infrastructure	1,200 hrs	2/1/18
1.3.1.1.1	Dev-Ready Infrastructure	800 hrs	2/1/18
1.3.1.1.2	Ops Infrastructure	400 hrs	8/23/19
1.3.2	Software Infrastructure	7,698 hrs	5/28/18
1.3.2.1	Service Release 1 (Science Data M	597 hrs	5/28/18
1.3.2.2	Service Release 2 (SDP, EDM)	696 hrs	8/27/18
1.3.2.3	Service Release 3 (SDP, Search)	2,025 hrs	3/18/19
1.3.2.4	Service Release 4 (SDP, Search, D	1,605 hrs	4/10/19
1.3.2.5	Service Release 5 (Search)	1,575 hrs	7/1/19
1.3.2.6	Maturity Target 6 : Tech Debt	600 hrs	10/1/19
1.3.2.7	Scaling/Performance	600 hrs	10/30/19
1.3.2.8	Service Development Complete	0 hrs	1/17/20
1.3.3	User Tools Development	2,634 hrs	10/19/18
1.3.4	Science Data Quality Development	7,020 hrs	5/21/19
1.4	DC Integration & Acceptance	5,022 hrs	1/17/20
1.5	Data Center Commissioning	3,300 hrs	7/3/20
2	Ops Tools	3,614.4 hrs	10/1/18

Figure 5-24. DKIST Data Center development schedule.

Development of the Data Center infrastructure, which at this point includes the infrastructure as well as the calibration code for at least the VISP, is expected to be completed by June of 2020. The schedule as it stands has approximately one month of total float to the expected time when the DKIST will begin streaming data from at least some instruments. During this operational ramp-up time, it is expected that issues will manifest themselves, software bugs will be discovered, and unthought of use cases will become apparent, requiring some undetermined mix of new rework and new work. This work as well commissioning and testing will extend the development phase into August of 2021.

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 provided analysis tools to manipulate and visualize the data.

5.7.5 Development Status

Table 5-7 lists the tasks and milestones that have been completed as well as those that remain to be completed. Figure 5-25 shows the expected personal profile that will take the DKIST DC into full operations.

Table 5-7. DKIST Data Center Development Status	
Activity	Time Interval
Early Definition	2013 - 2014
PM Arrives; First Staff	2014
CA Budget Reprofiling	Late 2014 - Early 2015
Science & System Concept Definition	Late 2014 - Mid 2015
Operational Concept, Science	Mid 2015 - Mid 2016
Prototyping	2015 - 2018
System Concept, System Requirements	2016 – 2017
Conceptual Design, System Sizing	2016 - 2017
Conceptual Design Review	March 2017
Final Design & System Decomposition	2017 - 2018
Critical Design Review	Feb 2019
Implementation	2018 - 2020
Staff Augmentation	2018 - 2020
Infrastructure development complete	Jan 2020
Integration, Test, and Commissioning	2020 -2021
Ramp to Operations Start	June 2020

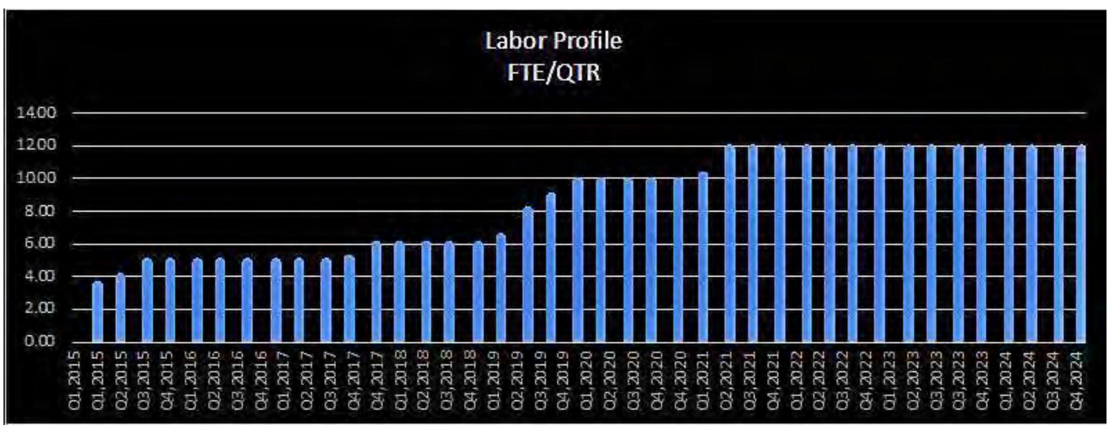


Figure 5-25. DKIST DC labor profile.

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

- Complete Software Development.
  - Complete coding scope on time, within budget, with resources.
  - Continuous testing & integration.
  - Strive toward "automated" test-release program.
- System Development.
  - Completion of infrastructure & administration tooling, resources.
  - Performance Tuning.
- Calibrations Development.
  - Optimize Construction (verification) codes.
  - Integrate with science data processing system.

5.7.6 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.

5.7.6.1 DKIST DC Science Processing Operations

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

5.7.6.1.1 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.

5.7.6.1.2 Science Data Quality

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

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

5.7.6.1.3 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 responsiblility 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.

5.7.6.2 Technical Operations

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

5.7.6.2.1 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 is being and received and delivered without loss, as well as to monitor the web servers to assure that no security related events are occurring on the web portals that would adversely affect the DC capability to serve data. In the event that such an occurrence is detected, the system engineers will inform the DKIST cybersecurity officer and take appropriate remedial actions in accordance with DKIST security policies.

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

5.7.6.2.2 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, except for the tape library, 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.

5.7.6.2.3 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 or through Help Desk activities, whereby a user of the DKIST DC infrastructure submitted a ticket for a perceived issue.

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.

5.7.6.2.4 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.

5.7.6.3 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.

5.7.6.4 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.

5.8 DKIST Instrument Program

5.8.1 Multi-Conjugate Adaptive Optics (MCAO) and DKIST

5.8.1.1 Upgrade of Classical Adaptive Optics to MCAO

The initial High-Order Adaptive Optics (HOAO) system of DKIST, which is scheduled to be integrated in spring of 2019, is a *classical adaptive optics* system and is based upon well-established techniques and scaled-up technologies, such as the first and pioneering high-order system in solar adaptive optics developed at the DST. Being a single conjugate or *classical* system, the DKIST HOAO deploys one deformable mirror (conjugate to the telescope aperture) to correct the light path and one unidirectional wavefront sensor to measure the adjustments needed. In such a system, the corrected field of view is typically limited to a patch on the of order 10 arcseconds in diameter around the viewing direction of the wavefront sensor. Scientifically interesting regions, however, can span dozens of arcseconds.

Deployment of multiple deformable mirrors that are conjugate to different atmospheric altitudes in which strong turbulence occurs—a concept that became known as *Multi-Conjugate Adaptive Optics (MCAO)*—can widen the corrected field. While drafting the science requirements for the DKIST the science working group early on recognized the importance of pursuing this promising technology, which at the time (early 2000s) was not demonstrated to work for the solar application.

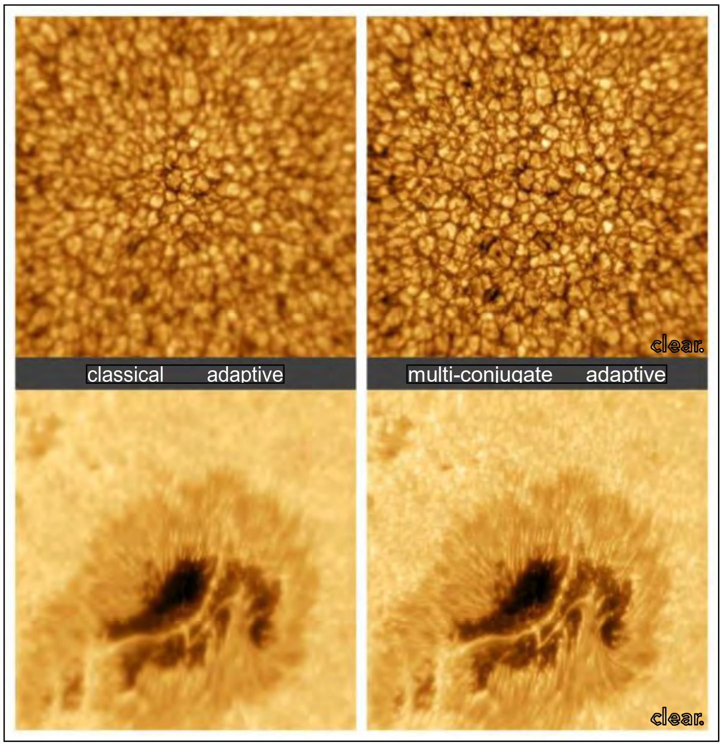


Figure 5-26. Solar granulation and a sunspot corrected for atmospheric turbulence by the adaptive optics system "Clear" (left) on the Goode Solar Telescope.

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

In parallel to the ongoing construction of DKIST, NSO has pushed the development of multi-conjugate adaptive optics for solar observations with the goal of demonstrating the technology on smaller telescopes and to MCAO-upgrade DKIST as soon as possible. For over a decade, NSO has been collaborating with the German Kiepenheuer-Institute (KIS, now Leibniz-Institute for Solar Physics) and the New Jersey Institute of Technology (NJIT) in the development of MCAO. Under the leadership of NSO and funded by NSF grants, the experimental solar MCAO pathfinder, called *Clear*, was developed for NJIT's 1.6-meter Goode Solar Telescope (GST) located at the Big Bear Solar Observatory in Southern California (Figure 5-26).

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

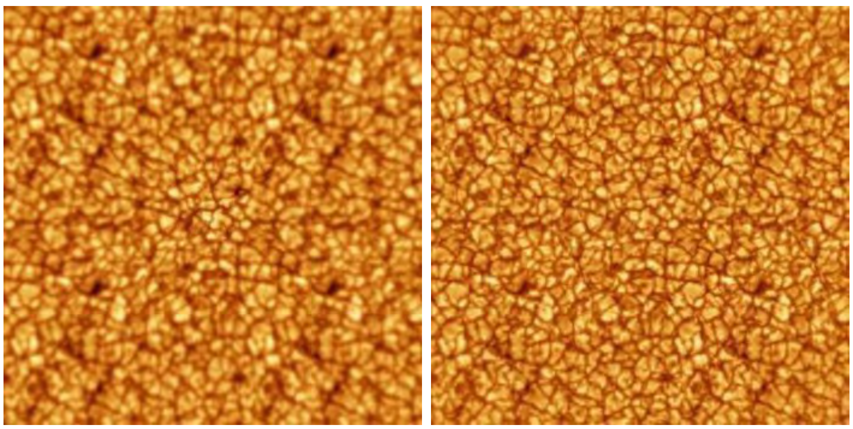


Figure 5-27. Simulated observation with DKIST of artificial solar granulation made with "Blur" using classical (left) and multi-conjugate (right) adaptive optics image correction (artificial granulation image courtesy of M. Rempel, High Altitude Observatory).

DKIST will be upgraded with a three deformable mirror MCAO system that will provide a corrected field of view of 60 arcsec in diameter (Figure 5-27), corresponding to the field of view of DKIST's Fabry-Perot spectro-polarimeter "Visible Tunable Filter" (VTF). The fundamental principles for DKIST's MCAO follow closely the most successful configuration of *Clear*. Due to the sheer aperture size of DKIST however, *Clear* cannot simply be scaled up for DKIST with currently available technology. In *Clear*, using a single CMOS detector for wavefront sensing and one high-performance computer is sufficient. For a similar system on DKIST, a much greater number of pixels is needed than there is currently available in fast and applicable image sensors. Furthermore, no current single computer is able to process the wavefront sensor data and to timely compute the control commands for the deformable mirrors in a DKIST size MCAO system. Our concept therefore is to split up both the wavefront sensor and the computer system into a number of identical parallel subsystems. Some of the basic specifications are listed in Table 5-8 and compared against the *Clear* configuration.

5.8.1.2 Deformable Mirrors

DKIST's MCAO shall have three deformable mirrors, conjugate to 0, 4, and 11 km on the optical axis. The "M10" ("DM0") mirror is the conjugate to the puple deformable mirror in DKIST's initial HOAO and will be reused for MCAO. The additional two deformable mirrors shall replace the existing folding-flat mirrors "M9" and "M7". The original flat "M9" is about 400 mm in diameter while the footprint of 60 arcsec on this mirror is only about 300 mm. The deformable mirror "DM4" replacing "M9" will also be 400 mm in diameter with the central 300mm actively controlled. The fabrication of "DM4" is under contract with Northrop Grumman AOX Xinetics and delivery is scheduled for **October 2020**. Its technology will be similar to the existing "DM0" made by the same company. For the second deformable mirror "DM11" that shall replace "M7", DKIST is currently contracting Northrop Grumman AOX Xinetics to conduct a design study. We anticipate leading a contract for M7 in FY19.

The wavefront sensor system in DKIST's MCAO will be made of nine separate sensors and will replace the sensor of the HOAO. Each sensor will be similar to the existing HOAO wavefront sensor but points at different directions in the 60 arcsec field of view (Figure 5-28). Each sensor shall carry its own CMOS camera. We plan to contract the camera manufacturer in order to upgrade to one of their latest-generation commercial camera models with a fast streaming interface.

Table 5-8. **Basic Specifications of 'Clear' and of DKIST's MCAO**

	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, ≈800
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	1	9
Frame 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 (100 Gbps)

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

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

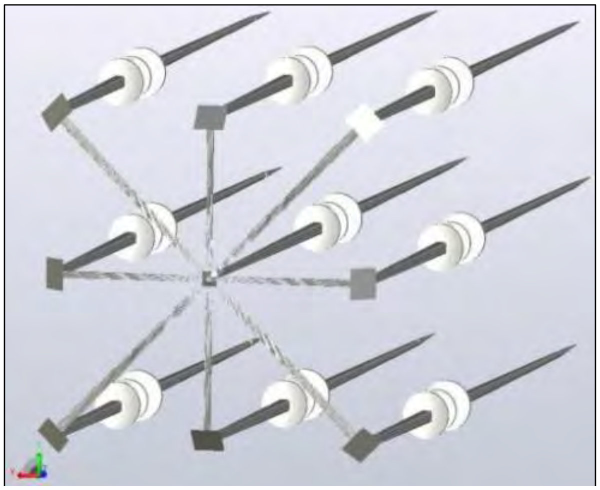


Figure 5-28. Nine separate wavefront sensor units in a 3×3 grid shall span a field of view of 60 arcsec.

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

Figure 5-27 compares an example of a simulated observation with the DKIST HOAO and a preliminary version of the MCAO system.

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

5.8.1.3 Numerical Simulations of DKIST MCAO Performance

Summary

The MCAO upgrade is expected to provide the DKIST with at least a nine times larger corrected image area than the initial HOAO system. The project aims to replace the classical HOAO system with MCAO in 2022/2023. Based upon the successful Clear MCAO system, this project will apply its findings, from the NSF-funded development effort, to DKIST and will thereby uphold NSO's decades long pioneering role in solar adaptive optics in creating the clearest images of the sun.

5.9 Instrument Upgrades

The Daniel K. Inouye Solar Telescope will incorporate five state-of-the-art instruments for observations of the solar atmosphere (Figure 5-29). In addition to replacement of technology lifecycle items, such as detectors and replacement of failing components (e.g., motors) there are opportunities for enhancing the capabilities of these instruments. The first light set of DKIST instruments constitutes a considerable investment. Upgrades and enhancements of capability of instruments, including software upgrades, is therefore a cost-effective way to extend the scientific viability and lifetime of instrumentation. Furthermore, due to budget constraints of the construction project de-scopes had to be implemented for some first light instruments. For example, the slit-jaw imager was removed from the VISP and the CRYO-NIRSP "cold" context viewer was de-scoped to a "warm" context imager with reduced IR performance. Re-gaining these capabilities during operations is a long-term objective. Infrared detectors for DL-NIRSP and CRYO-NIRSP continue to be a concern. There are currently no spares for these custom-built detector systems.

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

Figure 5-29. Left: Layout of the five first light instruments on the Coudé platform. Right: April 17, 2019 state of the Coudé platform showing the VBI and WFC tables.

In the following, we describe upgrade and enhancement opportunities for each of the DKIST instruments, which will be prioritized with input from the community and pursued contingent on funding. We plan to obtain one or two IR camera systems, preferably off-the-shelf solutions.

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

Upgrade paths for the ViSP:

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

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

Upgrade paths for the VBI:

1. Near term: Each filter wheel in each arm of the VBI provides space for one additional interference filter. These filter wheel positions could be equipped with one additional interference filter in the blue arm, and one additional interference filter in the red arm. The choice of central wavelength and bandpass can be arbitrary as long as they are within the wavelength ranges of the blue and red arms (380-550 nm and 550-850 nm, respectively).

2. Mid term: One, or both arms of the VBI could be upgraded to obtain polarimetric capabilities. In particular such an upgrade in the blue arm would enhance DKIST scientific capabilities, as the DKIST VTF Instrument, also an imaging spectro-polarimeter, currently does not have the capability to observe between 390-525 nm.

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

Upgrade paths for the VTF:

1. Near term: the VTF will be upgraded with a second Fabry-Perot etalon. This will allow a larger spectral window that the VTF will be able to scan and provide improved throughput performance, increasing the instrument's efficiency. The SWG requested this upgrade option with high priority. NSO/DKIST is pursuing the upgrade in partnership with the German instrument partner (KIS) developing the VTF. Development of the second etalon is in progress. The VTF is expected to be upgraded to a dual etalon system in 2022.

2. Near term: the VTF can be upgraded to include additional interference filters as pre-filters to include more diagnostics for the solar atmosphere. Any spectral line within the range of 525-850 nm can be accessed with the VTF, and would only require the corresponding pre-filter.

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

Upgrade paths for the DL-NIRSP:

1. Near term: the DL-NIRSP can be upgraded with a fiber-fed IFU that is expected to show significant performance enhancements at wavelengths above 1000 nm.
2. 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. Mid/long term: the DL-NIRSP can be upgraded by replacing the fiber-fed IFU with an image-slicer unit to improve throughput and performance above 1800 nm (Figure 5-30).

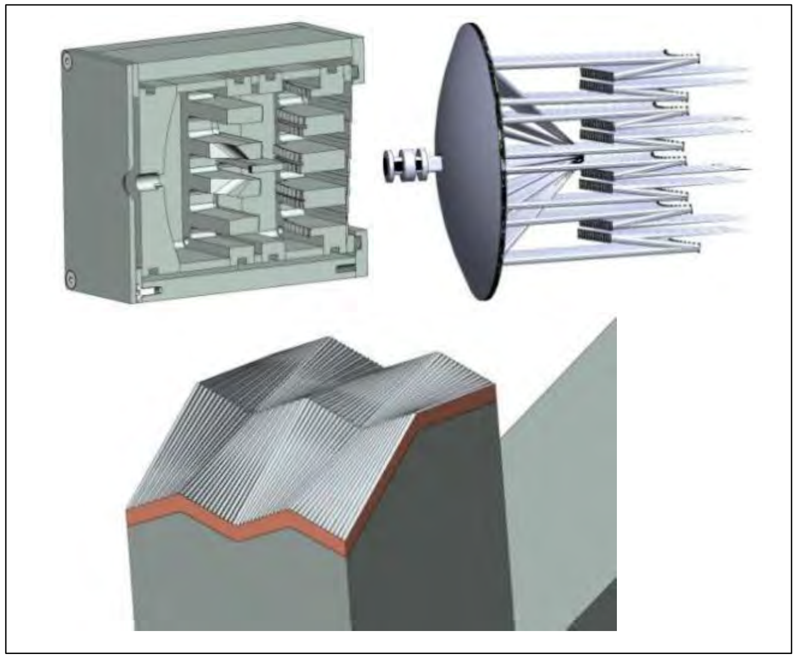


Figure 5-30. Optical design (right) and CAD models (top left, bottom) of image slicer upgrade option for DL-NIRSP.

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

Upgrade paths for the Cryo-NIRSP:

1. Near term: the Cryo-NIRSP can be upgraded by including more order-sorting filters in both the spectrograph and context imager dewars. This will enhance the instruments' scientific versatility.
2. Mid term: the mirror that is inserted into the science beam can be replaced by a dichroic beamsplitter, allowing the instrument to operate simultaneously with all other DKIST first light instruments. This will enhance the ability to address more complex scientific use cases.
3. Long term: the Cryo-NIRSP can be upgraded with a low-order adaptive optics system. This would increase the average output of high spatial resolution data since the frequency of diffraction limited observations at infrared wavelengths will therefore be increased.

5.10 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 construction effort but once DKIST is in operations will continue to support summit operations.

The approximately 13,000 sqft DSSC provides offices and work areas for the scientists and postdoctoral researchers (permanent and guest), non-site operations and engineering personnel and administrative staff not required to work at the summit on a day-to-day basis (Figure 5-31). The DSSC provides individual and shared office spaces. On average, 25 to 30 permanent and visiting staff will use the facility daily. Limited instrument lab and workshop space is provided. In addition to staff and visitor vehicles, facility vehicles for the DKIST facility will be staged in the parking lot of the DSSC.

Figure 5-31. DKIST Science Support Center at Pukalani, Maui.

In addition to office space, the DSSC will support 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.

Construction of the DSSC began in FY17 and was completed on-budget in 2018. The building is now occupied by DKIST staff.

In operations, the DSSC will serve as the off-summit center for day-to-day operations of DKIST. We note that 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.

In FY 2017, NSO relocated the machine shop equipment from Sunspot to a Boulder off-campus leased space. Early in the transition, NSO initiated discussions with LASP about co-locating our machines at their facilities in the LASP engineering building. Because of prevailing International Traffic in Arms Regulations (ITAR) at LASP and complex liability concerns, it was necessary to search for an off-campus machine shop location. NSO/AURA has leased 2,757 square feet of usable space at an industrial warehouse. To augment the aging equipment transferred from Sunspot a new CNC mill was purchased and installed at the machine shop, greatly enhancing the production capability of the shop (Figure 5-32). The DKIST construction project has had

Figure 5-32. A section of the Boulder machine shop facility showing the new CNC mill.

an ongoing need for what has been oversubscribed machine shop time. DKIST will continue to have priority for use of the machine shop until the end of the project. After completion of DKIST construction, the machine shop will be an Observatory-wide resource. DKIST Operations plans to utilize the machine shop to manufacture parts for new instrument developments. In the near term, the MCAO is likely to be the main development effort.

The NSO Headquarters building in Boulder houses the instrument lab facility. Currently the facility is utilized mainly by the DKIST construction project. The wavefront correction system, the Visible Broad Band Imager and the Polarization Analysis and Calibration system were developed, integrated and tested in the Boulder instrument lab. These systems have been or will be shipped to Maui for integration on the summit in FY19. Moving forward the lab will be used to develop new instruments such as the multi-conjugate adaptive optics system.

5.11 Safety Program

5.11.1 Construction Phase Safety Summary

Safety in the construction phase primarily focused on monitoring and correcting contractor groups safety behaviors and mitigation of unsafe conditions on daily, weekly and monthly intervals and feedback reporting. The process started with the participation of safety in the Source Selection Board (SSB) including rating of the contractors OSHA safety record and their insurance Experience Modifier Rate (EMR). Contractors are then required to comply with the SPEC-0030, "Conditions for Working at the DKIST Project Site and Safety and Health Specifications for Contractors". The project's safety management required corrections and updates to several contractor's own safety and health plans to meet DKIST project requirements. In at least one case, a contractors DKIST improved safety plan was essential in their capture of additional contracts in the state. The project implemented best practice elements from DOE construction projects and visited the National Renewable Energy Laboratory (NREL) construction site. These safety program processes where transitioned and evolved into the IT&C phase as contractors were replaced with temporary and fulltime DKIST employees. Injury incident rates, although somewhat high, likely due to altitude and reporting accuracies, have shown a steady decline indicating the positive influence of the safety program. The project has had eight Annual Safety Reviews, and the Committee reported last year that "The project has done an impressive job of managing safety in a difficult project environment."

5.11.2 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 will 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 will be 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. (Figure 5-33) that are applicable to the operations phase. The Safety Committee and safety staff has been developing the detailed safety manual for the operations and maintenance phase while implementing sections incrementally as needed for the construction and IT&C phases. Also, several checklist procedures developed for IT&C, from construction task job hazard analysis, will transition to and be further evolved into the operational procedures.

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

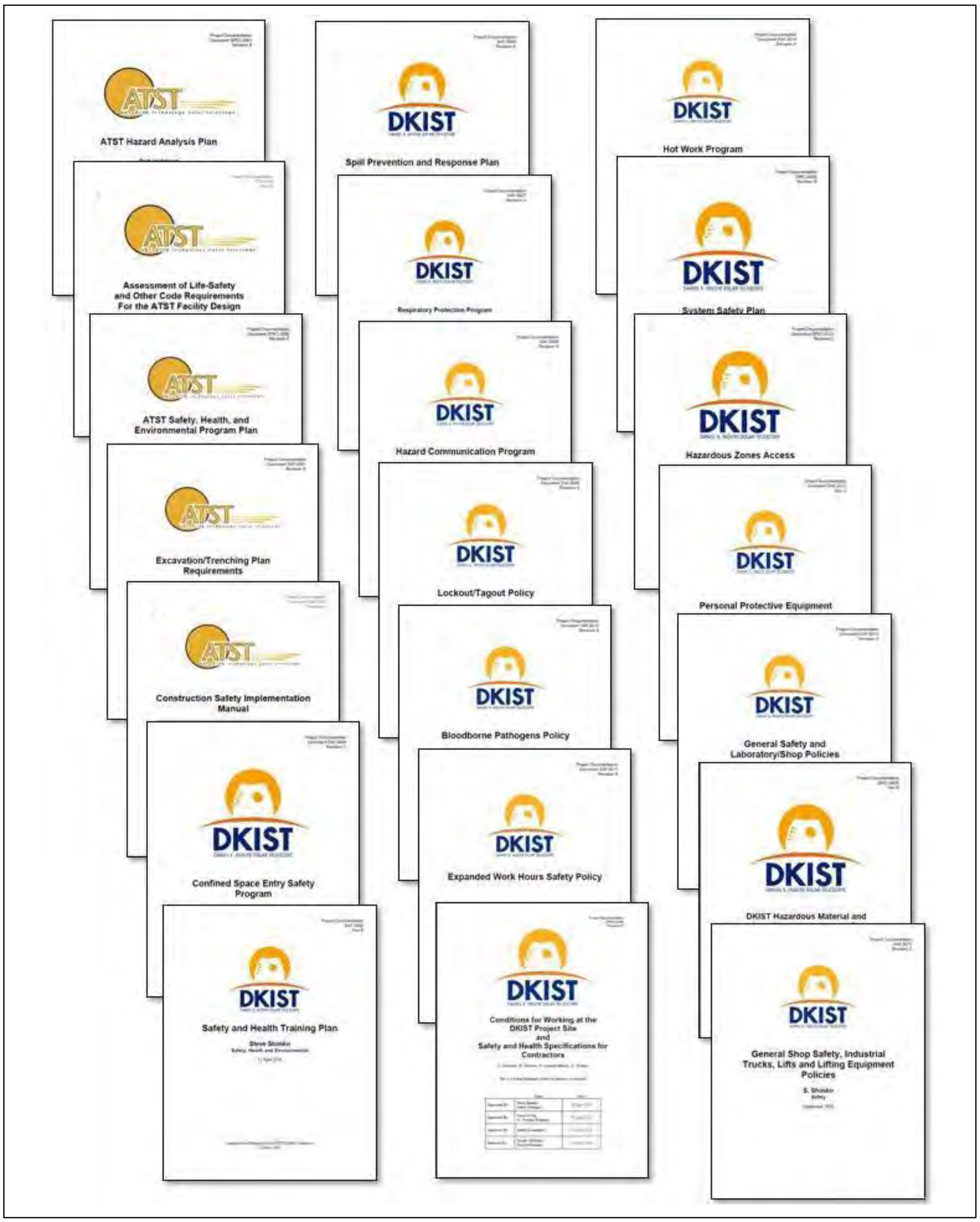


__Figure 5-33.__ Safety element program plans documents.

6 NSO INTEGRATED SYNOPTIC PROGRAM (NISP)

This Chapter addresses all Goals in Section 2.2 and Activities 5, 7, 9, 10, 14, 17 and 18.

While the DKIST is the prime focus of NSO during the time period covered by this Cooperative Agreement, it cannot provide a comprehensive view of the Sun due to the small field of view (2.4% of the full-disk area) and the multiple observing programs it will support. Furthermore, DKIST data greatly benefit from context data that provide information on the solar conditions adjacent to the DKIST observations in both space and time. Thus, the NSO needs to maintain its long-standing synoptic program to ensure that the scientific returns from DKIST are maximized. The research community has been using NSO synoptic data for more than 45 years, and non-NSF agencies such as the US Air Force (both the Air Force 557th Weather Wing and the Air Force Research Laboratory), the NOAA Space Weather Prediction Center (SWPC), and NASA, are all substantial users of NISP data for both scientific research and space weather awareness and forecasting. Emerging space weather programs in other countries are also regular users of NISP data.

The NSO Integrated Synoptic Program (NISP) was formed in July 2011, combining the Global Oscillation Network Group (GONG) and Synoptic Optical Long-term Investigations of the Sun (SOLIS) programs, increasing organizational efficiency, and yielding greater scientific synergy. Together, DKIST and NISP provide a complete view of solar phenomena on a range of spatial scales from tens of kilometers to the full disk, and on time scales from milliseconds to decades. In particular, NISP is a long-term and consistent source of synoptic solar physics that observes the Sun as a whole globe over solar-cycle time scales. While space missions, such as SOHO and SDO, also observe the entire solar disk, they cannot match the long-term coverage provided by NISP, which started in 1974 with the advent of the Kitt Peak magnetograph, Sac Peak flare patrol, and spectroheliograms. Space missions are also vulnerable to the effects of solar flares and CMEs, cannot be repaired, and are considerably more expensive.

In addition to supporting solar variation and helioseismology studies, NISP is a valuable source of data for national space weather needs. 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. This and an Office of Management and Budget (OMB) directive to NOAA has led to the initiation of a partnership with the Space Weather Prediction Center to provide substantial operational support for GONG. Space weather has become increasingly important to national security and planning. 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[6]. NISP 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."*

[6] *https://www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf*

Beyond maintaining normal operations, advancing scientific research, and providing support to the community, NISP's activities and goals over the first half of this CA have been and continue to be heavily impacted by relocation efforts and several large special initiatives. With its staff, data center, and engineering site now located in Colorado, NISP is focused on completing the relocation of SOLIS. In parallel, work continues on a significant refurbishment of the GONG network, the migration of its space weather data processing to NOAA/SWPC, and additional instrument upgrades. Loss of personnel resulting, in part, from NISP's relocation and budget reductions (see Section 4.3) have made carrying out this ambitious agenda challenging; however, a dedicated and resourceful staff is committed to NISP's forward progress on each of these fronts.

6.1 NISP Science

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

To a significant degree, NISP's scientific enterprise is intermingled with the business of acquiring and processing observations. NISP scientists use insights from their own research to monitor and improve the quality of the data and to suggest and develop new data products. Examples of such interplay include the previously mentioned GONG refurbishment, GONG magnetic zero-point improvements, photospheric vector 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 before they emerge.

The solar meridional flow is a crucial ingredient in modern dynamo theory. However, seismic estimation of the flow has been challenging, particularly in the deeper layers. Recent measurements using the time-distance technique and GONG data confirm a shallow return flow (Böning et al., 2017). Both the Global and local helioseismology continue to track the evolution of large-scale flows, including the north-south meridional flow and the east-west zonal flow known as the torsional oscillation (Howe et al., 2018; Komm et al., 2018). These flows are intimately connected with the dynamo mechanism that produces the solar magnetic field and associated activity. For example, the timing of the migration of the zonal flow has proven to be a good indicator of the future behavior of sunspot activity. Current observations suggest that the flow patterns of the next activity cycle, number 25, have reached 25 degrees latitude with a strength that is weaker than the current cycle but comparable to Cycle 23 (see Figure 6-1). Based on the current position of this pattern, Howe et al. (2018) have speculated that the onset of widespread activity for Cycle 25 is unlikely to be earlier than the middle of 2019, most likely sometime in 2020. The observations also indicate that the rotation of the Sun at high latitudes may vary by 1% on a time scale of five years. A community effort to determine the internal solar rotation rate using all available helioseismic data is now underway. This effort will take advantage of GONG, the longest available helioseismology time series at just over 23 years, as well as data from other ground- and space-based experiments. This is an ongoing work, initiated by Michael Thompson, and helioseismologists from all over the world are involved in this effort. This project is now led by Joergen Christensen-Dalsgaard (Aarhus University, Denmark) with significant support from NSO. The project aims to produce a unique rotation profile that can be used without the biases present in existing ones.

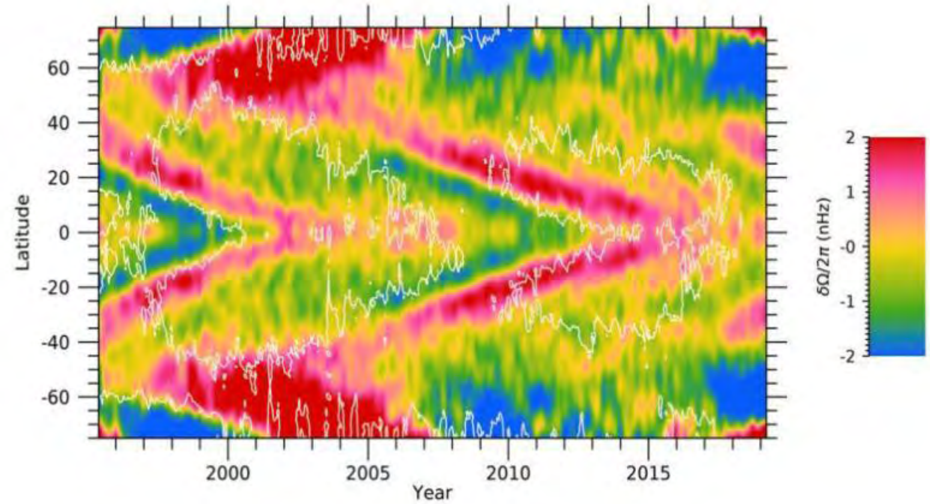


Figure 6-1. Rotation-rate residuals as a function of latitude and time, from inversions of GONG, MDI, and HMI data. The mean to be subtracted was taken separately over the whole data set for GONG and the combined MDI and HMI set. The white contours represent 10 % of the maximum level of the synoptic unsigned magnetic field strength. Note the equatorward branch for Cycle 25 visible around 2018 and that reaches close to 25 deg latitude.

One of the most pressing problems in helioseismology is understanding the influence of magnetic fields on the acoustic waves as this is a complex interaction phenomenon and there is insufficient understanding of the processes involved. Moreover, numerical simulations suggest that processes occurring higher up in the atmosphere can contaminate the acoustic signal and affect the inferences from local helioseismology in the presence of strong fields. In this context, NISP scientists (Tripathy et al., 2018) are analyzing the propagation of acoustic waves in active regions as a function of the height from the photosphere to the chromosphere and as a function of the magnetic field and its inclination. Work for several active regions is in progress. Understanding the interactions between acoustic waves, the magnetic fields they encounter, and how the acoustic power is transformed into various MHD waves is crucial for making progress in the area of local helioseismology. Over the next five years, progress in calibrating local helioseismology techniques to refine the inference of subsurface flows beneath active regions will be crucial to substantiate the extent to which flux emergence can be predicted before it is observed at the surface.

Beneath the surface, GONG has revealed that frequently flaring active regions are always accompanied by a distinctive flow pattern below the surface. This velocity field is in the form of two horizontal "tornadoes" with oppositely directed senses of rotation and revealing that high vorticity is correlated with a mean magnetic field strength in an active region, thus indicating the likelihood of producing energetic flares. Substantial flow variations occur prior to a flare and can provide timing information (Reinard, et al. 2010). This discovery suggests that subsurface flows from GONG can be developed into a predictive tool for space weather.

Improving the scientific value of our data products has always been a priority for the NISP research and development group. During the past five years, several major projects were undertaken that address this goal. First, we revised the SOLIS/VSM Milne-Eddington inversion code for the full-Stokes photospheric magnetic measurements taken in the Fe I 630.15 and 630.25 nm lines (Figure 6-2). This upgrade addresses

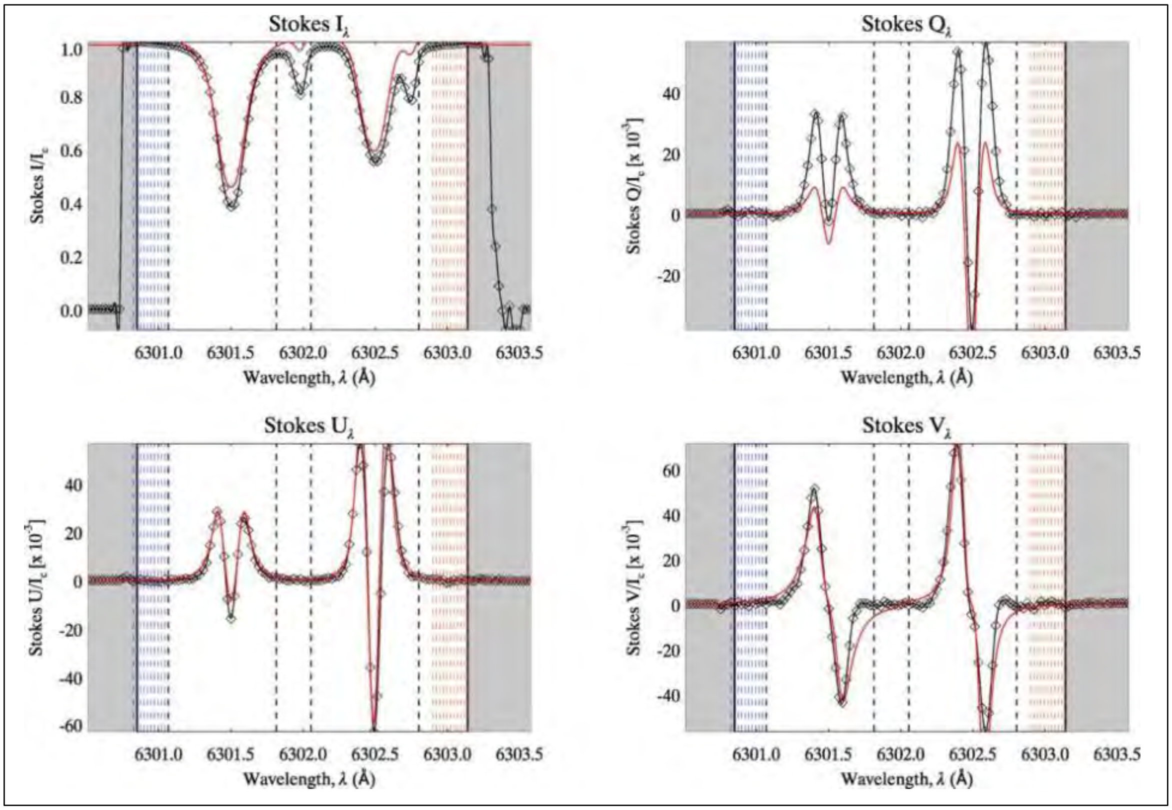


Figure 6-2. Example of a SOLIS two-line Milne-Eddington inversion (diamonds data, red line resulting fit). The gray areas are outside of the usefully-illuminated portion of the CCD. The black vertical dashed lines bracket each line region (6301.5, 6302.5), and the red/blue vertical striped regions denote the spectral regions where we calculate continuum intensity. The fit returned B=1571 G, inclination of 27 deg, and azimuth of -31 deg.

some of the limitations contained in the old code. Both lines are now included in the inversion code, and better treatment of the scattered light contribution is incorporated. With these modifications, the determination of the vector magnetic field becomes more reliable, resulting in an improvement of the current Carrington synoptic maps derived from those measurements. These maps are the main drivers of coronal and heliospheric models and play a critical role in models designed for space weather prediction purposes.

Second, a new algorithm was developed that merges longitudinal (line-of-sight) and full-Stokes photospheric measurements of the solar magnetic field. The basic idea behind this effort is to exploit the best properties of these two types of measures, by explicitly addressing the poor sensitivity of vector measurements in regions of low magnetic field. Two new data products based on SOLIS/VSM data have been developed: composite synoptic maps, which combine radial field derived from vector maps (for stronger fields) and pseudo-radial from line-of-sight magnetograms (for weaker field areas). These maps are now available via the NISP Data Center at *ftp://nispdata.nso.edu/HMI_composite/*. The other data product is synoptic maps of the pseudo-radial chromospheric field also available for the community at *ftp://nispdata.nso.edu/VSM_pseudo_radial*. It is anticipated that these data products will be useful for models used in space weather forecast. NASA funded the development of these new data products under a grant. The impact of these new products on space weather forecast will be evaluated under a recent NASA/NSF grant to the CU Boulder Space Weather Technology, Research, and Education Center (SWx-TREC).

Similarly, the SOLIS/VSM instrument was upgraded by the SOLIS team in 2015 to perform full Stokes polarimetry of the chromospheric Ca II 854.2 nm spectral line (Harvey et al., in preparation). This upgrade has provided the capability to derive vector magnetograms in the chromosphere over a large field-of-view (full disk) daily. These chromospheric data represent a unique capability now available with SOLIS/VSM instrumentation. Chromospheric vector magnetograms have several potential benefits for the study of solar activity phenomena. Due to lower plasma beta, the magnetic forces dominate at this height, and the magnetic field is closer to force-free approximation (i.e., Lorentz force being zero) than at the photospheric level. This property makes the chromospheric vector field data very useful for coronal field extrapolations and determination of free magnetic energy in active regions. Further, the flare related changes in the magnetic configuration of solar active regions can be studied more effectively with chromospheric vector magnetograms as the field is more responsive to coronal field changes in comparison to the magnetic field in the lower layers where the field is essentially line-tied to the dense photosphere.

When SOLIS returns to full operations at Big Bear Solar Observatory late in 2019, NISP plans to distribute Quick-Look vector magnetic fields such as those displayed in Figure 6-3. These Quick-Look images use a modified center-of-gravity approach to estimate the field strength, while the inclination and azimuth are calculated using simplified methods such as those based on the weak-field approximation equations. Some very preliminary tests are underway with a NLTE inversion code developed at NSO in collaboration with the Instituto de Astrofisica de Canarias (IAC) able to process Ca II 854.2 nm

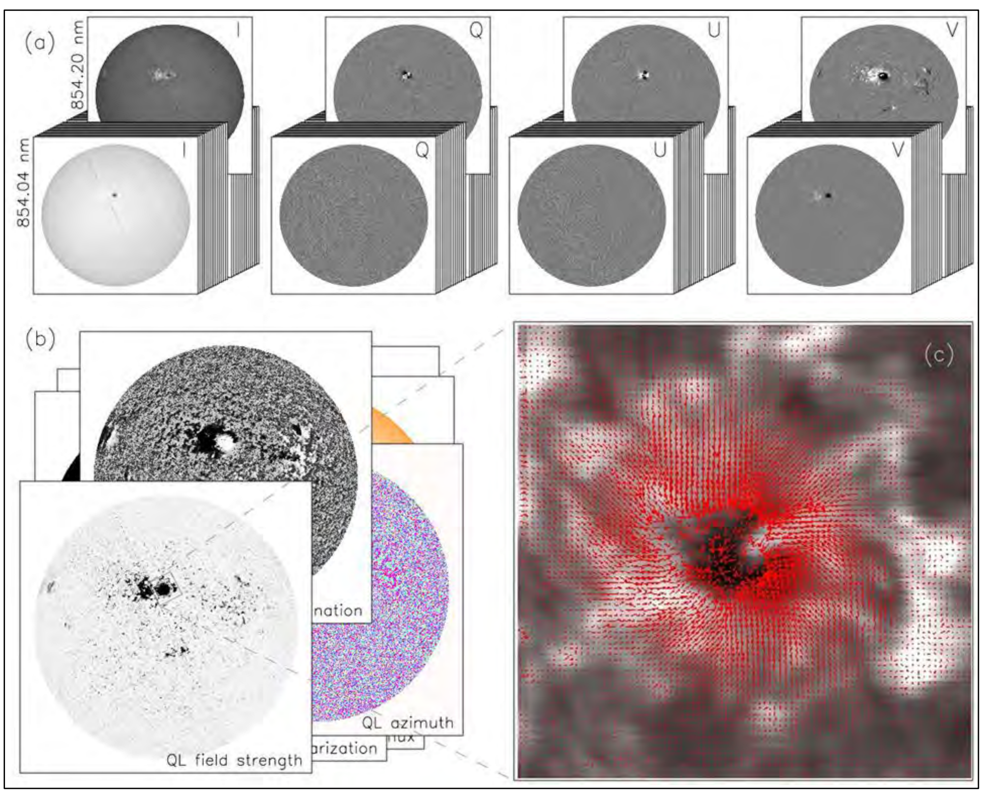


Figure 6-3. Spectral cubes (a) and Quick-Look magnetic field and geometry data products (b) for VSM 854.2 nm vector observations (the examples shown here are for April 13, 2016) are made available to the community to facilitate advances such as the those shown in (c) for a single large sunspot using the NLTE inversion code NICOLE (courtesy S. Gosain and H. Socas-Navarro).

chromospheric data from the full-Stokes spectra. These inversions are an ongoing collaboration between the DKIST Level-2 project at NCSP and NISP. Additional to the chromospheric vector maps resulting from these inversions, other potentially relevant data products that can result from this upgrade are filaments magnetic fields and scattering polarization and Hanle effect determinations of the magnetism of quiet regions.

In collaboration with international colleagues, NISP scientists worked on the creation of a working group on promoting the use of vector field synoptic maps in the modeling of solar and heliospheric phenomena (for research and space weather forecast). The activity of this group aims at bringing together "data providers" (observers) and "data users" (modelers) to discuss various issues related to synoptic vector magnetic fields. While the activity of this group is not directly related to the NISP data-providing activity, the discussions of the data products are beneficial to the program. To date, three working group meetings were organized: first in Oulu, Finland, January 23-25, 2017; the second working meeting was held in Boulder, Colorado, November 6-10, 2017, and the third meeting was held at Max Planck Institute for Solar System Research on September 18-21, 2018, in Göttingen, Germany. NASA partially supported US scientists' participation in the third meeting. The working group plans to have additional meetings in the coming years. The community that participated in this series of workshops will see renewed interest in using and interpreting vector data with the advent of magnetographs that observe outside of the Sun-Earth line-of-sight. Examples are the ESA/NASA Solar Orbiter mission, but potentially also from new instruments at the Lagrange points L5 and/or L4. The combinations of these observations with ground-based observations will help understand the limitations of the radial assumption used to correct longitudinal magnetic field data.

The possible benefits of full-disk magnetogram data observed from the Lagrange points L5, L4 and L3 and combined with the Earth line-of-sight observations, has been an area of research at NISP (Petrie et al., 2018). The study ran a photospheric flux-transport model to simulate the full-surface flux distribution over a full 11-year activity cycle and modeled daily full-disk magnetogram observations from Earth and L3, L4, and L5. From these data, the NISP team constructed synoptic maps, modifying the conventional construction method to allow new data from a given viewpoint to update older data for the same solar location from another perspective. We found that adding observations from each Lagrange point significantly reduces the difference between the synoptic map and the ground-truth flux-transport model field, suggesting ways to improve near-real-time modeling of the solar atmosphere and forecasting space weather. These results are essential in the context of the space opportunities described in Section 6.2.2.

The connections between the use of NISP data and space weather research and forecasting are numerous. Use of GONG data by the space weather community is ubiquitous and the examples are numerous. 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. Because of presentations at the Office of the Federal Coordinator for Meteorology (OFCM), NOAA was directed by the OMB to operationalize GONG space weather data and provide financial support for the operation of GONG. A support agreement between NOAA and the NSF is now in place, with NOAA providing $1M annually for five years (ending in 2021) to SWPC for GONG operations. NISP is working with SWPC to migrate GONG's space weather data-processing pipelines into SWPC's more robust infrastructural environment and is transferring approximately $800K per year to NSO to support operations of the GONG. 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[7] that predicts the magnetic connectivity with the Sun of the Parker Solar Probe mission also has GONG as provider of the necessary boundary data.

Helioseismology research is also helping space weather modeling. NISP produces estimates of the magnetic field on the far side of the Sun that is turned away from the Earth (González Hernández, 2007). These far-side maps provide a signal that new active regions have emerged that will appear on the Earth-facing side up to two weeks in advance, as demonstrated in the appearance of the giant sunspot AR2192. 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, and the STEREO spacecraft move into positions where it is impossible to acquire the data. 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 the errors at the edge of the map that would otherwise contain older data from 28 days earlier. Over the last part of this CA, NISP plans to reinvigorate research on far-side techniques to improve the reliability and understanding of far-side imaging so that it can be used operationally.

Finally, an area where NISP data and research has marked community relevance is in the context of the modeling of the solar polar magnetism. The Sun's polar fields are globally influential. Polar coronal holes dominate the large-scale structure of the corona and channel most of the fast solar wind over most of the solar cycle. However, full-disk synoptic magnetographs lack the spatial resolution and sensitivity to resolve the facular-scale magnetic structure that dominates the high-latitude photospheric vector field. With a view to future applications with high-resolution DKIST data, high-resolution polar vector magnetic field measurements from *Hinode*/SOT-SP were combined with NISP synoptic magnetograms, and their effect on global coronal and modeling was studied (Petrie, 2017). When the polar fields were strongest, the representation of the polar fields was much improved. However, there remained a lack of sensitivity to smaller-scale structure, mainly when the polar field was weak overall, close to its polarity reversal. We anticipate much-improved sensitivity with DKIST. Better regular mapping of the polar fields is one of the main scientific drivers of the new network described in Section 6.2.2.

6.2 The NISP GONG Component

GONG is a six-site network, located in California, Hawaii, 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 also to support critical space weather monitoring and modeling needs. Every minute, 1K×1K 2.5-arcsec pixel velocity, intensity, and magnetic flux images are obtained in the photospheric Ni I 676.7 nm line. The network's duty cycle of approximately 90% enables continuous measurement of local and global helioseismic probes from just below the visible surface to nearly the center of the Sun. Highly sensitive magnetograms averaged over ten minutes, seismic images of the far side of the Sun, and 20-second cadence 2K×2K Hα intensity images are produced in near-real-time.

[7] *https://github.com/dstansby/publication-code/tree/master/2019-psp-connection*.

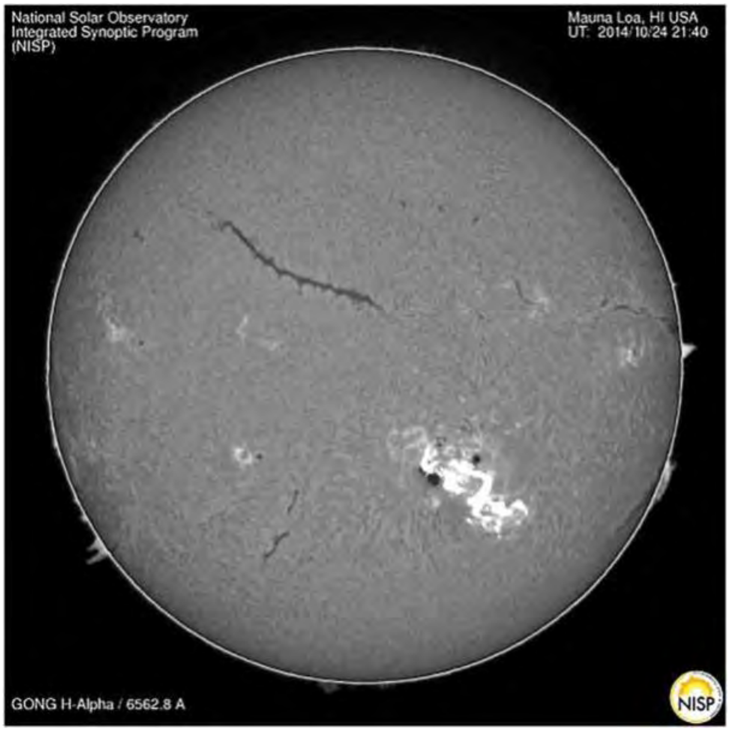


Figure 6-4. Sample Hα image from Mauna Loa at 21:40 UT on 24 October 2014, catching AR 12192 during a flare.

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 6-4) are an increasingly popular data product and have been used to study filaments, flares, and the oscillations of the chromosphere.

The effectiveness of a network is measured by its duty cycle, or fraction of clear-sky observing time achieved during some time period such as a day or month with a duty cycle of one indicating no missing data in that time period. The GONG sites were selected in 1990 after a world-wide survey of 15 locations using a simple instrument that measured the cloud cover at each site. GONG selected the six sites that produced the best network in terms of duty cycle. Note that a good duty cycle for a single site is 0.3, given the daily setting of the Sun and the weather. However, at any given time, two or three GONG sites are observing the Sun simultaneously, increasing the overall network coverage. This improved coverage is critical for the continuity in the measurements required by both helioseismology and space weather monitoring. Figure 6-5 shows a histogram and a cumulative histogram of the daily duty cycle of GONG from its deployment in 1995 to mid-2017. The median daily duty cycle of GONG is 0.91, which is less than what can be achieved from observations from L1, but compares well with near-Earth orbit observatories impacted by eclipses.

The relocation of NISP from Tucson to Boulder included the GONG engineering site. Construction of the new site near the NSO Headquarters was largely carried out during the first quarter of FY18 (see Figure 6-6), with completion of the project and configuration of the two engineering instruments occurring during the second quarter. A first-light image was acquired in April of 2018, and a formal dedication ceremony was held in August. The engineering site is now being used regularly for supporting remote site operations, new initiatives, and the GONG refurbishment project.

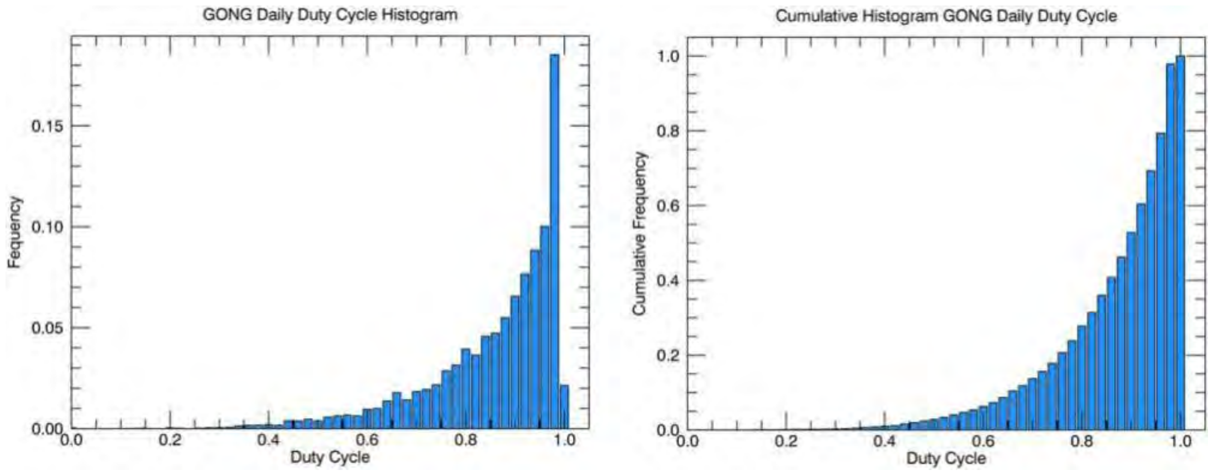


Figure 6-5. Histogram and cumulative histogram of the daily duty cycle of GONG from May 1995 to July 2017. The median daily duty cycle is 0.91.

The GONG network has been operating since 1995, and many instrumental components are aging and becoming increasingly difficult to maintain. Thus, in 2016, the NSF allocated $2.5M to NSO for a multi-year refurbishment of GONG so that it can continue to operate for another 10 to 15 years while its replacement (see Section 6.5) is developed. In consultation with the NSO Users' Committee and community space-weather forecasters, the upgrades listed below are underway; however, progress has been necessarily impacted by the number of large projects being carried out simultaneously with limited staff resources.

- Replacement of 1K × 1K cameras. Following consideration of numerous cameras (including one that was unexpectedly discontinued prior to purchase), proper characterization of the current leading candidate (Emergent HB-1800-S) is underway. Replacing the existing GONG detector will require a mechanical adaptation of the new camera to the rotating mount.
- Improved polarization modulators. Replacement modulators were respectively deployed at the Learmonth and Big Bear sites in the second and third quarters of FY18, and another will be put into operation at the Udaipur site during the first quarter of FY19. The final two (of six) deployments will be coordinated with future site visits.
- Tunable Hα filters. Previous temporary unavailability related to the 2017 total solar eclipse ultimately resulted in the withdrawal of interest on the part of the selected vendor. A subsequent design re-evaluation for greater simplicity and robustness is being carried out, but the feasibility of this upgrade needs careful reassessment shortly. Tuning the existing Hα mica etalons by tiltilng is currently the most promising option.
- Data Center upgrades. Additional nodes for the data storage cluster have been purchased and incorporated. Replacement data processing servers were also acquired and are now in use.
- Refreshed workstations. Consolidated replacements for aging workstations that currently handle Hα and 676.7 nm observations separately have been acquired and are being configured and tested.

- Magnetic zero-point improvements. In addition to modifications already made to the Data Acquisition System at all of the GONG sites to exclude the initial integration frames following modulator transitions, hardware enhancements to allow remote characterization of residual magnetic bias are being pursued, and analysis of the software responsible for zero-point correction in post-processing is underway.
- Additional improvements. Replacement site maintenance kits and restocked spare components have been deployed to the remote sites, and weather station upgrades are being coordinated with future site visits.

Figure 6-6. Alignment of the turret with the instrument mounting plates (left) and enclosure (middle). Completed GONG engineering site in Boulder (right).

6.2.1 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 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 the 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 lead by SWx-TREC/CU-Boulder.

6.2.2 Adapting the GONG Concept for Space Use: The Compact Magnetograph (CMAG)

The Sun is a global and interconnected system whereby events happening at one location can create changes at another place separated by more than half of the solar circumference. Also, coronal mass ejections can be ejected from any solar longitude, which is frequently on the side of the Sun oriented away from the Earth and thus impossible to observe. For these reasons, there is currently considerable interest in providing solar observations from multiple viewpoints in interplanetary space. Three classes of viewpoints are typically considered: out-of-the-ecliptic heliocentric solar polar orbits (e.g., Ulysses, Solar Orbiter); heliocentric drifting orbits close to that of the Earth (e.g., STEREO); or at one of the Lagrangian points where the gravitational fields of the Sun, Earth, and Moon create stable points in space around which spacecraft can orbit (e.g., Solar and Heliospheric Observatory (SOHO); Advanced Composition Explorer (ACE)). One of these points, L5, is located 60° eastward of the Earth's subsolar position, which makes it particularly attractive for space weather observations as it increases the warning time of activity by three days.

A technical challenge for these multi-viewpoint missions is the difficulty of traveling to the viewpoint, such as the large amount of energy required to reach an orbit out of the ecliptic, or at L5. This distance creates a stringent requirement, restricting the mass of the instrumentation for the mission. To help meet the need for light-weight solar instrumentation, NSO/NISP has started a program to develop a compact and light-weight magnetograph for space applications, based on the GONG measurement principle. By replacing the Lyot prefilter and rotating half-wave plate with modern narrow-band filters and liquid-crystal variable retarders (LCVRs), and eliminating the camera rotator, Sanjay Gosain and Jack Harvey have produced a design and a prototype with a mass of around 10 kg, compared to the range of 30 to 70 kg for currently flying space-borne magnetographs. Known as CMAG (Compact Magnetograph), the NISP team has produced a breadboard instrument, which has already obtained test magnetograms.

NSO is working with two groups interested in including CMAG on space missions, both in the Boulder area. One group is led by Tom Woods at the Laboratory for Atmospheric and Space Physics (LASP), and the other is at Southwest Research Institute (SWRI) with Don Hassler as PI. The LASP mission is known as Magnetic Explorer (MagEx) and is a small mission of opportunity that, if selected, would launch along with the Interstellar Mapping and Acceleration Probe (IMAP) to L1, then continue to L5. MagEx would also include a EUV imager/irradiance spectrometer and a flux-gate magnetometer. The proposal for MagEx was submitted in November 2018. The SWRI mission is a Small Explorer (SMEX)-class mission that would travel to the solar poles in an out-of-ecliptic orbit. CMAG would be one of several instruments. The proposal for the SWRI mission is expected to be due in summer 2019.

6.3 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. The ISS can observe any other spectral lines within its operating range.

A potential instrumental upgrade to SOLIS will be the addition of the Visible Tunable Filter (VTF) to the FDP. The VTF was built and tested in May 2014; however, the installation was delayed by the relocation of SOLIS from Kitt Peak to Tucson, repairs of resultant damage to the FDP, and the addition of the 854.2 nm vector modulator to the VSM. The VTF is slated for installation following the final relocation of SOLIS to Big Bear Solar Observatory (BBSO).

In August 2014, SOLIS was temporarily relocated from Kitt Peak to the University of Arizona agricultural campus in preparation for NSO's relocation to Boulder, the divestment of the McMP, and planned instrument upgrades. After consideration of several sites, it was decided to permanently relocate SOLIS to Big Bear Solar Observatory (see Figure 6-7, left). BBSO is an excellent site for the type of synoptic observations acquired by SOLIS; the daytime seeing is excellent and, perhaps more importantly, it is generally stable over the course of the day. BBSO also enjoys a clear daytime fraction of 71%, already hosts a GONG site, and has sufficient internet bandwidth to transfer SOLIS data to the NISP Data Center. BBSO is three hours east of the DKIST site, so SOLIS will be able to supply solar context observations to DKIST in advance of daily operations.

Figure 6-7. An aerial view (left) of Big Bear Solar Observatory indicates the final location of SOLIS relative to the existing GONG site. The NISP engineering team starting the VSM instrument inspection at BBSO in May 2019 (right).

The last day of SOLIS observations in Tucson was October 22, 2017. During the remainder of the first quarter of FY 2018, SOLIS was disassembled, and the Tucson site was restored to its previous state. In the second quarter, SOLIS was delivered to BBSO, Scott Bulau retired from NSO, and Greg Card assumed management of the SOLIS relocation project. As of this writing, construction site plans are being readied for final approval by the County of San Bernardino, following a protracted engineering and permitting process. Selection of a construction company has been formalized; however, a four-month winter moratorium on construction activity near the Big Bear lakeshore began in December 2018.

The relocation of SOLIS to the Big Bear Solar Observatory has been an arduous task as the County of San Bernardino has imposed a number of new regulations and building-permit application processes. At the beginning of the relocation process, very few of these changes were completely understood by the local (Big Bear) consulting engineer who was retained for the project. The structural design process was also hampered by the fact that the structural engineer of record did not perform the necessary tasks and had retired before the design process was completed. NSO retained a new structural engineer in late October 2018. This new engineering firm was able to come up to speed on the project quite quickly and was able to produce first-draft check plans by the first week of January 2019. All structural, civil and architectural details for the new SOLIS site were coordinated and the project filed for land disturbance (grading) permit in late April 2019. In May 2019, NISP sent a technical and scientific team to BBSO to start instrument inspection and preparation (Figure 6-7, right). The SOLIS/VSM has been made operational under an ambient-controlled tent after almost two years of no activity. Successive visits to the site will bring other SOLIS components online before the final move to the new site once the civil construction ends near the lake. Moving forward into late Q3 of FY19, NISP will proceed with obtaining a construction contractor and the building permit. Construction is scheduled to begin in Q4 FY19 and completed the end of Q1 FY20. The entire SOLIS instrument suite is scheduled to be fully operational by mid-to-late Q2 FY20.

AURA and NJIT signed an MOU in June 2018 that describes the long-term operations of SOLIS and the GONG unit at BBSO. The agreement includes NISP funding a total of 1.5 FTEs at BBSO for the combined operations of the two facilities. The viability of such an arrangement will depend on the overall health of the NISP budget.

6.4 NISP Data Center

Between SOLIS and GONG (post-refurbishment), NISP acquires (depending on the observing cadence of the SOLIS/FDP) approximately 370 K – 470 K full-disk observations in an average month. That corresponds to 900 K – 990 K raw data files that are transferred from the remote sites to the NISP Data Center (see Figure 6-8) 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 roughly 10 M – 11 M 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 5 FTEs, two of them working remotely from Tucson.

In addition to the direct observations discussed already, 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 (Figure 6-2), and time series for spectral parameters as well as global and polar mean magnetic fluxes. These data products are essential for understanding the

Figure 6-8. Photos of the NISP Data Center in Boulder showing the data processing server rack (left), the POD in the SPSC Data Center that houses all four NISP racks (middle), and the Isilon data storage cluster rack (right).

Sun, its activity cycle and related space weather, and even the impact of stellar activity on habitable planets.

The final phase of relocating NISP Data Center operations from Tucson to Boulder was completed in FY18. In the first quarter, following the cessation of production operations in Tucson, a subset of the hardware previously in use there was prepared for transport and relocated to Boulder for R&D purposes. Integration and configuration of these auxiliary resources commenced in the background during the remainder of FY18 and are now being actively used for reprocessing, research, and development activities. One major project related to this relocation was the development of the AutoVMBI software package as a replacement for the manually-intensive VMBICAL. This first stage of the fully-calibrated (i.e., not near-real-time) GONG data processing is responsible for the creation of one-minute cadence velocity (V), modulation (M), magnetic field (B), and intensity (I) images from raw GONG data. VMBICAL, and the corresponding manual inspection and rejection of observations with insufficient data quality, historically required a full-time operator. The retirement of the individual previously responsible for this processing prompted the development of the far more automated AutoVMBI, which now nominally accomplishes the same data processing steps with approximately 0.15 FTE of operator interaction.

Significant effort was invested over the past years towards improving the SOLIS/VSM 6302v vector data products. In addition to identifying and addressing a multi-faceted weak-field calibration problem, a more sophisticated scattered light correction was implemented, the inversion algorithm was modified to fit the filling factor simultaneously, and the disambiguation was adjusted to eliminate weak-field artifacts that only became apparent as a result of correcting the previously mentioned calibration issue. With relocation-related activities complete and these improvements in place, a long-anticipated campaign to reprocess the SOLIS/VSM 6302v vector observations is now underway. This will provide for a homogeneous synoptic data set that reflects these improvements as well as the current two-line inversion methodology (see Figure 6-2 and accompanying discussion) based on both the 630.15 nm and 630.25 nm spectral lines (originally, prior to June 2017, only the 630.25 nm line was considered).

Supporting the protracted migration of GONG's near-real-time space weather data processing to NOAA/SWPC continues to be a significant emphasis, as has advanced development of the Virtual Solar Observatory (VSO) node hosted at NSO. Operationalizing the GONG space weather data processing has required retooling for new computing environments; however, progress has predominantly been delayed by backlogged support and repeated procedural changes within the division of NOAA that manages such projects. SWPC and NSO hope that these pipelines will be operational at NOAA by the end of 2019. A comprehensive evaluation of the GONG zero-point software correction pipeline has begun and will extend over FY20. The goals of this effort are to better understand and document the detailed working of this pipeline following the retirement of those most directly involved in its original implementation, identify potential improvements for subtracting residual bias in the magnetic field of both new and archival observations, and incorporate zero-point corrections into the parallel fully-calibrated data processing pipelines.

GONG H-alpha data products were originally only intended for near-real-time space weather monitoring purposes. As such, the archived data has received little attention beyond ensuring its safekeeping and availability. However, as these data have become increasingly used for research purposes, corresponding emphasis is being placed on them as a curated archival data set. This includes assessing the utility of the metadata provided in the FITS headers and reprocessing select subsets to eliminate known discrepancies. For example, observations from the Learmonth site were originally only fully processed at a five-minute cadence due to data transfer bandwidth constraints in place during 2011-2014, and completion of the processing of those intermediate data products is now being carried out for consistency.

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.

6.4.1 Access to NISP and Legacy NSO Data: The NSO Digital Library and the Virtual Solar Observatory

In addition to its dedicated telescopes, the NISP Data Center operates the NSO Digital Library that provides historical synoptic data sets to the research community. Current NSO Digital Library archives include 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, and solar activity indices. In addition, 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 H-alpha, far-side, and magnetic-field products.

The near-real-time products are automatically disseminated to various agencies, including the US Air Force 557th Weather Wing (previously known as AFWA), AFRL, NOAA/SWPC, the United Kingdom Meterological Bureau, and NorthWest Research Associates (NWRA) for space weather prediction applications. The SOLIS data archive includes the VSM, ISS and FDP. In 2018, about 60 TB of combined NISP and Digital Library data were exported to over 1,300 users. We also host some non-NSO data sets such as the Mt. Wilson Ca K synoptic maps, the AFRL Air Force Data Assimilative Photospheric flux Transport (ADAPT) magnetic field forecasts and forecasts of the F10.7-cm flux and EUV flux. Historical data, particularly eclipse images dating back to 1869, are also now available. The Digital Library also hosts the data sets from the DST Service Mode observing runs.

Since the inception of the Digital Library in May 1998, more than 5000 TB of science data files have been distributed to the user community. These figures exclude any NSO or NOAO staff members. The holdings of the NSO Digital Library are currently stored on a set of disk arrays and are searchable via a Web-based interface to a relational database. The current storage system has 800 TB of on-line storage. The Digital Library is an important component of the Virtual Solar Observatory.

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

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

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

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

NSO is promoting the definition and design of a new global network that replaces GONG and SOLIS as both facilities are more than 20 years old and as new requirements for synoptic solar observations arise. There is a strong interest for a new solar synoptic network within the space weather research and forecasting agencies in the US, but also within the broader international solar community. In Europe, the Kiepenheuer Institute for Solar Physics (KIS, Germany) has led a proposal to the European Union (EU) for the definition of the Solar Physics Research Integrated Network Group (SPRING) that has involved the active participation of NSO (Gosain et al., 2018). The SPRING effort is ongoing and is part of the existing SOLARNET program that coordinates solar physics efforts in Europe. Our European colleagues expect additional funding opportunities that can be used to further the SPRING concept in the coming years. In the US, and after an initial request from the AFRL expressing interest in a new solar network able to accommodate requirements for improved space weather forecasting, the NSO and the High-

Altitude Observatory (HAO) jointly submitted a proposal to the NSF. This joint proposal described a network that incorporates the space weather requirements from the AFRL and additional research-driven scientific objectives common to SPRING. The NSO and HAO Step-1 proposal[8] was submitted to the NSF in February of 2019 but was not invited for the Step-2 phase. In spite of this setback, NSO firmly believes that there is sufficient community interest and pressure for a new, more capable network encompassing both the research and operations communities. Thus, NSO will consider, over the next five years, new opportunities to consolidate the requirements for a next generation Global Observatory Network Group (ngGONG) in close collaboration with interested partners, starting with the needs from the forecasting community and complementing the network with relevant research opportunities demanded by the community. ngGONG will be the first solar synoptic network designed to consider, from initial conception, operationally-driven requirements established by the space weather forecasting community, but also enables new research opportunities that build on decades-long observations from the NSO of the global Sun and its magnetic environment.

The proposed network consists of a set of six fully-instrumented observing stations distributed around the world. Similar to its predecessor, 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 spectro-polarimeter; visible-infrared tunable filter spectro-polarimeter; helioseismic doppler imager; and two coronagraphs: internally- and externally-occulted. This approach has been adequately demonstrated to succeed with existing solar networks, both research and operational. ngGONG incorporates heritage and elements from a number of existing and planned operational networks: the extant Global Oscillation Network Group operated by NSO; the conceptual design developed for the European Union-led activity SPRING; and requirements identified by the US Air Force Research Laboratory for solar observations essential for future space weather modeling and forecasting. Together, these stations will provide a set of observations of the solar disk and corona to facilitate research into the origins and evolution of the solar magnetic field, including its topology and eruption from the Sun.

By joining efforts in the US, Europe, and elsewhere, ngGONG will be an international effort that builds on our experience with GONG and incorporates the US expertise with that of other countries that operate synoptic programs. Once operational, ngGONG will:

- Measure the boundary data that propagate the magnetic connectivity from the solar surface into the heliosphere;
- Map the 3D magnetic topology of solar erupting structures in the chromosphere and corona, increasing advanced warning of space weather events from hours to days;
- Anticipate processes in the solar interior and the far side that impact heliospheric conditions; and
- Provide context for high-resolution observations of the Sun as well as for in situ single-point measurements throughout the heliosphere.

The science case for a new synoptic network is described in a white paper submitted to the ASTRO2020 Decadal survey.[9]

[8] This proposal was named as Ground-Based Solar Observations Network (GBSON).
[9] *https://arxiv.org/ftp/arxiv/papers/1903/1903.06944.pdf*

The proposed ngGONG has to provide as a novel prime target the boundary data needed to forecast the direction of the magnetic field of a CME when it interacts with the Earth's magnetosphere. This direction is a key determinant of the effectiveness of the CME in creating geomagnetic storms. But we lack routine forecast of the magnetic field of a propagating CME at 1 AU. GONG radial magnetic field measurements are used as boundary conditions to feed heliospheric models (such as the Wang–Sheeley–Arge/Enlil model) that produce a prediction of the relatively smooth solar wind conditions, including the magnetic field, at 1 AU. However, existing models that forecast CME properties, such as arrival time, do not predict magnetic field orientations partly because there are currently no suitable measurements of magnetic fields in the filaments that comprise the cores of CMEs. By regularly observing the He I 1083 nm spectral region, ngGONG will fill this gap and provide synoptic observations of the vector magnetic field observed in the massive 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 Lagrangian 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). Producing the observations that can help solve these erroneous inferences has been a major driver for the SPRING concept. 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, a technique ngGONG will continue by using an upgraded replica of the GONG measurements. Far-side maps are now routinely used in coronal and heliospheric models and have improved their diagnostic capability for space weather forecasts (Lindsey & Braun, 2017). Since the sensitivity in these maps depends on accurate and precise measurements of the phase shift between acoustic waves in the solar atmosphere, the improved understanding of phase shift from multi-height observations may well reduce the noise in far-side maps, therefore enhancing the detectability of weaker active regions. While this area remains to be explored, the simple averaging of two or three maps from different spectral lines should, by itself, reduce the noise in the maps.

6.5.1 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).
- Relaxation of stringent scientific requirements for space weather forecast data.
- 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 would be devoted to carrying out delta conceptual design activities for the AFRL requirements, starting the coronal site survey, carrying out trade studies, and researching vendor options. Year 2 will culminate in the Preliminary Design Review, and Year 3 will produce the Final Design Review and a detailed construction proposal.

Figure 6-9. 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.

Based on the experience of GONG, six sites are sufficient to provide solar observations with median daily temporal coverage of 91%. However, GONG sites were selected on the basis of helioseismology requirements that were primarily driven by the total amount of clear observing time at a site. ngGONG has somewhat more stringent requirements for atmospheric stability (driven by the need to observe small magnetic features), and low sky brightness (driven by the coronal observations). In addition, the US Air Force has other requirements concerning security and personnel that will need to be satisfied. It is thus possible that ngGONG will consist of six or more sites, but not all sites will necessarily have the same set of instrumentation depending on site characteristics. The most difficult requirement to meet is that of coronal sky brightness, so a dedicated site survey for that requirement will be needed.

To provide the required increased magnetic field sensitivity compared to GONG, it is estimated that a telescope with a 50-cm aperture is required. A conceptual design is based on that of the European Solar Telescope and has the advantages that it is polarization-free and compensates for image rotation. The telescope will feed a stable optical bench that carries the infrared slit spectro-polarimeter and the helioseismic Doppler imager. In addition to this telescope, the two coronagraphs each require direct sunlight. The visible-infrared tunable filter spectro-polarimeter also needs a dedicated light feed because it overlaps in spectral range with the infrared slit spectro-polarimeter. 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 6-9) in order to avoid as much as possible ground turbulence boundary layer; this height will be determined in a trade study with a ground-layer adaptive optics system.

One aspect that remains to be developed is the requirement from the USAF for 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. However, for a robust and reliable operation of a large suite of sophisticated instruments, automation of the observatory is 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 spectro-polarimeter (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 is likely not possible 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.

7 NSO COMMUNITY SCIENCE PROGRAM (NCSP)

Traditionally, the NSO program has been conducted in two almost separate branches, with the synoptic part centered around GONG and SOLIS in NISP, and the high-resolution efforts centered around first 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, 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, with possible extension of a second year with the same amount. This Strategic Initiative is described in more detail below (Section 7.1).

This Chapter addresses Goals 3 and 4 and Activities 7, 10, and 16 described in Section 2.2.

7.1 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 have to be derived from (Level-1 calibrated) observations of the solar spectrum and its state of polarization with so-called spectro-polarimetric inversions.

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

- Data Products Initiative: Identify a limited, but generally relevant, set of Level-2 data products that NSO will generate and distribute through the DKIST Data Center. These Level-2 data products will correspond to specific, well-defined observing modes of selected DKIST instruments. The NSO will strive to make these tools efficient in dealing with large volumes of data, and intuitive enough for a large fraction of the community to take part in. However, the effort will concentrate first at NSO. This initiative will also establish the hardware capabilities at the NSO to provide support for the inversions described here.
- University Focused Initiative: Establish a graduate student support program for US universities with existing solar research faculty. The series of Critical Science Plan (CSP)

Workshops has demonstrated a clear desire of the US university solar community to receive training and guidance in the generation of various Level-2 data products. This program will combine both the interest of the local faculty members and of existing DKIST Science Use Cases (SUCs) contained in the CSP. This effort will grow the workforce able to run the inversions in scientifically competitive ways. It will also provide—to the extent possible—hardware capabilities for the inversions required by the graduate students' research.

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

Sections 7.1.1 through 7.1.3 describe each of these initiatives in more detail.

7.1.1 Routine Inversion Pipeline Development

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

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

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

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

4. Basic coronal parameters from single-line full Stokes spectro-polarimetry. Spectral lines candidates for this type of analysis are Fe XIII 1074.7 nm, Si X 1430 nm, Si IX 3925 nm,

and perhaps He I 1083 nm. Except for the Si IX line, which can only be observed with Cryo-NIRSP, all of these lines are accessible with both the Cryo-NIRSP and the DL-NIRSP. The proposed analysis consists of three main products: 1) Gaussian fit to the Stokes I profiles providing peak intensities, thermal and non-thermal doppler broadenings, and LOS velocities; 2) the azimuth of the magnetic field vector projected on the plane of the sky using the standard derivation from the ratio of Stokes Q and U; and 3) the LOS magnetic field strength from the weak field approximation and/or Eq (14) of Plowman (2014) that includes the effect of atomic alignment. The DKIST Level-2 initiative will consider other, more elaborated, coronal data products (such as the permitted/forbidden line pair technique of Dima et al., 2016) but their feasibility can only be ascertained after some example data have been acquired with the Cryo-NIRSP instrument.

Figure 7-1. 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).

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. In agreement with the CU Boulder High-Performance Computing Facility (HPCF), these machines will be managed by HPCF at no cost to NSO. The first machine is already available at the CU Boulder Office of IT since April 2019 (see Figure 7-1).

7.1.2 DKIST Ambassador Program

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

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

The recipients of the matching-fund subcontracts will be called "DKIST Ambassadors", with the understanding that they will help to bring the expertise they acquire in their programs to their host institutions to broaden the base of US solar scientists skilled in using the unprecedented volume and quality of DKIST data to its full potential. After reviewing the applications, twelve students/postdocs have been selected to become Ambassadors (see Table 7-1).

Table 7-1. 2019 DKIST Ambassadors

Name	Institution	Supervisor
Momchil Molnar	Colorado University	Kevin Reardon
Ryan Hofmann	Colorado University	Kevin Reardon
Shah Bahauddin	Colorado University	Mark Rast
TBD	Colorado University	Maria Kazachenko
Shuo Wang	New Mexico State Univ.	James McAteer
Aparna V.	Georgia State University	Piet Martens
Bradley Cox	George Mason Univ.	Jie Zhang
Suman Dhakal	George Mason Univ.	Jie Zhang
Grad Student	Michigan University	Enrico Landi
Alyssa Derks	Montana State Univ.	Dana Loncope
Grad Student	Univ. of Alabama	Qiang Hu
Grad student	Univ. Hawaii	Xudong Sun

7.1.3 DKIST Data-Use Workshops

A second prong in the effort to prepare the US solar community for the DKIST era will be the organization of a number of data-training workshops. These will 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 fully exploit the DKIST potential. As the activity is mostly preparatory, we will take 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 will be 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/*) will take place on June 4 - 9, 2019 in Boulder. We expect 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.

7.2 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 magnetohydrodynamics, 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.

7.2.1 Applying Machine Learning to Level-2 Production

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

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

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

7.2.2 Forward Modeling Data Bases

Our understanding of the physical processes that govern an astrophysical body in general, and the solar atmosphere in particular, is ultimately 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.

8 EDUCATION AND PUBLIC OUTREACH (EPO)

NSO has hired two Education and Public Outreach (EPO) officers since 2016. The Head of Education and Outreach is based at Boulder Headquarters and is responsible for the overall implementation of all EPO programming, as well as representing the interests and mission of NSO nationwide. NSO's Education and Community Liaison Officer is located in Hawaiʻi and is chiefly responsible for NSO's formal education (K-12) programming, in addition to developing and nurturing relationships with educators, community members, and stakeholders in Maui and across the State of Hawaiʻi.

8.1 NSO EPO Accomplishments

Some of the accomplishments achieved since the establishment of the EPO office include:

- Citizen CATE eclipse program success in 2017.
- Solar Eclipse Webinars produced and positively received.
- NSO website redesigned.
- Interfacing with policy makers on Capitol Hill.
- Journey to the Sun (JTTS) teacher workshop and telescope program launched.
- Public outreach in Hawaiʻi building positive interaction with Maui community.
- Two-week Spectropolarimetry Graduate Fall School successfully planned and implemented.

8.1.1 Citizen CATE 2017

Supporting the 2017 Citizen CATE Total Solar Eclipse Project in which members of the public used donated telescopes to observe and record data from the 2017 solar eclipse. Observers included scientists, high school students, and educators. The Citizen Continental-America Telescopic Eclipse (CATE) Experiment monitored the outer atmosphere of the Sun, the corona, using a network of 68 identical telescopes located at various places along the path of totality. The individual high-quality images taken during the approximate two minutes of totality at each site are being combined to create an uninterrupted 93-minute sequence of the inner solar corona. Each of the volunteer groups were trained via a set of 11 workshops run at locations across the country. CATE 2017 was funded with support from a combination of federal, corporate and private sources including the National Science Foundation.

CATE data sampled the region around the Sun at wavelengths between 480 nm and 680 nm. With 1.5 arcsec pixels, the transverse velocity sensitivity of the CATE data will be roughly from 1-150 km/s. CATE sites collected a sequence of eight exposures from 0.4 milliseconds up to 1.3-sec duration. These exposures will be used to produce one high-dynamic-range image every 2.1 seconds. The expected signal to noise should allow brightness fluctuations of about 5% to be detected. The initial science goal is to measure the solar wind velocity and acceleration in polar plumes as the wind accelerates from 1 to 100 km/s in the CATE field-of-view. However, many other scientific results are anticipated.

The CATE site volunteer group was made up of 270 volunteers, 117 of those were students. They each traveled from their home locations to the path of totality on their own, with no financial support from the project. Of the 68 CATE sites, volunteers from 67 successfully traveled to the agreed upon observing locations; the only exception was the volunteer group for Site 22. This group observed from a location very close to Site 21 instead of traveling halfway between Sites 21 and 23. This group successfully collected eclipse data at this different location.

In 2017, up to August 14, CATE groups were featured in more than 60 newspapers, radio and TV programs (see #60DaysOfCitizenCATE social media campaign below). These are archived with a description and a link at: *https://sites.google.com/site/citizencateexperiment/cate-media*. An automated search of the internet news for stories about the CATE project has found over 200 links and it can be found here: *http://eclipse2017.nso.edu/citizen-cate/citizen-cate-news/*. A large number of people were impacted with CATE stories in the, *NY Times* the *LA Times*, the *Washington Post*, the *Seattle Times*, *Sky & Telescope* magazine, National Public Radio (NPR) and Science Friday on Public Radio International (PRI). The CATE project was featured in the June 21, 2017 NASA press conference and the July 21 NSF press conference. We guess that several million people were exposed to information about the CATE experiment through these media stories.

For other CATE events that were held before the August 21, 2017 eclipse, the project impacted:

- 17,077 adults reached through conference presentations, public events, information booths at public events (like local farmer's market), presentations to teachers/educators, science lunches at universities, etc.
- 7,400 K-12 students reached through summer camp activities, library presentations, school science nights, STEM clubs, Jr. Ranger Club, family science nights, planetarium talks, public events.
- Approximately 90,000 adults and children reached through large public events including information booths at music and cultural festivals, Eclipse Expos, Eclipse Fests.

Estimations of the number of people that CATE impacted on the day of the eclipse are more difficult to produce, as CATE was part of many larger eclipse programs. For several of the 22 CATE high schools, the CATE project inspired the schools to host larger eclipse events and engage more students in viewing the eclipse: we estimate the CATE impact here to be 20,000 students. At college campuses where CATE teams took data, some in large stadiums, the project again instigated the development of larger events. A very rough estimate is that 100,000 people were impacted by some way from the CATE project held on several college campuses. In small towns across the path of totality, the CATE project inspired local events, such as in Weiser, Idaho and McKay, Idaho. Estimates from those two towns alone suggest 70,000 visitors on the day of the eclipse, and so conservatively we guess that CATE impacted about 300,000 people in small towns across the path of totality.

The media impact is difficult to determine too. CATE was part of the NASA Edge live television events and also the live CBS news show eclipse program. Discovery did a program following one CATE group (Site 32), and Sky News live from the UK did interviews. Many other local TV and radio affiliates were involved in broadcasting eclipse programs, and CATE was a part of many of these. Estimates in the USA are that 134 million viewers watched TV and internet broadcasts, and likely CATE was involved in at least half of those. For world-wide estimates, one group suggests 600 million viewers, and again CATE was likely included in about half of those.

8.1.2 Solar Eclipse Webinars

Following the 2017 AAS Eclipse Taskforce meeting in Carbondale, Illinois, it became clear that there was a lack of scientific understanding of solar science and the eclipse amongst eclipse event coordinators. In order to address this need, NSO produced a monthly webcast preparing for the eclipse.

Each month covered three topics:

1. Solar Spotlight: What do you really need to know about the Sun to understand what's happening during the eclipse?
2. Eclipse Tips: Learn about some fun ideas to engage kids (and adults!) in eclipse fun, fitting for the run up to eclipse day, and also for the main event!
3. Straight from the Scientists: Learn about cutting edge research being done in the field of solar science, straight from the researchers!

The topics covered each month are shown in Table 8-1, which includes science focus, activity demonstrated, invited speaker and YouTube views as of May 2019.

The webcasts exist in their full ~30-minute format on the NSO YouTube page (*www.youtube.com/nationalsolarobservatory*), as well as each segment (approximately five minutes) broken out separately, allowing viewers to watch the elements most relevant to them.

Table 8-1. Eclipse Webcast Topics, Invited Speaker, Science Focus and YouTube Views as of May 2019

Solar Spotlight	Views	Eclipse Tips	Views	Straight from the Scientists	Views	Entire Webinar	Total Views on This Topic
The Sun as a Star	87	Sun-Earth Scale Model	112	Adam Kowalski (NSO/CU)	83	1,130	1,402
Layers of the Sun	443	Build Your Own Eclipse	238	Frank Hill (NSO)	120	725	1,526
The Sun is Magnetic	152	Mapping Magnetic Fields	68	Gianna Cauzzi (NSO)	81	509	810
Introducing Solar Activity	54	CME Slingshot	96	Alex Young (NASA)	61	296	507
Observing the Solar Eclipse	105	Make a Pinhole Viewer	107,908	Shadia Habbal (UH)	187	532	108,733
Using eclipses to Prove General	40	Build Your Own Coronagraph	646	Laurent Pueyo (STSci)	73	512	1,271
Mapping Solar Eclipses	502	Yardstick Eclipse (ASP)	308	Michael Zeilier (Great American Eclipse.com) & Xavier Jubier (Interactive Eclipse Mapper)	224	541	1,575
The Sun's Effect on Earth	182	The Energy Game	132	Robert Steenburgh (NOAA/SWPC)	68	168	550
What to Expect on Eclipse Day	N/A	Viewing the Eclipse Safely	N/A	Rick Feinberg (AAS)	N/A	252	252

8.1.3 NSO Website Redesign

With the operationalization of DKIST immanent, the eyes of the solar physics community, the general public, and policy makers will turn to NSO. In order to provide the best outward facing interface with these audiences, the EPO group has led the redesign of the NSO (including DKIST and NISP) website. The existing NSO website was difficult to navigate and not public friendly. We embarked on a mission to simplify the website and make it more intuitive for non-expert visitors, and provide a forum from which the world can learn about DKIST, NSO, and our other programs. The new website was launched in September 2018 and will continue to be honed early into 2019 in preparation for DKIST first light.

In addition to more intuitive layout and more readable pages, we focused on the efforts of the people at NSO. In response to the request for career advice, we have developed a searchable staff page which includes photos of staff and a short biography explaining their career path and role at the Observatory. We continue to work with staff to complete this section, but we are focused on increasing the visibility of important roles previously taken for granted.

In addition, we have launched an NSO Blog site. This page is a mechanism for NSO staff to share their work and achievements in a high-level, accessible way with the general public.

During FY19, we anticipate the new website will become more valuable with DKIST engineering first light expected towards the end of the fiscal year. In particular, the blog will be leveraged to increase awareness of both the technical advancements, and the people behind the project.

8.1.4 Interfacing with Capitol Hill

The EPO Lead has participated in activities on Capitol Hill, including visits with Congress and Senate leaders, including:

1. In 2017, NSO was invited to represent the American Astronomical Society (AAS) at the Coalition for National Science Funding (CNSF) conference in the Rayburn House Building on May 16, 2017 during which time NSO delegates interacted with staffers, members of Congress and the Director of NSF, Dr. France Cordova. In conjunction with this visit, NSO and AAS delegates met with staffers from a number of senate and representatives' offices. Those of particular interest to NSO are Senator Brian Schatz (D-HI), Representative Ed Perlmutter (D-CO), Representative Jarid Polis (D-CO).
2. Following the 2017 eclipse, NSO scientist Dr. Matt Penn and AURA Executive Vice President Dr. Heidi Hammel were invited to testify at the House of Representatives' Subcommittees on Research and Technology and Space held a Hearing on "The Great American Eclipse: To Totality and Beyond". The focus of the hearing was on safety, science, public engagement, and preparation for the future. Dr. Matt Penn, an NSO tenured astronomer, testified on behalf of NSO with a focus on Citizen CATE. Dr. Heidi Hammel, Executive Vice President for AURA—NSO's management organization—spoke of NSO's work in educating the general public on the scientific elements of the eclipse.

Figure 8-1. Dr. Hammel (left) and Dr. Penn testifying during the House Hearing on "The Great American Eclipse: To Totality and Beyond".

3. On October 23, 2017, NSO received a visit from Ms. Leslie Albright, staff member of the Commerce, Justice, Science (CJS) subcommittee of the House Appropriations Committee. She has been working on the science issues of the bill (NASA, NSF, and Office of Science and Technology Policy (OSTP)) since Representative John Culberson became the Chairman of the CJS subcommittee (January 2015). Prior to that, she worked on the Commerce Department budget for CJS. She has also worked on the committee in other capacities and worked at the Department of Commerce budget office. During the 1.5-hour visit, the NSO Director presented some early results from the Citizen CATE campaign, the current on-budget and on-time status of DKIST, the importance of DKIST for understanding the fundamental processes involved in space weather, and how the NSO GONG network is integrating into NOAA's Space Weather Prediction Center. Following the conversation, the DKIST Project Manager led a tour of the optical clean rooms, demonstrating the talent and prowess of the DKIST engineering teams in pushing technology to the limit in order to provide excellence in the acquisition of scientific data.

8.1.5 Journey to the Sun (JTTS) Teacher Workshop and Telescope Program

Using a gift of $20,000 from Sting, the performer, NSO has purchased and donated portable solar telescopes for every public middle school in Maui County (including the islands of Maui, Lānaʻi and Molokaʻi). Leveraging this donation, we have assembled a curriculum designed to teach middle school science standards through topics in modern solar astronomy. Both the curriculum and the personal solar telescopes work to engage students in modern-day observations and scientific practices in a culturally responsive way.

Figure 8-2. Teachers working with NSO scientist Dr. Sarah Jaeggli at the Journey to the Sun Workshop.

The set of six classroom lessons were developed in part by adapting existing resources and by creating new content especially for this program. They have been developed primarily for middle school students of Maui County, using principles in place-based education and culturally responsive teaching practices.

Prior to their dissemination, lessons and activities from the curriculum were piloted by two local educators. The educators provided valuable feedback, which NSO used to make revisions and improvements.

To facilitate the adoption of the Journey to the Sun curriculum in schools, and to begin the process of building a relationship with local science teachers, NSO's education team partnered with the Maui Economic Development Board to host a professional development workshop in spring 2018. All Maui county (Maui, Lānaʻi, and Molokaʻi) public middle schools were represented in Journey to the Sun's 2018 cohort of educators. The cohort is made up of 13 science educators, including a teacher from *ʻO Hina I Ka Malama*, a Hawaiian Immersion program within Molokaʻi Middle School. At the workshop, teachers explored the activities and received lectures on the content covered in the curriculum. In addition, they were trained on how to use the solar telescopes, and were given the opportunity to discuss topics in solar physics and technology with solar experts and educator peers.

The feedback received from the exit surveys administered at the end of the workshop show an overall rating of 4.8 out of 5. All teachers reported an increase in their comfort level with teaching solar science content. Included on the surveys were comments such as "*Mahalo nui* for the wonderful opportunity and support"; "Loved all the lesson plans!"; "The explanations were clear and very well presented"; "It was wonderful. *Mahalo*!"

8.1.6 Public Outreach in Hawaiʻi

8.1.6.1 The University of Hawaiʻiʻs Institute for Astronomy (UH IfA)

As of November 2018, we have attended three Astro Days on the Big Island of Hawaiʻi, all of which were organized by the University of Hawai'i's Institute for Astronomy. In addition, NSO/DKIST participates annually in IfA-Maui's Open House, providing a booth and interaction with the general public, informing them of DKIST's goals and objectives. These were very successful with attendance reaching thousands.

NSO has also partnered with IfA and Las Cumbres Observatory in delivering a Haleakalā Observatories field trip experience to students from two of Maui County's most remote and isolated communities: Molokaʻi Elementary and Hana High and Elementary students. During the field trips, students toured the Haleakalā Observatories site, specifically the Faulkes Telescope. They also had the opportunity to view DKIST, speak with NSO astronomers, make H-alpha solar observations, and conduct solar experiments.

8.1.6.2 Kamehameha Schools (KS) Paukukalo Preschool

NSO, in collaboration with KS *kumus* (teachers), planned and organized solar science activities for local keiki. Students and teachers alike were fascinated at observing the sun through our Personal Solar Telescope, the same make and model that was donated to Maui county public schools through the Journey to the Sun program. *Kumus* expressed deep gratitude for this unique opportunity. Likewise, NSO is fortunate to have been so warmly welcomed by the school community to engage teachers and students.

Kumus were provided with solar science content and education as it related to the activities. With this, they translated the material and provided solar education to their students in an age-appropriate way, geared towards young learners. Preschool and pre-kindergarten students learned about the movements of the Earth and our Sun as they witnessed a solar image moving out of the telescope's field of view. They experimented with different forms of light energy as they created UV beadwork. Students also learned about magnetism as it relates to the force behind the magnets that they're familiar with, and to the Sun's magnetic fields.

Figure 8-3. Children at the Kamehameha Schools Paukukalo Preschool Kindergarten learning about the Sun from their teacher during a visit by the NSO EPO Officer to their school.

8.1.6.3 *Hui No'eau* Visual Arts Center

NSO has participated in the *Hui No'eau* Visual Arts Center's summer youth program to engage their participants in solar science through STEAM (Science, Technology, Education, Arts, and Mathematics) education. EPO staff engaged students in a solar science STEAM art project, and solar viewing through an H-alpha telescope. This collaboration with *Hui No'eau* has since led to an outreach partnership to include the "My Sun, My Star" 2018 Art Contest.

8.1.6.4 Maui Economic Development Board (MEDB)

Women in Technology is a Hawaii statewide workforce initiative of MEDB. NSO has contributed to the following MEDB partnered events: Patsy T. Mink Summit, Hawaiʻi World of Work (WOW) Week, and the Advanced Maui Optical and Space Surveillance Technologies (AMOS) Space Exploration Day event.

Figure 8-4. NSO Outreach Officer Tishanna Ben presenting during the Nepris-hosted Hawaiʻi WOW week.

Figure 8-5. Students explore thermal control systems during an outreach event.

The Maui Patsy T. Mink Summit empowers girls from Maui County and introduces them to careers and industry partners. At the event, NSO led two STEM sessions and activities. Hawaiʻi WOW week was geared towards Hawaiʻi K-12 students. NSO staff led three "Industry Chats" virtually via the online platform Nepris. At the AMOS Space Exploration event, MEDB hosts over 100 Maui STEM students and teachers. The students experience space related presentations and activities by exhibitors.

8.1.6.5 Girl Scouts of Hawaiʻi

NSO has participated in Girl Scouts STEM fest on the island of Hawaiʻi. Girl Scouts experienced STEM presentations and activities led by NSO.

8.1.7 Spectropolarimetry Graduate Fall School

NSO EPO staff and scientists partnered with the National Center for Atmospheric Research (NCAR) Advanced Study Program and High Altitude Observatory (HAO) to run the first Spectropolarimetry School for graduate students and early career researchers. This two-week immersive school was held in Estes Park, Colorado and hosted 28 graduate students and postdoctoral fellows. The content focused on understanding and using inversion techniques for use in the DKIST era. NSO's EPO team contributed considerable facilitation support in order to ensure good pedagogical methods were implemented, and participants received an effective experience. We also developed and analyzed both formative and summative evaluation instruments for this endeavor, using a pre-post self-reporting survey, and daily course evaluations and feedback forms. This has resulted in a wealth of information on the effectiveness of the school and its instructors. Using a pre-post self-reflection instrument, we established that participants increased their knowledge and comfort, on average, by 3.8/10 points. The largest gains were obtained in how to use spectro-polarimetric data (6/10-point increase) and how to use the inversion codes (5.3/10-point increase). These gains are in line with the objective of the workshop.

Figure 8-6. *Participants at the Spectropolarimetry Graduate Fall School learn about polarization.*

The NSO EPO team also recorded all of the lectures during the course with a view to hosting them online. Given how critical spectropolarimetry is to DKIST, proving a wide range of educational resources to the US community is essential. Not only will participants be able to return to these lectures at a future date to reiterate or refresh their understanding, but others who could not attend the school will now have access to the materials covered. Nothing can replace the value of in-person attendance, but this can be a starting point for future participants.

8.2 NSO EPO Priorities for FY 2019 – FY 2024

The overarching EPO goals for the next five years are:

1. Have NSO recognized as a community-facing organization that is in support of education and community, especially in Hawaiʻi.
2. Grow and maintain authentic relationships with members of our target audiences. These relationships will be rooted in education and engagement best practices that support both the needs of NSO, and the communities in which NSO is based.
3. Work towards NSO being recognized as a nationwide leader in science engagement and education.

8.2.1 Formal Education

Following on from the successful launch of the "Journey to the Sun" teacher education program launched in 2018, the NSO EPO team will continue to develop the existing relationships with Maui teachers and grow the program to encompass State-wide educators. During the inaugural 2018 workshop, every publicly funded Maui County (Maui, Lanaʻi and Molokaʻi) middle school was represented. Although the initial response from participants was enthusiastic, we will continue to work closely with teachers to support the implementation of our customized, place-based solar science curriculum in their classroom. Maintaining a constant and reliable interface with local educators will help us to achieve goal #1 above: "Have NSO recognized as a community-facing organization that is in support of education and community, especially in Hawaiʻi."

Figure 8-7. *First Journey to the Sun cohort with their telescopes.*

We will continue to implement our Journey to the Sun program annually in the fall, with the program growing and adapting each year. Starting with the second iteration, planned for fall 2019, we will be implementing a two-stage workshop. The first stage will be for new participants around the state who wish to be introduced to the curriculum and solar science content. The second stage will be a follow-on workshop for existing participants who wish to renew and improve their understanding of the content. We will also continue to adapt the lessons we are distributing as we get ongoing feedback from users.

The first set of adaptations planned are to provide a series of short, isolated lessons (20–30 minutes in length) that can be implemented in isolation, as a "teaser" for the more intensive lesson series. These will also act as tester lessons for new teachers who are not yet comfortable with the more intensive content.

In addition to our formal education professional development in Hawai'i, we will explore the opportunity to provide teacher professional development out of our Boulder offices and identify ways to continue to support educators through in-person and virtual mechanisms as we can.

8.2.2 Engaging Students in NSO Research

Students across all levels of their education represent the next generation of solar astronomers. One mechanism for engaging K-16 students in the solar astrophysics field is to provide opportunities for students to engage in the scientific process through research. NSO has a long legacy of student engagement through the Research Experience for Undergraduates (REU) and Summer Research Assistant (SRA) programs. In recent years, the needs of students and the priorities for NSF have shifted, and NSO has responded accordingly.

8.2.2.1. Research Experience for Undergraduates

NSO has a long legacy of student participation in research, which we aspire to maintain. NSO is a current partner in the NSF-funded "Boulder Solar Alliance Research Experience for Undergraduates" (BSA REU) that is led by CU Boulder's Laboratory for Atmospheric and Space Physics (PI Daniel Baker). Since NSO's participation in this program was established, the annual numbers of applications have risen from an average of 160 per year to 400+ for 2018 and 2019. This 250% increase can be attributed to many things, but two major changes that occurred due to NSO involvement were:

A. Redevelopment of the application form to use more inclusive language and direct questions; and
B. Provision of three short videos interviewing participants on their experiences.

Both of these initiatives were provided by NSO EPO staff, and similar contributions will be made to maintain the ongoing improvement of this program.

Figure 8-8. *Entire REU cohort 2017 outside of NSO, Boulder.*

Figure 8-9. *REU 2016 cohort celebrating a successful summer.*

In addition to providing a new focus on inclusion for the REU program, NSO and partners are redirecting the focus of the program in alignment with the vision provided by the REU program officer, that is to move the program focus away from being used as a recruitment tool, and to focus on the experience and inclusion of the students. Of course, if the participants have a successful experience, then the likelihood is that they will have a desire to stay in the field. But this programmatic redirection moves the recruitment focus away from the student who will likely succeed anyway, and provides a renewed effort to recruit the student to whom this will be a career-changing opportunity. This equitable strategy manifests as an increase in the numbers of community college, liberal arts, mature, non-traditional students and in particular students of color, and a reduction in the number of Ivy League participants.

Figure 8-10. *Students observe the Sun at the DKIST site through one of the Sting-funded H-alpha solar telescopes.*

8.2.2.2. Student Engagement in Hawai'i

Once regular operations of DKIST begin in 2020+, we will establish a mechanism for student involvement. Given the heavy emphasis on engineering amongst our Maui-based staff, we are considering an engineering REU program, or a hybrid science/engineering program. We are exploring the viability of hosting our own REU site versus participating in a partnership REU site with other Hawai'i educational institutions and observatories (e.g., UH Institute for Astronomy has been an astronomy REU site for many years and we could partner with them). The best route forward will not become clear until DKIST construction has ended. However, we have already begun exploring the various options that will become available to use.

8.2.2.3. Partnerships with CU Boulder

In addition to the engagement of summer interns through the BSA REU, we continue to develop a relationship with the various academic departments at CU Boulder. The formal interaction manifests through a number of channels:

- 2 x joint faculty members in the Astronomy and Planetary Sciences Department: Dr. Adam F. Kowalski, a graduate of the University of Washington, joined CU-Boulder and NSO in August 2016.
- 1 x visiting faculty in the Physics Department: Dr. Ivan Milic joined CU-Boulder as the second visiting faculty position in January 2019, after terminating his appoinment at the Max Planck Institute for Solar-System Physics (Gottingen, Germany).
- Hale Scholarship Program: The George Ellery Hale (GEH) Graduate Fellowship is a three-year award offered each year to two students; nominally, six graduate fellows are enrolled in any given year, though sometimes extra fellows are funded if one wins external funding (e.g., an NSF graduate fellowship). The Hale Fellowship is generally offered to incoming graduate students, but those more advanced in their education may also be eligible (*https://www.nso.edu/students/hale-fellowships/*).
- COLLAGE Graduate Education Program: The Hale COLLAGE course is a graduate level series of courses designed to give students exposure to material in solar and space physics that is not taught in the standard curriculum. One Hale

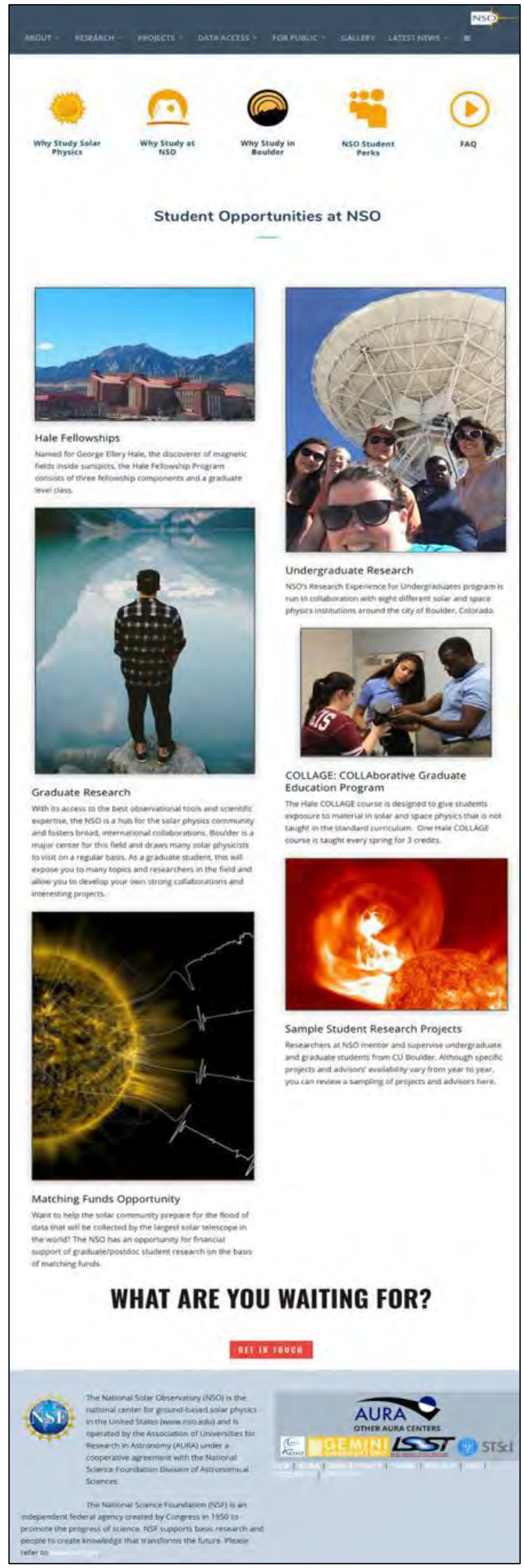


Figure 8-11. *NSO student website www.nso.edu/students.*

COLLAGE course is taught every spring for three credits. The lectures are taught jointly by up to four professors across several universities and institutes including University of Colorado Boulder, the National Solar Observatory, the New Jersey Institute of Technology, the University of Hawai‘i, New Mexico State University, Montana State University, and the High Altitude Observatory. Each lecturer teaches 2-10 lectures to the students at their home university/institute, and the lectures are broadcast live over WebEx to the students at the other universities, and recorded and hosted online for later use. Students participating remotely can ask questions in real time during the live broadcast. The classes are structured like other graduate classes with problem sets and independent projects. NSO maintains an archive of past* and existing lecture material and recordings, starting from 2013 (https://www.nso.edu/students/collage/).

- NSO's EPO team has been involved in the creation of a new lobby exhibit at Fiske Planetarium—the planetarium and science museum on the University of Colorado Boulder campus. This exhibit is focused on "magnetic fields from the Sun and through space", a topic extremely relevant to NSO and DKIST in particular. The project is being undertaken by a partnership between Fiske Planetarium, NSO, and CU Boulder's Atlas Institute. The consortium recently won an award of $25,000 from CU Boulder to accomplish this effort (funds are for student salary and materials; no NSO salary is covered by this award). The project involved co-teaching a multi-level (undergraduate and graduate), multi-disciplinary (astronomy, graphic design, museum studies, computer science, media amongst others) class for one semester, guiding students in the process of designing and building hands-on exhibits for an informal education space, all with the focus of solar and space magnetism. This resulted in five successful prototypes, two of which will be elaborated upon during summer 2019. We are exploring the possibility of repeating this effort in the future, this time with a focus on DKIST.

Figure 8-12. *Prototype of one Fiske Planetarium exhibit developed by students, guided by NSO EPO. The exhibit represents solar coronal loops and allows visitors to "create" a solar flare.*

- Future collaboration with CU Boulder's Physics Education Research group. This world leading research group has leading expertise in the pedagogical processes involved in successful educational programs. We hope to continue to build a relationship with them in the future and are actively seeking opportunities to directly collaborate.

  The "Physics Education Technology" or PhET simulations team is based at CU Boulder. The EPO team is exploring the possibility of collaborating on DKIST-related topics such as polarization. These online tools are used by teachers all over the world. This would be an excellent opportunity to leverage the reach of an existing program to increase awareness of DKIST around the globe.

*Not all past lectures have been made available. We have archived all resources that have been provided.

- Other educational partnerships and collaborations with departments and groups with CU Boulder continue to emerge. These include partnerships with the BOLD Center—a Center within the Engineering Department that is committedt to creating a diverse environment where all engineering students, especially those who are traditionally underrepresented in engineering, are welcome. Direct engagement with Centers such as BOLD will help integrate NSO into the CU system.

- Engagement with third-level institutions in Hawaiʻi is not as well established. We have been able to benefit from the heritage of DKIST in developing a relationship with University of Hawaiʻi Institute for Astronomy. However, there are many other institutes with whom a relationship would be beneficial. These include UH Manoa, UH Hilo, UH Maui College and others. We will endeavor to develop relationships with more institutes in Hawaiʻi in order to further the mission of NSO, DKIST and the EPO team.

8.2.3 Public Outreach and Community Engagement

NSO EPO team will continue to be very active in conducting community engagement and public outreach, in particular in Hawaiʻi. As listed above, NSO has been involved in a plethora of outreach events covering a wide range of audiences. We anticipate this will continue, and likely increase in number as the reputation of NSO and DKIST increases.

In order to have the best impact at outreach events, we will continue to explore ways to effectively describe and demonstrate the science conducted at NSO and DKIST using engaging and exciting tabletop demonstrations.

In addition to traditional outreach opportunities, NSO will continue to support the engagement of students and teachers through outreach. To date, this has included career panels, career talks, advising students, etc.

***Figure 9-13**. NSO participating in the Institute for Astronomy led "Astronomy Day" event.*

***Figure 9-14.** NSO participating at public outreach events in Maui.*

We will also continue to do outreach within the science community through attendance at professional conferences, such as the American Astronomical Society and American Geophysical Society meetings.

We will explore the possibility of assembling an outreach committee modeled after the Mauna Kea Astronomy Outreach Committee (MKAOC). Committee members would include not only EPO professionals but will welcome other staff members interested in conducting outreach (e.g., astronomers, engineers, technicians, etc.). As with MKAOC, the committee could involve members from not just NSO, but members of various other observatories located on Haleakalā and in Boulder, or it may be more effective to have a committee of just NSO employees. Once a committee is formed, we can become more organized in fulfilling community requests and opportunities, through sign-up sheets, a shared emailing list, recurring meetings/brainstorms, etc. This will cover both Boulder and Maui sites, but likely won't be explored until after DKIST Operations has begun.

8.2.4. Solar Eclipse Preparation

Preparations for the 2024 eclipse has already begun in earnest. NSO's primary contribution is expected to involve the rejuvenation of the Citizen CATE project. The exact details of this are still in development but following significant interests from the community and federal agencies alike, it is clear that this program will be valued for 2024.

In addition to Citizen CATE, we will explore additional opportunities for public outreach and education as we did for 2017. Following the establishment of DKIST Operations, preparations for the solar eclipse will become one of our major endeavors.

8.2.5 Social Media

NSO has continued to build its social media presence using Facebook, Instagram and Twitter platforms. Leveraging the increase in followers from the 2017 solar eclipse, we have continued to engage with our followers on a variety of topics. NSO's following has increased by 1800 to 5100 on Facebook, increased by 1140 to 1900 on Twitter, and currently stands at 350 on Instagram.

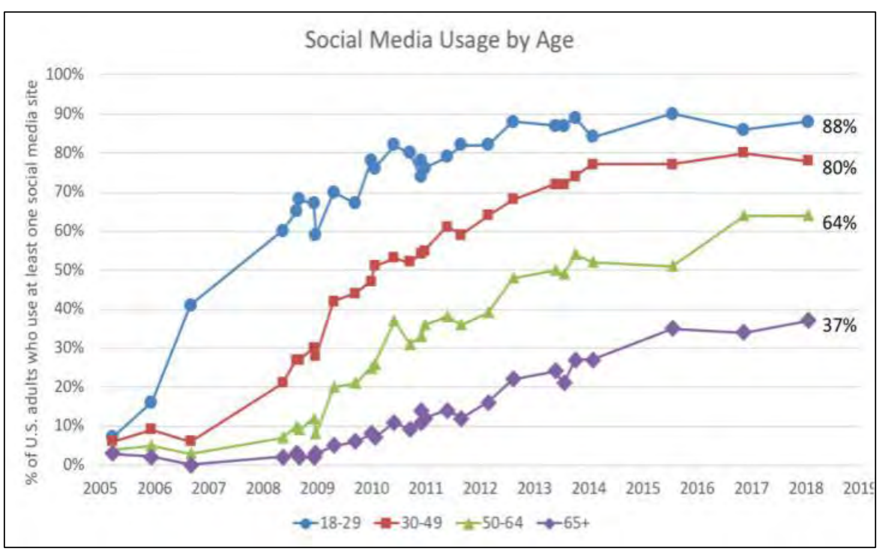


Figure 8-15. *Social media usage by age over time. Data from www.pewinternet.org/fact-sheet/social-media/.*

Social media will feature heavily throughout our efforts, especially around the DKIST first light campaign. Social media continues to be one of the primary mechanisms by which people communicate and learn about current events. In order to continue to reach the public about the successes of NSO scientific and engineering successes, we must continue to focus on growing our social media presence. As it stands, we are focused on five platforms—Facebook, Twitter, Instagram, YouTube and LinkedIn—and continue to follow the constantly changing trends in each.

8.3. The Case for Additional EPO Staff

Relative to the other AURA-run Centers, NSO severely lags behind in terms of EPO and Communications staff, relative to Center size. NSF-funded Centers have an average of 4% EPO and Communications staff by FTE (average eight EPO/C for average of 210 staff), while NSO is at 1% (two EPO/C for 137 staff). Getting NSO to par with the other NSF-funded Centers would require the NSO EPO/C staff to increase to six or seven FTEs.

Here we make a case for two additional staff members, which would bring us closer to alignment with other NSF-funded Centers.

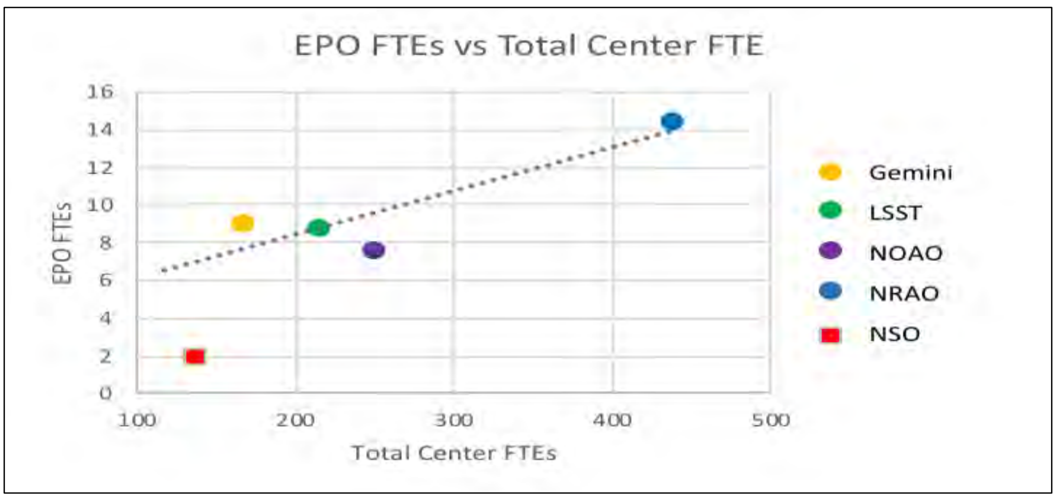


Figure 8-16. *Number of EPO/Communications staff per Center vs total Center FTEs,*

8.3.1. The Case for a Communications Officer

In the era of DKIST, there has been, and will continue to be occasions when the role of an Education and Public Outreach Officer will be in direct conflict of that of a Communications Officer. At NSO, we have both EPO and Communications under the guidance of one office, consisting of two people – the EPO Director, Claire Raftery, and the Formal Education/Hawaii Community Liaison Officer, Tishanna Ben. A recent example of this was during the inaugural Journey to the Sun teacher workshop. During that workshop, the EPO team's primary objective was to build an authentic, trusting relationship with the teachers in attendance. To do so meant that we had to leave all promise of external promotion aside and focus entirely on the interaction in the moment with the participants. Although it might have been appealing to simultaneously promote the great work NSO was doing with this workshop, it was contradictory to do so. In this case, having a dedicated Communications Officer would have meant we could have had the authentic interaction with the teachers AND we could have publicized the efforts to the outside world. The Communications Officer would have been responsible for creating informative, engaging content, such as interviewing participants, photographing the event, generating press and media coverage in advance of, and following the workshop. The work of an EPO Officer and a Communications Officer are not the same. Though occasionally they overlap, the skillsets and priorities are often in conflict.

By generating a role at NSO for a Communications Officer, we will be able to

- Promote the NSO mission, products and services (internally and externally).
- Create engaging content (press releases, press kits, marketing materials graphics).
- Develop and maintain effective marketing materials.
- Create communications and marketing strategies for new products, launches, events and promotions.
- Maintain and enhance website content (engaging content and informative features).
- Foster media relationships with scientific publications and science influencers online.
- Help train scientists in engaging journalists.
- Help train scientists in communications skills.
- Effectively and efficiently respond and coordinate media requests.

With the new guidelines on branding coming from NSF, it is clear that the external push on NSF Centers' recognition is becoming increasingly essential to the agency. Without a Communications Officer position, we are unlikely to meet the expectations set by the NSF in this regard.

NSO currently employs one person with the skills needed to succeed in this role. To date, this person, John Williams, has been supported with carry forward funds from the Director's office and supplemental funding. However, he has not been in a position to focus on the activities listed above due to other commitments required by the sources from which he is funded. Providing a dedicated Communications Officer position will ensure NSO is in a position to highlight and emphasize the excellent science coming from DKIST and across NSO.

8.3.2. The Case for a Second Position in Maui

With the enormity of the scale of work facing the EPO team in Maui, from building good will amongst the community, to engaging with cultural leaders, building education programs and providing academic support, we would like to request the addition of at least one additional team member in an entry level, assistant role. The vision for this role is to support Tishanna Ben, the EPO Officer/Community Liaison, by conducting low-level engagement, outreach and other activities that occur on a near-constant basis. In particular, we will require someone who will be responsible for conducting tours of DKIST once it is operational in order to minimize the impact on the DKIST Operations team. We envision this being one full time person, or a small group of community college students from nearby University of Hawaiʻi Maui College each working part time on a rolling basis. This will not only provide a boost of support if need be (e.g., for a large outreach event where more than one extra person would be valuable) but provide an excellent way for local students to become directly engaged in DKIST.

At present, this position is completely unfunded and its support would require additional funding from NSF.

9 RESTRUCTURING THE NSO FOR THE DKIST ERA

This section describes a new organizational structure of the NSO that fosters a sense of community at the Observatory. This reorganization is intended to occur over the second half of the current Cooperative Agreement; it is modest in scope and intended to minimize barriers in functional and programmatic aspects that exist in the current structure. The historical split of NSO into two operational programs (high resolution and synoptic) has created structures with different priorities that result in challenges related to the sharing of personnel, equipment, or expertise, giving rise to minor inconveniences in some cases (such as planning vacation time for personnel) but also unreasonable divides. An example is the current lack of plans in the DKIST Data Center to ingest context, synoptic data from the NISP Data Center (and vice versa). During the first five years of this Cooperative Agreement it has become clear that these logical synergistic opportunities do not occur naturally and need to be promoted by Observatory leadership.

The restructuring described in this document is minimal. Most of the NSO employees will remain unaffected by the new (matrix) structure. The implementation process we propose is gradual, initially reaching only the obvious areas of NSO where a unified approach is urgently needed: Administration, Business, EPO, and IT. The proposed matrix structure also promotes a synergistic combination of the data efforts leading to a unified Data Center, but with the expertise residing primarily in the program where it was created and where it is most needed. The Data Center matrix structure aims at leveraging opportunities for sharing knowledge, creating professional development opportunities, and facilitating data sharing between the otherwise distinct NISP and DKIST Data Centers.

For this new structure to be successful, it needs to create a culture whereby the Programs (vertical) are the *customers* of the Services (horizontal). This culture is key to any matrix organization however minimal. Programs do the strategic planning and Services respond to those plans. The NSO Directorate should be the forum in which challenges that the new structure might create can be discussed, with the NSO Director acting as the final conflict-resolution element.

9.1 Description of the NSO's Restructuring

The restructuring of the NSO aims at:

- Promoting a unified culture at the Observatory;
- Optimizing resource allocations by adapting them to evolving needs;
- Promoting a synergistic scientific culture common to DKIST and NISP;
- Improving the internal exchange of information;
- Creating a new program that addresses strategic, community-driven, scientific initiatives;
- Increasing the exposure of the Observatory to the community[10] as demanded by the DKIST era;
- Offering career development opportunities for the staff.

[10] NSO interacts in several ways with the community. More formally, it does so through the Users' Committee that reports to the NSO Director. In this document, references to the community should be understood as implying interactions with the Users' Committee.

Figure 9-1. Existing block diagrams for NSO. FTEs correspond to FY 2019 estimates. The steady DKIST operations phase will allocate about 70 FTEs. For NISP, the number will fluctuate depending on grant support but will not increase unless new opportunities arise. The number of FTEs here include grant-funded personnel

We describe a new organizational structure for the Observatory that targets these challenging goals. Currently, NSO is vertically organized into two programs, DKIST and NISP, each containing its distinct personnel, including scientists, technical staff, and administrative support. The programs are seen internally as silos. Minimal NSO-wide structures that bridge the two programs exist. Exceptions are upper administrative support, business support, and public outreach, as they report directly to the Director. This division creates a culture of 'Observatories inside the Observatory' that produces unnecessary duplications of effort and prevents scientific synergies from occurring.

The new structure also aims at providing a venue for NSO scientists—independent of their career track—to participate in community-driven activities that bridge the program operations of DKIST and NISP. With the current structure, initiatives that could benefit both programs are run in parallel, become duplicated, and create minimal to no interactions between the personnel involved. Efforts in data calibration and analyses is an example, whereby no collaborations exist despite the similar challenges faced by both programs.

Over the first five years of the Cooperative Agreement, we have no plans to transfer to the future DKIST pipelines any of the expertise gained by NISP in SOLIS spectropolarimetric data analysis even though the only distinction is the difference in spatial and temporal resolution. Other examples of lack of synergistic approaches exist. The new structure provides a forum for channeling such synergistic efforts in the form of the NSO Community Science Program (NCSP).

As in the past, scientists are assigned to programs in the new structure depending on their functional[11] dedication. Their research effort is independent but required to be consistent with the Observatory's mission (see Section 2). If the functional component of a scientist is exclusively oriented to operations, data validation, and instrument development of a specific program, the scientist is ascribed to the corresponding program. Whenever a synergistic service is identified as part of an initiative started by the NCSP, the NSO Directorate discusses the total or partial allocation of the relevant scientists for the period of the initiative. These temporary assignments of NSO scientists to the NCSP initiatives

[11] Science-track personnel at NSO have 75% of their time for functional tasks and 25% for research. The split for tenure-track staff is 50% each.

broaden the career development of our scientists beyond the narrower focus needed within the operational programs. These initiatives can also help offset those cases where programmatic constraints have prevented NSO scientists from familiarizing themselves with new research areas and state-of-the-art developments in the field of solar physics.

The proposed reorganization includes one new (vertical) Program and shared (horizontal) Services, including new funding authority lines and, thus, potentially will impact the annual distribution of NSF funding. We note, however, that these budget impacts will adhere to the guidelines provided by the NSF as part of the Cooperative Agreement with AURA. Specifically, NSF has requested that:

1. In FY 2019, the NSO budget allocates $17M for DKIST Operations of which $4M is used for other activities; and
2. The cost to NSF/AST in FY 2019 of the NISP stays at $2M as part of the $4M above.
3. Out-year budgets follow the projections in Section 10.

The proposed restructuring of NSO will follow these guidelines and, therefore, remains budget-neutral. Budget authority stays with the NSO Director, whose responsibility is to demonstrate that the annual budgets follow the guidelines in the annual and multi-year Observatory reports.

In the existing Observatory structure, with DKIST and NISP as self-contained vertical programs, the budget distribution is relatively straightforward as the funds are directly allocated to each program. The Director uses about $2M, primarily for shared services that benefit the Observatory as a whole but also, to help the operational programs. In the proposed new, richer structure, demonstrating that the allocated budgets for DKIST and NISP follow the above NSF guidelines will require additional effort. We plan to achieve this through a multipronged approach that includes adequate budgeting tools (such as WEBUD), restructuring of the NSO-CAS accounts to reflect the new organizational units as needed, midyear and quarterly budget reconciliations, and training employees in carefully tracking time allocations and proper timecard practices. These elements will require coordination with the AURA CAS and Human Resources (HR) departments.

We do not envision developing formal indirect rates to be included in AURA’s cost rate proposal to NSF, but rather anticipate the development of NSO internal cost allocation models (similar to existing internal cost allocations described in Section 10.1). The budgets in Section 10 do not assume any Observatory specific indirect cost pools. We do not anticipate such a cost reallocation model to start prior to FY 2021, once it has been internally developed and discussed with the stakeholders.

The proposed restructuring contains matrix-type management components, and it potentially introduces reporting lines for some of the NSO personnel that can have programmatic and service inputs to performance management. NSO personnel could have yearly allocations to multiple programs that can change dynamically depending on priorities. The NSO Directorate discusses annual plans and their changes that, in case they have budget implications, will follow the NSO's budget control process (see Appendix B).

AURA is also maturing plans for dual reporting lines within NCOA and their impact on performance management and assessment. We plan to benefit from these discussions and implement a similar model at NSO.

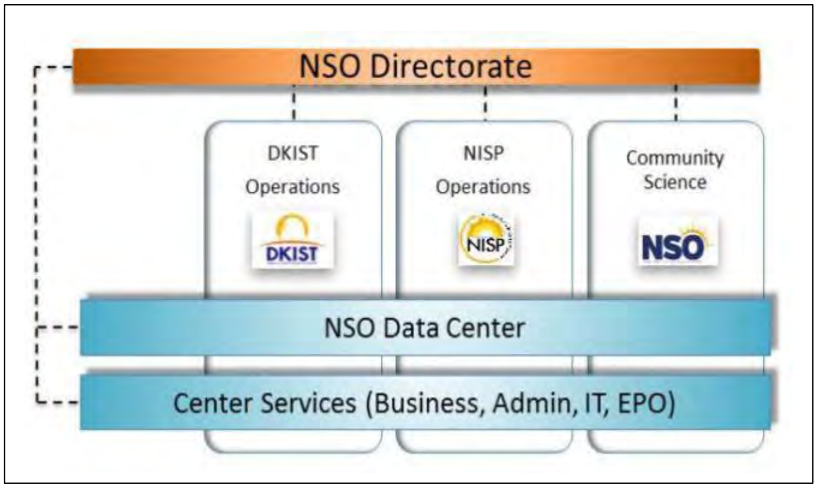


Figure 9-2. The proposed new structure for the NSO that implements a minimal matrix structure for the center services and the Data Center.

In defining the new NSO structure, we will consider as vertical components, or Programs, the units that contain personnel whose dedication stays within the Program and does not usually get reassigned (with exceptions such as the strategic initiatives inside the NCSP). Programs act as the primary science-enabling units of the Observatory. As such, they establish all scientific priorities for the Observatory. Three Programs are proposed:

- DKIST Operations;
- NISP Operations; and
- NCSP.

Horizontal components, or Services, of the matrix structure are the units that act as labor pools, where the efforts of personnel may be reassigned depending on Observatory needs. Services are vital in supporting the science of the Observatory but do not include scientific staff. Two Services are proposed, the integrated NSO Data Center and the Center Services. The creation of a unified NSO Data Center follows the recommendation of the original CA proposal, which states: "*After ATST has developed their data handling and processing needs, NSO will form an integrated Data Center.*"

Note that one could envisage additional Services that enrich the matrix structure with engineering and scientific labor pools. However, given the existing differences between the operations Programs and the technologies used by them, we consider that creating such pools can potentially have a detrimental impact, in particular at the time when DKIST becomes operational. These labor pools will not be created at the beginning of the five years described in this LRP, but NSO might consider evolving the matrix structure further and revisit the creation of these pools once DKIST Operations are well established and understood.

Each of the three Programs has an Associate Director (AD). The NSO Data Center Service will be under the Data Center Service Manager (SM). All four report to the NSO Director. The Center Services, because of its diverse nature, will have several top-level managers, all reporting to the NSO Director.

Resource allocation, priority adjudication, and conflict resolution within the matrix structure are discussed at the NSO Directorate and are based on the Observatory's strategic scientific priorities set by the Programs. Budget and personnel allocations are presented as part of the annual Program Plan implementation. The NSO Director retains ultimate authority in conflict resolution.

What follows is an explanation of the scope of each of the Programs and Services, including staff allocations as well as responsibilities and funding sources. The following descriptions refer to the steady-state phase after a phased implementation described in Section 9.2.

9.1.1 DKIST Operations Program

The DKIST Operations Program is responsible for all aspects related to operations of the DKIST facility in Maui and instrument development activities in Boulder. The DKIST Operations Program is under the direction of the DKIST Associate Director. The Program's responsibilities include telescope operations, maintenance, telescope upgrades, instrumentation program, and scientific validation of DKIST data as currently defined by the DKIST Program (Level-1). NSO staff included in this Program are:

- The DKIST AD.
- Scientists with a functional component related to DKIST Operations as described above, including the scientific validation of Level-1 data products. The functional and research dedication of the scientists reports annually to the DKIST AD.
- Science Operation Specialists (Observers).
- Technical and engineering personnel required for DKIST Operations as described above, including the instrumentation program.
- The technical personnel required to ensure proper delivery of data from the summit to the DSSC in Pukalani.
- The DKIST Operations Safety Team.

DKIST Operations will use personnel and services from the NSO matrix, which in some cases might require dual reporting to both the DKIST Program and the corresponding Center Service. Examples are:

- Administrative Services.
- IT support.
- EPO.

The DKIST AD responsibilities include:

- Overall responsibility and authority to conduct the operations and maintenance of DKIST.
- Developing and updating the DKIST Operations staffing plan.
- Developing and managing yearly budgets for DKIST Operations.
- Planning, in collaboration with the community, for future instrumental upgrades of DKIST.
- Scientific validation of Level-1 data.
- Developing DKIST-specific higher-level data products; collaborates with NCSP as needed.
- Interacting and communicating with NSF, AURA and DKIST partners.
- Working to attract national and international partner contributions for operations.
- Writing reports on DKIST Operations as needed.
- Chairing the DKIST Time Allocation Committee.
- Conducting an active research program involving original and creative development work, which forms part of the Observatory's overall scientific program.

The number of FTEs directly allocated to this program in the steady-state phase is expected to be 80. The planned FY 2020 budget is $17M.

9.1.2 NISP Operations

The NSO Integrated Synoptic Program Operations is responsible for all aspects related to operations of the GONG network (including the engineering units in Boulder) and SOLIS. This Program is under the direction of the NISP Associate Director. The Program's responsibilities include GONG network operations, SOLIS telescope-suite operations, maintenance, GONG and SOLIS technical upgrades, new instrumentation projects such as ngGONG, and scientific validation of data produced by NISP (Level-1 and higher). NSO staff included in this Program are:

- The NISP AD.
- Scientists with a functional component related to GONG and SOLIS operations as described above, including the scientific validation of the data. The functional and research dedication of the scientists reports annually to the NISP AD.
- Operation specialists, including the field maintenance team.
- Technical and engineering personnel as required for NISP operations.
- The technical personnel required to ensure proper delivery of data from the remote locations to HQ in Boulder.

NISP Operations will use personnel and services from the NSO matrix, which in some cases might require dual reporting to both NISP and the corresponding Center Service. Examples are:

- Administrative Services.
- IT support.
- EPO.

The NISP AD responsibilities include:

- Overall responsibility and authority for the operations and maintenance of the GONG network and the SOLIS suite of instruments.
- Developing and updating the NISP operations staffing plan.
- Developing and managing yearly budgets for NISP operations.
- Planning, in collaboration with the community, for future upgrades of NISP, including the ngGONG project.
- Scientific validation of Level-1 (helioseismology and magnetic) data from GONG and SOLIS.
- Developing NISP-specific higher-level data products; collaborates with NCSP as needed.
- Interacting and communicating with NSF, AURA and NISP partners as needed.
- Working to attract additional national and international partner contributions.
- Writing reports on NISP operations as needed.
- Conducting an active research program involving original and creative development work, which forms part of the Observatory's overall scientific program.

The number of FTEs directly allocated to this program is 20, but this number depends on existing non-NSF funding sources. The expected FY 2020 budget is $2.2M.

9.1.3 NSO Community Science Program

As mandated by the NSF, it is NSO's task to recruit and develop an outstanding scientific staff that demonstrably support the community-based research carried out at NSO facilities. All programs commit to this mandate and nurture their respective scientific teams to provide better community-oriented services. The NSO Community Science Program (NCSP) helps the DKIST and NISP operational programs with this nurturing by advocating for the science pursued by all NSO scientists and by promoting synergies between the two programs based on community input. NCSP supports scientists in their career development and ensures uniformity in the research pursuits across the Observatory. To do so, the NCSP will provide forums regularly for the interaction of all NSO scientists, including annual scientific retreats and other more targeted events as discussed and agreed at the NSO Directorate.

NCSP fosters the NSF strategic vision of advancing discovery, innovation, and education beyond the frontiers of current knowledge, and empowering future generations in science as it pertains to the field of solar physics.

NCSP will utilize as the primary tool for promoting synergistic activities the creation of Strategic Initiatives (SI). These initiatives will have a research impact extending to both DKIST and NISP and can integrate scientists from the two programs. An SI is organized around a clear scientific objective that supports NSO's overall mission and has a clear deliverable and time span. SIs have a (non-technological) focus aimed at enhancing the value of the data produced by NSO. The time used for an SI will be reported as functional time. These enhancements will often take the form of higher-end science-ready data products, auxiliary data that augment the scientific reach of NSO's facilities, and/or analysis and modeling tools. Examples are radiative transfer codes that target effects under active research (NLTE, atomic polarization, Hanle effect, etc.), inversion codes (including state-of-the-art spatially-coupled algorithms), numerical simulations, novel data-driven coronal modeling, etc.

All NSO scientists may propose an SI to the NSO Director, who will consider it for further evaluation. The NSO Director will prepare a process and a template for formally submitting an SI. Before submitting an SI, the proponents will gather community input that demonstrates the need for such action. This community input may be in the form of a recommendation from the NSO Users' Committee or support letters from scientists internal and external to NSO. Discussions in forums, such as the Solar Physics Division (SPD), American Astronomical Society (AAS), and American Geophysical Union (AGU) may also serve as support for an SI. After receiving a SI proposal, the NSO Directorate will discuss it, giving due consideration to the personnel and financial resources required in light of the proposed effort. If the SI is considered viable, the Directorate will guide the NCSP for its implementation. Approval of an SI stays with the NSO Director.

The NCSP is targeted at helping to empower future generations in solar physics and, as such, it should promote, when feasible, involving graduate students and postdoctoral fellows as active participating scientists in the various SIs. NCSP may also request the allocation of fractions of functional time of specific NSO scientists who are considered key to achieving the goals of the SI. If this functional dedication exceeds the dedication to the other operationally oriented programs, the scientist adopts NCSP as his/her home program for the duration of the initiative.

All Strategic Initiatives will have a Principal Investigator (PI) who will be included in the NCSP. To realistically promote synergistic science, the number of active SIs at the Observatory at any given time is expected to be at least one. SIs should be proposed and approved with the Observatory's reporting and budgetary cycles in mind to ensure that SIs are adequately explained and documented in the Annual Progress Report and Program Plan (APRPP).

Funding for SIs will be from a combination of the following sources:

- The Director's office when available. As part of the yearly budget schedule, the Director allocates 10% of the NSF annual new funds to Observatory-wide needs. SIs will have a priority in funding allocation, after budgeting for all non-discretionary obligations.
- External funding. All SI proposals must include an external-funding-request strategy identifying the related work packages.
- Base funding from the programs. The SI will indicate the percentage of impact they expect to have in each of the programs using a three-tier scale: 25%, 50%, or 75%. The Directorate will discuss these percentages. The remaining unfunded SI budget will come from the corresponding programs. Conflicts are resolved by the NSO Director.

Use of base funding by NCSP should reflect the NSF budgetary guidance discussed in Section 1 which indicates that 80% of NSO base funding should support DKIST efforts.

The NCSP will be under a new Associate Director nominated by, and reporting to, the NSO Director. The NCSP AD may or may not be the PI of an ongoing SI, but it is expected that his/her research background will be closely related to the SI. As new SIs appear, the NCSP AD position may be rotated to better fit differing needs.

NSO staff included in this program are:

- The NCSP AD.
- All PIs of the ongoing SIs.
- NSO scientists participating in the SIs as discussed in the Directorate.
- Postdocs and graduate students participating in the SIs.

NCSP will use and help support personnel and services from the NSO matrix structure as needed.

The NCSP AD ("Chief Scientist") responsibilities include:

- Chairing the Scientific Personnel Committee (SPC) and monitoring the research dedication, evaluation, and promotion criteria of all scientists.
- Maintaining an ongoing oversight of research staff career development.
- Informing the NSO Director and the respective program ADs of disparities in research dedication and support that may arise at the Observatory.
- Acting as NSO's Deputy Director.
- Monitoring SI progress and communicating deviations from the original plan.
- Evaluating and promoting future SIs in close interactions with the community.
- Promoting participation of NSO science staff in scientific meetings, in particular those relevant to the SIs.
- Developing and managing yearly budgets for the promotion of community science at NSO (as it pertains to the SIs).
- Seeks external grant funding to support existing or future SIs.
- Participates in the hiring of all scientific positions at NSO.
- Write reports on NCSP activities as needed.

- Conducts an active research program involving original and creative development work, which forms part of the Observatory's overall scientific program.

The number of FTEs directly allocated to this program is nine. The expected FY 2020 budget corresponds to carry-forward funds from the DKIST Level-2 supplemental funding.

9.1.4 The NSO Data Center Service

NSO serves as the steward of high-quality scientific data from NSO facilities on behalf of the US solar and space physics communities, through pipelines, reduction processes, dissemination, and archiving. Currently, NSO uses two Data Centers that are part of the corresponding operational program. We propose to change the model to a unified Data Center that will integrate data from the DKIST Program, NISP, the Virtual Solar Observatory (VSO); legacy NSO data also will be included.

All scientific guidance and priorities required by the NSO Data Center flows from the three NSO Programs: DKIST, NISP, and NCSP. To prepare for the yearly Program Plan, the NSO Directorate will submit to the Data Center a list of all tasks that need attention during the incoming year, including new developments. In response, the Data Center will submit to the NSO Directorate a Data Center Action Plan (DCAP), detailing personnel and budget allocations that will be subject to approval. The NSO Directorate will regularly monitor the progress according to the approved plan and will document any changes via the NSO Budget-Control Process (Appendix B).

The budget for the NSO unified Data Center is the sum of the existing Data Center budgets for DKIST, NISP, and NCSP. The Data Center SM will demonstrate in the DCAP how funds are allocated and benefit the programs. The DCAP will also address the cost of Data Center use of NSO's Center Services.

The scope of the NSO Data Center includes:

- Data ingestion from DKIST and NISP facilities, and potentially others.
- Operating all corresponding data-reduction pipelines.
- Archiving, curating, and aggregation of all NSO facilities data.
- Maintaining and upgrading the Data Center hardware.
- Ensuring appropriate access to the data, including search tools, by the community.
- Developing and maintaining operational tools.
- Technical interfacing with the corresponding stakeholders (CU Boulder, UH/IfA, NOAA, VSO, etc.).

NSO staff included in the NSO Data Service are:

- All existing and future personnel allocated to the DKIST Data Center, including the operational tools development team.
- All personnel currently allocated to the NISP Data Center.

The Data Center SM manages the NSO Data Center. Responsibilities include:

- Hardware and software development, implementation, and maintenance of the NSO Data Center.
- Supervision of the NSO Data Center staff.

- Preparation of, and presentation to the NSO Directorate for approval, the yearly personnel and budget allocations for the NSO Data Center.
- Managing a merge of the DKIST Data Center and the existing NISP data system.
- NSO-wide data archiving and curation, including access and distribution to the community.
- The reduction pipelines infrastructure, implementation, and routine technical operation.
- The operations tools infrastructure, implementation, and routine technical operation.
- The network provisioning between NSO sites, NSO facilities, and the external community.
- Establishing coordination mechanisms to work closely with the relevant DKIST, NISP, and NCSP scientists in charge of scientifically validating data products.
- Establishing coordination mechanisms to work closely with the relevant DKIST, NISP, and NCSP scientists to leverage existing expertise from related data center efforts (SDO, *Hinode*, IRIS, and others).
- Interactions with community stakeholders as it pertains to technical aspects.

The NSO Data Center will use personnel and services from the NSO Center Services. The expected start date for the unified NSO Data Center is near the end of the first year of DKIST Operations (mid-2021).

9.1.5 Center Services (CS)

Center Services includes four services that serve the Observatory as a whole. There is no Associate Director position for CS, but managers of the Services report directly to the NSO Director and attend the NSO Directorate meetings as needed. Services are as follows:

1. Administrative services under the Director's Office Administrative Manager. All administrative positions report to this position. Administrative services support the Observatory in the yearly reporting activities, grants management, meeting organization, facilities management (including the machine shop), and general support for other scientific and technical activities. The Director's Office Administrative Manager position is the point of contact for AURA property management.
2. Business services under the NSO Business Manager for Operations. Business services support the Observatory in the preparation and tracking of the annual budgets and required reporting to the NSF. Business services also provide support for grants budget preparations and reporting.
3. Education and Public Outreach (EPO) under the NSO Head of EPO. The EPO service supports the Observatory by disseminating to the broader public and stakeholders (via press releases, etc.) the scientific progress and discoveries made at NSO facilities. The EPO office leads the education and outreach program of NSO and has both a global and nation-wide focus with local emphasis, in particular in Hawaiʻi.
4. The Information Technology Department, under the Head of IT, provides NSO-wide IT support for mixed, heterogeneous computing equipment used by NSO personnel and visitors, including desktop support, AV, web services, etc. The IT Department is present at Boulder Headquarters and the Pukalani offices and is in charge of maintaining and upgrading NSO IT hardware. It interfaces with the stakeholders for IT-related issues (CU

Boulder, UH, software license providers, etc.), and contributes to compliance with NSF and AURA security policies, including cybersecurity.

Funding for these services derives for the most part from charges to the various subunits: Programs, the Data Center Service, the Director's Office, and grants.

In preparation for the annual budget, each program will request and provide justification for the expected support from each of the Services. Coordinated by the NSO Director, a Center Services Action Plan (CSAP) will be submitted to the NSO Directorate; the CSAP will list all higher-level tasks that need attention during the incoming year, in response to requests from the respective programs. The CSAP will also detail the expected Observatory broad support that the Services will provide. The Directorate will formulate and approve a final CSAP that should reflect the NSF budget guidelines. The NSO Directorate will regularly monitor progress according to the approved plan and will document any changes via the NSO Budget-Control Process (Appendix B). At the end of the year, a budget reconciliation (based on actuals from time cards) will adjust cost over/underruns.

9.2 Time Line for Implementation

The proposed restructuring of NSO will start after the midterm Cooperative Agreement review, although some preparatory measures have already been taken. The present five-year Long-Range Plan (2020-2024) serves as an opportunity to present this proposed new structure to the stakeholders.

The restructuring plan has three significant milestones that may occur at different times:

1. It is natural for the start of Center Services (not including the Data Center) elements to coincide with the beginning of FY 2020 and the upcoming budget cycle. Some preparations are needed, such as time-card updates for impacted personnel and changes in the supervisory structure. The first CSAP exercise is planned for FY 2020.
2. NCSP started in FY 2019 and apportions the supplemental funding received by NSO to generate DKIST Level-2 data products. NCSP will prepare the first round of discussions with the Users' Committee for existing and future SI ideas. The full implementation of NCSP and the AD position, however, will occur after the midterm review in order to benefit from the review discussions.
3. The consolidation into a unified Data Center is the most logistically complex component of the restructuring plan. The DKIST construction project did not include in its original scope the facility Data Center, in contrast with other similar MREFC projects. Arguably, it would have been more natural to have the Data Center as part of the construction project as it faces identical schedule challenges. The DKIST Data Center project is now part of the operations activities and has complex interfaces with the construction project. The Data Center milestones are closely linked to the construction milestones, and successfully achieving both sets of milestones is equally critical for the scientific readiness of the facility. *The proposed restructuring of the NSO is intended not to impact the DKIST construction project, and its implementation occurs largely after the end of the construction phase and the commissioning of the DKIST Data Center.* Thus, the timing for creating the unified NSO Data Center service will be at the end of both the DKIST construction project and the commissioning phase of the Data Center. The commissioning effort is expected to last

several months up to a year after the beginning of operations and will run into the first phase of the Critical Science Plan. Accordingly, a tentative date for the creation of the combined NSO Data Center Service is the first half of FY 2021. To prepare for this merger, and in consultation with the program ADs and the corresponding Data Center managers, NSO will generate a schedule and milestones plan, keeping in mind the respective ongoing activities of the NISP and DKIST Data Centers.

The FY 2020 Annual Progress Report/ FY 2021 Program Plan (APRPP) will provide a detailed description of the merger details.

9.3 Risk Register

The main objective of restructuring the NSO is the creation of a unified culture at the Observatory, alleviating the "us vs them" attitudes in the workplace. More effective communication may partially help solve this problem. For example, DKIST staff were delighted to learn during an NSO all-hands meeting that NISP/GONG data are considered essential by NOAA for Space Weather forecasting and alerts. But there is a limit to what better and more frequent communications can do, in particular, if the structure of the Observatory is such that it separates all activities into two distinct areas. Structural changes, however minimal, are needed to create a sense of being part of a larger effort. As explained above, the reorganization proposed here includes a gradually implemented matrix-type approach that should help create a more inclusive environment at the Observatory and, by improving the workplace culture, increases personnel productivity.

There also are risks associated with the proposed changes that need to be addressed. We have identified a total of seven risks described below, including potential mitigations. There is no identified budget contingency associated with this risk register, so mitigations are done via scope reductions and time-line adjustments.

1. NSO Senior Personnel Buy-in.

Rating: Likelihood 5; Impact 4

Description: Moving from self-contained programs to a matrix structure necessarily implies some mindset adjustments by all employees, but most importantly from NSO leadership. A matrix structure is often seen as a risk to potentially lose control.

Recommendation: *Track* via Directorate discussions and communications with leadership. *Mitigate* by using effective budget planning and reconciliations that provide clear accountability and demonstrate effectiveness of the services provided to the programs. Focus on building the organization, not imposing a new structure. Ensure that the program's leadership participate in the hiring committees for the common Services.

2. Dual Reporting Leads to Confusion.

Rating: Likelihood 4; Impact 4

Description: Staff included in the Services report to the corresponding Service Managers but also interact with the programs as their customers. In a matrix system, conflicting messages will result and can lead to confusion and frustration on both ends.

Recommendation: *Track* via Directorate discussions with Directors and Managers and communications with all personnel. *Mitigate* by providing training opportunities on matrix management to key personnel and the staff. Avoid the proliferation of channels that create conflicting information.

3. **Program Dissatisfaction.**

Rating: Likelihood 4; Impact 4

Description: Programs, as customers, do not receive adequate services. This risk is similar to Risk #1 but reflects dissatisfaction not of upper-level managers but of staff included in the programs. The dissatisfaction soon propagates to the personnel in the various Services as well.

Recommendation: *Track* via Programs and Services all-hands meetings and discussions at the Directorate. *Mitigate* by ensuring that leadership, Directors, and staff are aligned and share the Observatory's main objectives. Create opportunities for culture-building exercises.

4. **Matrix Management Becomes Time Consuming.**

Rating: Likelihood 4; Impact 4

Description: Matrix management requires fluent and frequent communications at all levels, resulting in a potential reduction of the available time for what is traditionally considered productive work. The NSO Directorate meetings will be more relevant than ever as it is the forum to address conflict resolution, and the time dedication of upper managers will be greater. All-hands meetings for effective communication of goals and objectives are key in a matrix system as they help create a unified culture compatible with the organizational structure and aligned with the Observatory mission, but they also consume time.

Recommendation: *Track*, if necessary, by establishing a time card system that allows for quantifying the time allocated to meetings. *Mitigate* by creating metrics of utility for the meetings: poll staff.

5. Degradation of Service.

Rating: Likelihood 3; Impact 5

Description: Restructuring of the Observatory can imply a degradation of the services we provide to the solar community. This degradation is a concern, particularly in the context of the consolidation of the two data centers. Lack of consensus in the process can result in personnel departures and malfunctioning services. This is particularly important as the data-providing services represent the primary way in which the Observatory links with the scientific community.

Recommendation: *Track* by enhancing the role of the NSO Users' Committee as the main body that provides oversight on the quality of the data produced by the Observatory and its accessibility. *Mitigate* by gaining the buy-in of the main actors involved in the data-center merge using a bottom-up approach. If necessary, redefine the time line and revisit the scope of the merger, establishing a minimum set of requirements.

6. Employee Dissatisfaction.

Rating: Likelihood 4; Impact 3

Description: Restructuring how the Observatory operates can affect everyone, not only the directly affected employees (Risk #2). A general lack of understanding of the contents and scope of the matrix reorganization might result. Non-affected employees might not understand why they are not given the same possibility as others to transfer among programs.

Recommendation: *Track* via all-hands meetings and workplace surveys. *Mitigate* by frequent communications and offering opportunities to suggest new approaches to the structure of the Observatory. Capture individual capabilities as much as possible.

7. Increased Cost.

Rating: Likelihood 3; Impact 3

Description: The restructuring described here is intended to be cost neutral in the sense that the budget allocations will follow the original NSF guidance explained in Section 1. The budget impact is expected to be minimal as no new outside hires are necessary, and the restructuring will focus on reallocating and promoting existing personnel. However, some elements might have a cost impact that needs to be understood. Examples are additional training that might be necessary and the creation of new opportunities for staff interactions. There is also an associated cost resulting from moving personnel across programs and the implied learning curves for which cost is harder to estimate.

Recommendation: *Track* by identifying budget expenditures that could be directly attributed to matrix needs. *Mitigate* by consolidating the NSO budget to produce precise cost accounting results and closures for Programs and Services, allowing easy tracking of direct and indirect costs. Keep personnel reallocations to a minimum, only as recommended by employee career development and expertise utilization. Do not move personnel with legitimate, but often ambiguous, arguments such as promoting cross-fertilization.

Table 9-1. NSO Restructuring Risks and Mitigation Strategies

Risk[1]	Likelihood[2]	Impact[3]	Implications	Mitigation
NSO Senior Personnel Buy-In 8	5	4	Sense of losing control by upper management.	Cost accounting. Improved communications.
Dual Reporting 6.4	4	4	Conflicting messages to staff from Programs and Services.	Matrix management training to key personnel and staff.
Programs Dissatisfaction 6.4	4	4	Programs receive unsatisfactory service.	Frequent Program and Services all hands. Align staff with Observatory vision
Time Consuming 6.4	4	4	Matrix management requires more time from personnel in meetings.	Track time spent in meetings and set utility metrics.
Degradation of Service 6.0	3	5	Impact on the quality and accessibility of the data produce at NSO facilities.	Bottoms-up approach to data center merge. Manage time line and scope.
Employee Dissatisfaction 4.8	4	3	Lack of understanding the contents and scope of the matrix reorganization.	All-hands and workplace surveys.
Increased Cost 3.6	3	3	Understand the cost of the new matrix system.	Cost accounting. Move personnel only when benefits are understood.

[1]Risk Rating = Likelihood×Impact×4/10. Maximum risk is 10.
[2]Likelihood: 1 less probable and 5 most probable.
[3]Severity: 1 less severe and 5 most severe.

10 FY 2020 – FY 2024 SPENDING PLAN

The five-year NSO spending plan presented here uses the estimated budget profile described in the original Request for Proposals (RFP) issued by the NSF for the renewal of the NSO Cooperative Agreement on August 14, 2013. The current version of the profile, as it appeared in the President's Budget Request (PBR) for FY 2019, is shown in Table 10-1 under the label 'Estimates' and spans the five years covered by this LRP. This profile shows a reduction over the original profile in the RFP during the period FY 2018 – FY 2022 by $0.5M per year to account for the $2.5M upfront payment made in FY 2016 for the DKIST Science Support Center in Maui. For the years FY 2023 – FY 2024, the estimates correspond to the original profile in the NSF RFP. Other than this modification, the estimated profile starts with the FY 2019 numbers and escalates the cost using an approximate 3% rate. NSO's program allocations presented here follow the guidelines in Table 8.4-2 of the Cooperative Agreement proposal submitted by AURA in October 2013 but reprofile the use of the funds in the DKIST Operations Program, thanks to a better understanding of the cost of running the facility. This reprofiling is presented in Section 10.3.

The PBR estimates in Table 10-1 (extracted from the FY 2019 PBR document) disclose the budget into NSO Base Operations, which include NISP, the NSO Education & Public Outreach Program, and the DKIST Operations in Boulder and Maui. Note that this table does not include supplemental funding opportunities that are limited in time such as NCSP and Sunspot operations. The spending plan presented here, however, is structured in five subdivisions: the Director's Office, which encompasses the EPO Program; the DKIST Operations Program; NISP; NCSP; and Sunspot. Of these, only the first three are run over the five years covered in this LRP. The last two only run for the first years. Original funding for the NCSP corresponded to FY 2018 – FY 2019 but will operate in FY 2020 using the program's carry forward. We note that the funding for NCSP was obligated late in the fiscal year, generating the relatively large unspent funds. For Sunspot, NSO plans to continue operating the site for the period FY 2020 – FY 2021 using a series of Supplemental Funding Requests (SFRs) not included in the PBR profile. The SFR budgets are discussed here, but they will need approval on a year-by-year basis.

Table 10-1. NSO Total Funding Obligations

(Dollars in Millions)

	FY 2017	FY 2018	FY 2019	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
NSO Base Operations	$5.74	-	$3.70	$3.82	$3.92	$4.04	$4.16	$4.29
NSO Education & Public Outreach	0.26	-	0.30	0.31	0.32	0.33	0.34	0.35
DKIST Operations[2]	11.50	-	16.50	17.01	17.54	18.08	19.13	19.71
Total	**$17.50**	**-**	**$20.50**	**$21.14**	**$21.78**	**$22.45**	**$23.63**	**$24.35**

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

[2] Excludes funding for cultural mitigation activities as agreed to during the compliance process. See the MREFC chapter for more information on DKIST.

Unlike the DKIST Operations, the carry-forward funds for the Director's Office and NISP are very low. Every year, these funds are budgeted according to these two program's priorities and presented in the APRPP. If the programs function according to the plan, they use the corresponding funds. Any unspent funds constitute next year's carry forward. In the case of the Director's Office and NISP, the carry-forward funds for FY 2020, but none for the outyears. The FY 2020 carry-forward allocation presented here will be revisited at the end of the year once the final unspent funds are precisely known and reallocated in the APRPP.

The carry-forward funds for DKIST Operations are treated differently in this budget exercise. Over the past five years, the DKIST Operations Program has accumulated a total carry forward slightly exceeding $13M. This unspent budget originates primarily from delays in implementing various aspects of the transition to DKIST Operations, such as the inability to implement the hires as described in the Cooperative Agreement resulting from the absence of a place to accommodate personnel in Maui. DKIST carry-forward funds also include costs for the Data Center that are on hold until the project's scope is finalized. As explained below, the program is reprofiling the use of this relatively large carry-forward funds by allocating various fractions to each of the next five years to supplement the PBR estimates. In each year, these extra funds help to cover several costs resulting from the much more accurate spending plan currently available. This more precise budgeting of operations for the next five years originates from a better understanding of the various costs to operate the facility in Maui and a nearly final plan that transfers expertise from construction employees to operations. Thus, and unlike the Director's Office and NISP, the DKIST spending plan in Section 10.3 augments for each year the PBR estimates with a given fraction of the program's carry-forward but does not budget these two income sources separately.

Figure 10-1 describes the organizational structure of the Observatory and includes all the cost- account managers with financial responsibilities. Red lines in the chart correspond to the DKIST construction project.

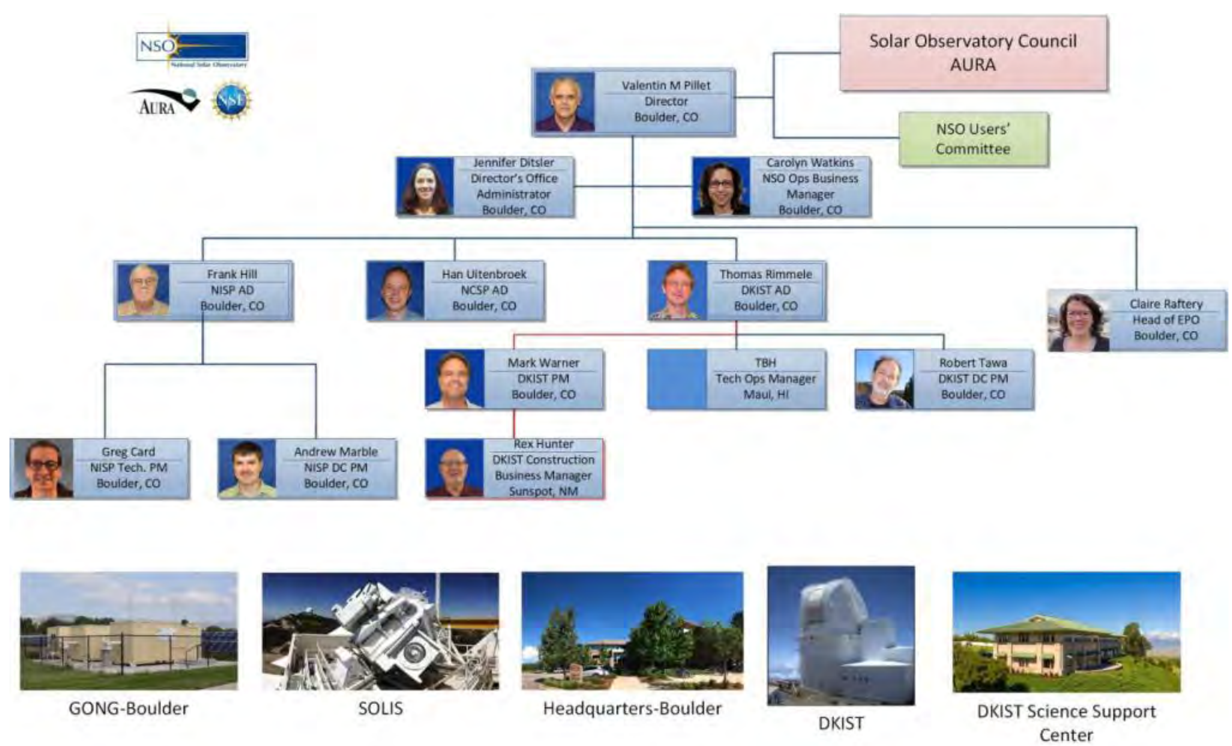


Figure 10-1. Organizational structure of the National Solar Observatory.

We note that as part of the improved business practices at NSO, we implemented in FY 2018 a change-control process that we will continue to use during the period covered by this LRP for documenting changes to the annual budgets (see Appendix B).

10.1 FY 2020 – FY 2024 Budgetary Assumptions

NSO continues to use AURA's WEBUD budgeting tool that details the expenditures associated with the subdivisions and the work packages for each fiscal year. The budgeting tool allows for the inclusion of the Basis of Estimates (BOE) to document the various costs. The five-year LRP budget is presented in the sandbox area in WEBUD. As in past years, WEBUD allows the selection of one of the three funding sources: new NSF funds corresponding to a specific year (also selectable); carry forward (note that for DKIST Operations they are folded together with the new funds); or grant funding. In this LRP, the largely unpredictable grant funding used by NISP is not included, and we only budget the NOAA funding provided to NISP for GONG operations. As reflected in the interagency agreement between NOAA and the NSF, this funding continues through the end of FY 2021, and its continuation depends on a future renegotiation between the agencies. This negotiation should consider an updated cost for operating the network that reflects inflation and new expenditures like the NOAO/CTIO site fee.

The fringe benefit rate for FY 2020 – FY 2024 was applied in accordance with the FY 2019 approved provisional indirect rate agreement letter from the NSF, dated November 8, 2018, remaining constant for all years. The indirect rates for FY 2020 – FY 2021 were applied in accordance with the NCOA Cost Model proposal submitted to the NSF on December 14, 2018, remaining constant for FY 2022 – FY 2024. Escalation on payroll and non-payroll was also applied in accordance with NCOA Cost Model proposal submitted to the NSF on December 14, 2018, at a rate of 3%.

Post-Retirement Benefits costs were based on FY 2019, escalated 3% per year, and allocated to the subdivisions based on projected payroll distribution per year from WEBUD. Historical Unfunded Liabilities were budgeted as described in AURA's Cost Rate Proposal dated October 11, 2018 ($50K/year), allocated to the subdivisions based also on projected payroll distribution per year. The University of Colorado Lease Office Space costs were based on FY 2019, escalated 3% per year, 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 2019, escalated 3% per year, and allocated to subdivisions based on projected Boulder headcount. AURA/CAS Human Resources software application (Ultipro) costs were based on FY 2019, escalated by 3% per year, and allocated to subdivisions based on projected Boulder headcount. Insurance costs were based on FY 2019, escalated by 3% per year, and allocated to subdivisions based on headcount, vehicle location, and direct usage as applicable.

The following tables provide a high-level description of how NSO is expecting to use the corresponding funds in each year, over the next five years. The sections that follow give a more detailed narrative of the budget allocations per subdivision and distinguish between payroll and non-payroll cost.

Table 10-2. NSO FY 2020 Spending Plan									
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance	Owner
NSO	NSO HQ	NSO Headquarters	No	8	$1,853,198	$1,817,884	$0	($35,314)	Pillet, Valentin M
NSO	DKIST OP	DKIST Operations	No	70.6	$17,413,749	$16,984,444	$0	($429,305)	Rimmele, Thomas R
NSO	NSO NISP	NSO NISP	No	11.6	$2,275,021	$2,268,660	$0	($6,361)	Hill, Frank
NSO	NSO SP	NSO SP	No	3	$402,198	$300,000	$0	($102,198)	
NSO	NSO NCSP	NSO Community Science Program	No	0	$0	$0	$0	$0	Uitenbroek, Han
NSO	NSO SP	NSO Management Fee	No	0	$69,012	$69,012	$0	$0	
			Total	93.3	$22,013,178	$21,440,000	-	$ (573,178)	

Table 10-2 provides for FY 2020 and each of the subdivisions the spending plan, new NSF funds, and the variance of the two (numbers in parenthesis indicate overspending). As explained below, the new NSF funds correspond to the PBR estimates for the Director's Office (NSO Headquarters), NISP, and the Management Fee (MF). DKIST funds are augmented by a portion of the program's carry forward (see Section 10.3). The negative variance in all subdivisions (except the MF) reflect guidance discussed with the NSF where all programs are budgeting above the corresponding year's target with the expectation that the use and scope of the additional funds are identified and explained. Several previous chapters in this document have already explained the need for extra funds. In the sections below, we will identify the additional costs and their proposed use for each of the subdivisions.

Table 10-2 does not include NCSP funds as the entire budget for the program corresponds to carry forward, and its use is described in Section 10.2.4.

Table 10-3. NSO FY 2021 Spending Plan									
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance	Owner
NSO	NSO HQ	NSO Headquarters	No	8.2	$1,998,310	$1,867,384	$0	($130,926)	Pillet, Valentin M
NSO	DKIST OP	DKIST Operations	No	95.3	$23,468,048	$17,514,444	$0	($5,953,604)	Rimmele, Thomas R
NSO	NSO NISP	NSO NISP	No	11.8	$2,339,925	$2,329,160	$0	($10,765)	Hill, Frank
NSO	NSO SP	NSO SP	No	2.3	$360,041	$300,000	$0	($60,041)	
NSO	NSO NCSP	NSO Community Science Program	No	0	$0	$0	$0	$0	Uitenbroek, Han
NSO	NSO SP	NSO Management Fee	No	0	$69,012	$69,012	$0	$0	
			Total	117.6	$28,235,336	$ 22,080,000	$ -	$(6,155,336)	

Tables 10-3, 10-4, 10-5, and 10-6 show the budgets for FY 2021, FY 2022, FY 2023, and FY 2024, respectively. Except for DKIST Operations, they are similar to FY 2020 with the only significant change corresponding to the escalation factor. For DKIST Operations, adding to the same escalation factor, the tables provide the reprofiling of carry-forward funds that peak in the early years of operations to help training the operations crew with the construction personnel that stays with NSO during this first years. The allocated funds for DKIST Operations in FY 2024 ramp down to a slightly lower budget that reflects our current best estimate for the steady-state cost of operating the facility.

The overall variance for the NSO Headquarters peaks in FY 2021 (Table 10-3). This higher deficit is due to the end of the DKIST Level-2 funding (NCSP) and the reabsorption of personnel that were temporarily allocated to this effort. This program is entirely funded from the DKIST Level-2 SFR, and its continuation depends on successfully obtaining additional funds. Section 7 describes future opportunities the NCSP is exploring to provide continuity to the Level-2 effort.

Table 10-4. NSO FY 2022 Spending Plan									
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance	Owner
NSO	NSO HQ	NSO Headquarters	No	7.9	$2,015,290	$1,925,884	$0	($89,406)	Pillet, Valentin M
NSO	DKIST OP	DKIST Operations	No	89.1	$23,552,479	$18,054,444	$0	($5,498,035)	Rimmele, Thomas R
NSO	NSO NISP	NSO NISP	No	11.8	$2,412,435	$2,400,660	$0	($11,775)	Hill, Frank
NSO	NSO SP	NSO SP	No	0			$0	$0	
NSO	NSO NCSP	NSO Community Science Program	No	0	$0	$0	$0	$0	Uitenbroek, Han
NSO	NSO SP	NSO Management Fee	No	0	$69,012	$69,012	$0	$0	
		Total		108.8	$28,049,215	$22,450,000	$0	($5,599,215)	

Table 10-4 (FY 2022) is the first year during which we are not planning to operate the Sunspot facility. The expectations are that, by then, the long-term viability of the Sunspot Solar Observatory Consortium (SSOC) will be better understood, and any site support will be an integral part of the Consortium plans. Alternatively, NSO's presence at and management of the site may be longer, in consultation with the NSF, for a variety of possible actions including decommissioning of the site.

Table 10-5. NSO FY 2023 Spending Plan									
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance	Owner
NSO	NSO HQ	NSO Headquarters	No	7.9	$2,076,750	$1,984,384	$0	($92,366)	Pillet, Valentin M
NSO	DKIST OP	DKIST Operations	No	84.6	$23,717,230	$19,104,444	$0	($4,612,786)	Rimmele, Thomas R
NSO	NSO NISP	NSO NISP	No	11.8	$2,486,405	$2,472,160	$0	($14,245)	Hill, Frank
NSO	NSO SP	NSO SP	No				$0	$0	
NSO	NSO NCSP	NSO Community Science Program	No	0	$0	$0	$0	$0	Uitenbroek, Han
NSO	NSO SP	NSO Management Fee	No	0	$69,012	$69,012	$0	$0	
		Total		104.3	$28,349,397	$23,630,000	$0	($4,719,397)	

Tables 10-5 and 10-6 are similar, with the only significant difference in the smaller budget for DKIST Operations in FY 2024. This difference originates from the end of the presence of construction personnel that transition temporarily to early operations.

Table 10-6. NSO FY 2024 Spending Plan									
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance	Owner
NSO	NSO HQ	NSO Headquarters	No	7.9	$2,139,950	$2,047,384	$0	($92,566)	Pillet, Valentin M
NSO	DKIST OP	DKIST Operations	No	80.9	$22,009,629	$19,684,444	$0	($2,325,185)	Rimmele, Thomas R
NSO	NSO NISP	NSO NISP	No	11.8	$2,562,214	$2,549,160	$0	($13,054)	Hill, Frank
NSO	NSO SP	NSO SP	No	0			$0	$0	
NSO	NSO NCSP	NSO Community Science Program	No	0	$0	$0	$0	$0	Uitenbroek, Han
NSO	NSO SP	NSO Management Fee	No	0	$69,012	$69,012	$0	$0	
		Total		100.6	$26,780,806	$24,350,000	$0	($2,430,806)	

The Management Fee included in the tables does not escalate and it remains at the AURA/NSF negotiated levels. The MF funds are used for allowable expenditures that are not part of the scope of the Cooperative Agreement.

Figure 10-2 provides the combined five-year spending plan for the three main programs of the Observatory.

	FY20	FY21	FY22	FY23	FY24
NISP	2,275,021	2,339,925	2,412,435	2,486,405	2,562,214
DKIST Ops	17,413,749	23,468,048	23,552,479	23,717,230	22,009,629
Director's Ofc	1,853,198	1,998,310	2,015,290	2,076,750	2,139,950

Figure 10-2 NSO Five-Year Spending Plan Summary.

10.2 Work Package Breakout

The online WEBUD tool allows various modes of visualizing the budget distributions and the BOE used in each subdivision. In this section, we present an overview of the most significant expenses projected for each program and the changes to the original CA proposal. The tables in this section show the spending plan for the major functional areas in more detail, breaking out payroll and non-payroll by work packages.

10.2.1 Director's Office (NSO HQ)

Table 10-7 presents the FY 2020 NSF funds for the Director's Office budget. Staff included in the Director's Office budget are the Director, the NSO Director's Office Executive Administrator, the NSO Business Manager for Operations, a combination of several fractional FTEs from various administrative positions, a similar mix of fractions of IT personnel, including the lead IT manager, and the entire NSO EPO group. Non-payroll expenses account for travel (including AURA oversight committees and the NSO Users' Committee), supplies and materials, and other miscellaneous costs incurred by the Director. A significant fraction of the budget ($318K, HQ Operations) is used to pay for about a third of the lease of the 3rd floor at the CU Boulder SPSC building. This cost includes many of the common areas.

The NSO EPO Program under the Director's Office consists of two FTEs, one in Colorado and one in Hawaiʻi. The Maui assistant focuses on promoting solar physics within the local community, in particular with K-12 students and teachers on the island. The late hire of EPO positions has provided some carry-forward funds that are being re-budgeted as a start-up package for the program. These resources are available primarily to increase the visibility of NSO in general, and of DKIST in particular, mostly by covering the cost of exhibit booths at AAS, AGU, and similar events.

Table 10-7. FY 2020 Director's Office Budget						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO HQ	8	$1,196,050	$657,148	$1,853,198	$0	$1,853,198
Director's Office	1.8	$483,498	$94,180	$577,678		$577,678
AURA Corporate Direct Charges			$8,432	$8,432		$8,432
Post-Retirement Benefits			$28,196	$28,196		$28,196
AURA Committees			$103,960	$103,960		$103,960
Business/Administration	1.7	$229,461	$57,360	$286,821		$286,821
Safety			$4,951	$4,951		$4,951
Recruitment/Relocation - New Positions				$0		$0
Recruitment/Relocation - Existing Positions				$0		$0
Carry Forward				$0		$0
Insurance			$5,430	$5,430		$5,430
CU Recharge Fees			$4,020	$4,020		$4,020
Science Staff - Research				$0		$0
Research Assistants				$0		$0
NSO Science-Collaborations				$0		$0
NISP Operations Service				$0		$0
DKIST Operations Service				$0		$0
Critical Science Plan (CSP) Activities				$0		$0
EPO - Scientists				$0		$0
Joint CU/NSO				$0		$0
Hale Post Doc				$0		$0
HQ Operations			$278,980	$278,980		$278,980
Boulder Computing IT	1.3	$142,367	$14,308	$156,675		$156,675
Vehicles			$4,401	$4,401		$4,401
HQ Development & Relocation				$0		$0
Instrument Development				$0		$0
Education and Public Outreach	3.3	$340,724	$52,930	$393,654		$393,654
Total:	8.0	$1,196,050	$657,148	$1,853,198	$0	$1,853,198
Target:						$1,817,884
Variance:						($35,314)

The reason for the $35K deficit in this budget (and all four additional years) is the inclusion of a third FTE to the EPO team. As explained in Section 10.8, additional personnel is needed if we want NSO to minimally compare with the manpower available at other similar astronomical centers.

Table 10-8 discloses the Director's Office carry forward, estimated to be $0.5M in FY 2020. WEBUD contains the re-budgeting details of these funds, including the BOE. Here we list the essential items covered by this budget:

1. The last series of DKIST Critical Science Plan (CSP) workshops intended to consolidate the multi-messenger science DKIST will carry out in coordination with the Parker Solar Probe (PSP) and Solar Orbiter (Section 3). Specifically, NSO will organize two workshops that include the PSP instrument teams, Solar Orbiter in-situ teams, and ground-based solar astronomers to discuss ways of establishing connections between remote sensing observations and in-situ measurements. These workshops will occur at US universities. A total budget of $49K (CSP Activities) has been allocated to this.

2. Equipment moves to Boulder and Maui that have not occurred yet because of delayed divestiture of the DST. The carry-forward budget is $114K (HQ Development & Relocation) for these pending transition activities.
3. Additional science support, not related to the programs, at a reduced level, compared to past years ($184K, Science Staff-Research).
4. The EPO start-up package ($32K, Education and Public Outreach).
5. Seed payroll funding ($27K, CMAG) for the Compact Magnetograph project.

Table 10-8. FY 2020 Director's Office Carry Forward

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	Carry Forward Base Revenue
NSO HQ	1.0	$121,664	$378,757	$500,420	$0	$500,420
Director's Office			$58,871	$58,871		$58,871
AURA Corporate Direct Charges			$0	$0		$0
SOLIS Tower Demolition			$0	$0		$0
AURA Committees			$0	$0		$0
Business/Administration			$8,976	$8,976		$8,976
Recruitment/Relocation - New Positions						
Recruitment/Relocation - Existing Positions						
Carry Forward			$0	$0		$0
Insurance			$0	$0		$0
CU Recharge Fees			$0	$0		$0
Science Staff - Research	0.7	$93,697	$90,608	$184,304		$184,304
Research Assistants			$0	$0		$0
NSO Science-Collaborations						
NISP Operations Service			$0	$0		$0
DKIST Operations Service			$0	$0		$0
Critical Science Plan (CSP) Activities			$49,368	$49,368		$49,368
EPO - Scientists			$0	$0		$0
Joint CU/NSO						
Hale Post Doc			$22,005	$22,005		$22,005
HQ Operations						
Boulder Computing IT						
Vehicles			$0	$0		$0
HQ Development & Relocation			$114,976	$114,976		$114,976
Instrument Development						
Education and Public Outreach			$32,046	$32,046		$32,046
Compact Magnetograph (CMAG)	0.3	$27,967	$1,907	$29,875		$29,875
Total:	1.0	$121,664	$378,757	$500,420	$0	$500,420
Target:						$500,000
Variance:						($420)

10.2.2 DKIST Operations Program

The budget profile provided by NSF for ramp up to operations of DKIST and subsequent steady-state operations was based on NSO's best understanding of DKIST Operations cost available at the time.

The multi-year budget profile was developed about eight years ago. Initial operations models were based on necessarily incomplete and in some cases inaccurate assumptions. For example, the staffing cost for Boulder and, in particular, Maui are significantly higher than was originally estimated. Early cost models used salary numbers for staff at Sacramento Peak Observatory, Sunspot, NM and applied an adjustment factor for Boulder/Maui. Given the salary structure in today's economy, the adjustment factors used have turned out to be too low. Also, the staffing levels to operate the complex DKIST facility were underestimated by about 10 FTE and non-payroll estimates, for example electricity (professional estimate by a company), were lower than current estimates.

A number of important and necessary items were not budgeted for in the CSA budget, including:

- SWG Chair/Community Liaison – Funded at three months/year during construction, this position has proven to be important to prepare and guide the community to ensure community readiness for making efficient use of the new capability DKIST offers. Preparation and maintenance of the Critical Science Plan and subsequent proposal preparation of CSP Science Use Cases as well as community outreach are part of this function. It is required that this function continues into early operations.
- Cost of Off-Site Storage. It was assumed previously that sufficient storage would be available at the telescope facility. However, it is now clear that the space within the summit facility is insufficient to store all, and in particular the larger items such as the M1 wash cart, M1 transport cart. Offsite storage will have to be leased to store these items.
- Time required daily to drive from DSSC to the summit and back for about 15-20 FTE was not properly accounted for in the CSA proposal.
- Increased Indirect Rates. The AURA indirect rates have increased since the time the CSA proposal was prepared.
- Unfunded Liabilities. Liabilities accumulated in past years (e.g., vacation) per agreement with NSF are now distributed to centers and programs via an annual "fee" over a period of 15 years.
- Post-Retirement Benefit Fee. Post retirement benefits expenses are now distributed to programs.
- Data Center Risk. Risk adjustment of cost for operations was unallowable at the time of CA proposal submission. However, the operations "project" includes major development efforts such as development of a Data Center and development of MCAO. For example, a detailed risk analysis has now been performed for the development and operations of the Data Center. The risk analysis was carried out according to recent NSF Large Facilities Manual (LFM) guidelines. The risk exposure for the development and operations of the Data Center is included in the new budget projections.

In FY 2018 and FY 2019, the staffing plan and estimates for non-payroll expenses for the steady-state operations phase has been updated based on current information of operations requirements. We note, as a caveat, that detailed bottom-up estimation of the summit technical operations effort, including maintenance, repairs and upgrades, is still incomplete in some areas and will be finalized during the final phase of construction. Estimates for non-payroll expenses such as electricity have also been refined based on more realistic (as implemented) system information that is now available.

In the CSA proposal, the first year of full operations was assumed to be FY 2019. According to the current Integrated Project Schedule (IPS), the end of construction is projected for April 2020. For operations budget planning purposes, we assume that planned construction schedule contingency will be used as planned, i.e., that the operations start will be in June 2020. According to the updated budget projections presented here, the steady-state operations budget has increased by about ~18%. Furthermore, the original proposal budget profile did not anticipate the 2.5-year transition phase requirements described in detail in Section 5.3.4.

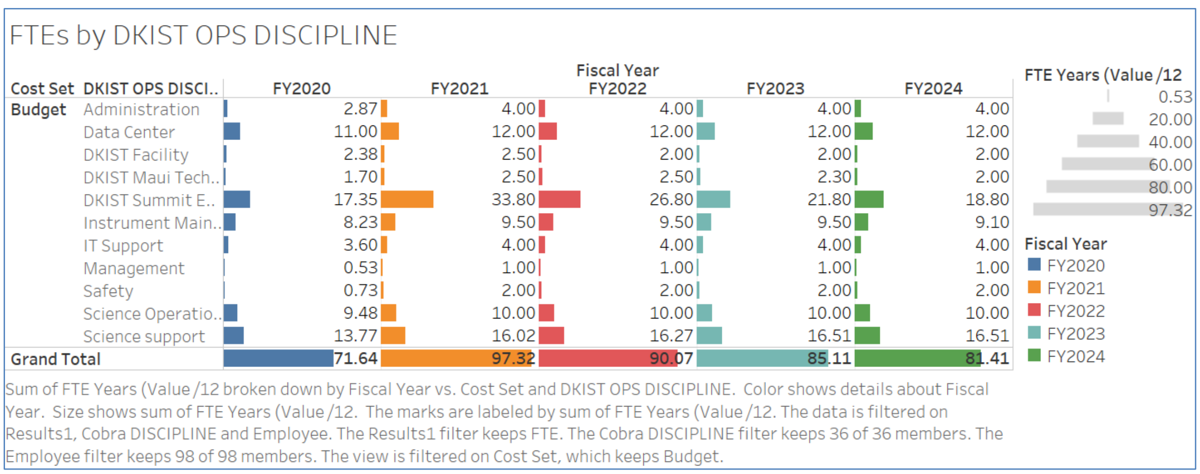
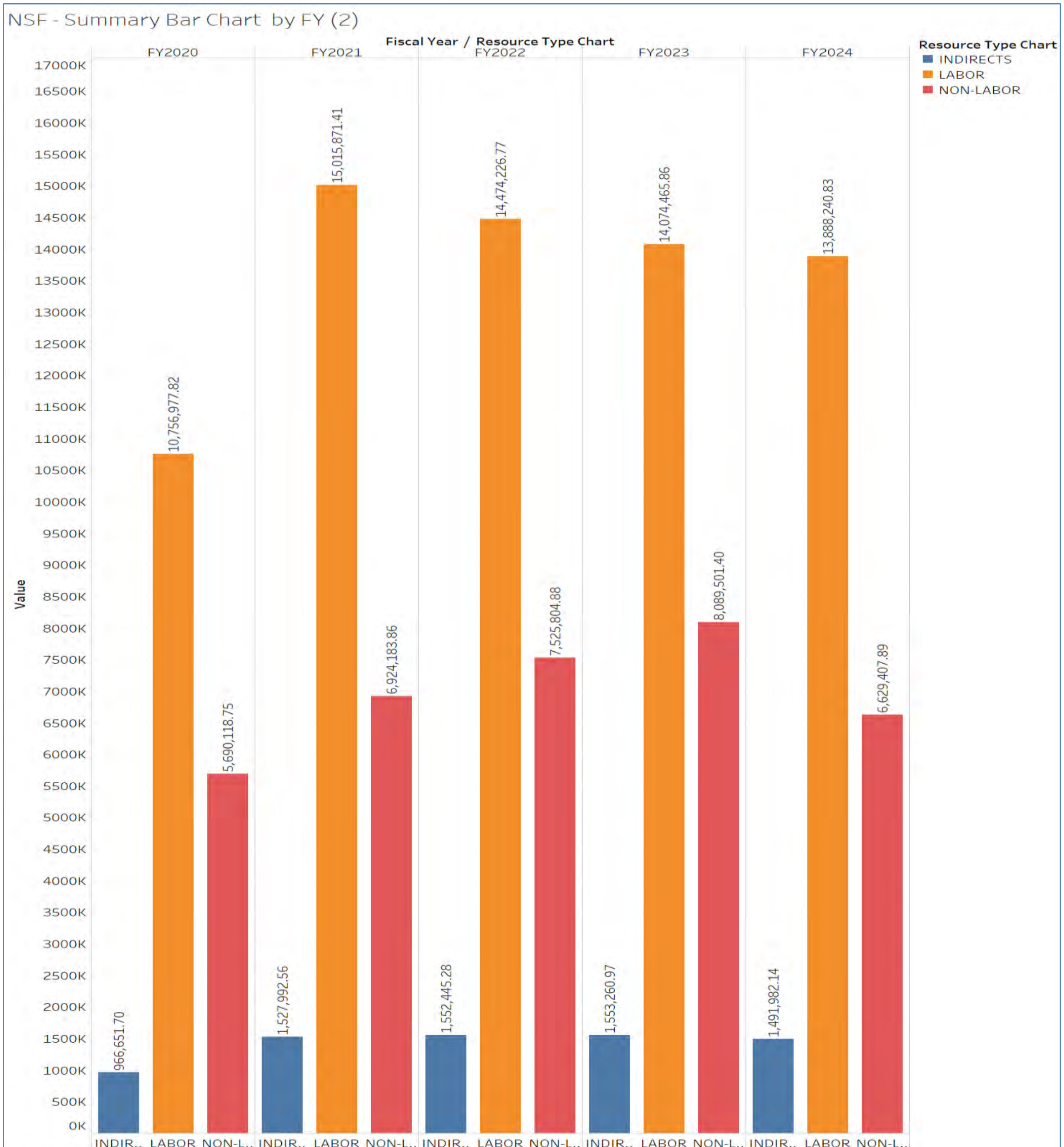


Figure 10-3. FTEs by DKIST Operations Discipline.

The transition-phase staffing cost adds to this steady-state estimate in the early operations years FY 2020 – FY 2023. Figure 10-3, which shows the staffing profile for each major WBS area as a function of fiscal year, visualizes this point. The WBS item 'DKIST Summit Engineering' is significantly enhanced during early operations (FY 2020 is a partial operations year) before steady state is reached in FY 2023. As mentioned before, 'DKIST Summit Engineering' consists of all necessary skills to support summit operations, including optical, mechanical, and electrical and software engineers and technicians. Our staffing estimates reflect our current best understanding of Observatory needs. We will dynamically manage staffing based on the realities "on the ground" as those develop, i.e., shift staffing between disciplines if needed. Consulting or contracting for expertise that is only needed on a short-term basis, for example, from other observatories will be utilized as practical.



Sum of Value for each Resource Type Chart broken down by Fiscal Year. Color shows details about Resource Type Chart. The marks are labeled by sum of Value. The data is filtered on Results1, Category, Cobra DISCIPLINE, Resourc Desc, Wbs Desc, Wp Desc, Employee, Resource, Cost Set and Resource Type. The Results1 filter keeps AURA_FEE, CAS_FEE, DIRECT, ESCALATION and FRINGE. The Category filter keeps 48 of 48 members. The Cobra DISCIPLINE filter keeps 36 of 36 members. The Resourc Desc filter keeps 242 of 242 members. The Wbs Desc filter keeps 7 of 7 members. The Wp Desc filter keeps 26 of 26 members. The Employee filter keeps 98 of 98 members. The Resource filter keeps 242 of 242 members. The Cost Set filter keeps Budget. The Resource Type filter keeps INDIRECTS, LABOR and NON-LABOR. The view is filtered on Fiscal Year and Resource Type Chart. The Fiscal Year filter keeps FY2020, FY2021, FY2022, FY2023 and FY2024. The Resource Type Chart filter keeps INDIRECTS, LABOR and NON-LABOR.

Figure 10-4. NSF summary bar chart by Fiscal Year.

Including the transition staffing and Data Center risk adjustment, the required budget profile for the years FY 2020 – FY 2024 is as follows. The detailed budget breakdown into work packages is summarized below.

Offsetting the increase in operations cost during FY 2020 – FY 2024 is the fact that we have so far underspent (compared to the CSA funding profile) during the operations ramp-up years FY 2015 – FY 2018 and we project a small underspent budget for FY 2019 as well. This has resulted in the significant funds that we plan to carry forward to FY 2020 and beyond as shown in Table 10-9. The carry forward is due to the fact that we have worked diligently to retain staff not just for construction but also with the goal of transferring many of the construction staff and their respective expertise into operations. This reduces to a significant extent the need for early hiring and cross training of an operations crew in parallel with the ongoing construction effort. Consequently, the operations ramp up of staffing has been slower than was projected in the original CSA proposal plan, which assumed an approximately linear ramp up of operations staff in parallel with the ongoing construction effort. The actual situation is a much slower ramp up in years before the end of construction and a very steep ramp up (transfer of construction staff) in FY 2020 (final year of construction).

Table 10-9. Proposed vs. Original CA Budget Profile

Year	LRP Budget Profile ($M)	NSF CSA Budget Profile($M)	NSF CSA Budget - Management Fee	Variance	CarryForward ($M)	Note	Note
		$13,030,000	$13,030,000		$13,030,000	carry forwad from FY19 to FY20	current best estimate
FY20	$17,413,749	$17,010,000	$16,984,444	($429,305)	$12,600,695	carry forwad from FY20 to FY21	LRP budget assumes June 2020 operations start
FY21	$23,468,048	$17,540,000	$17,514,444	($5,953,604)	$6,647,091	carry forwad from FY21 to FY22	includes transition staff
FY22	$23,552,479	$18,080,000	$18,054,444	($5,498,035)	$1,149,056	carry forwad from FY22 to FY23	transition labor ramping down
FY23	$23,717,230	$19,130,000	$19,104,444	($4,612,786)	$ (3,463,730)	unfunded amount FY23	transition labor ramping down, DC harware replacem. cycle
FY24	$22,009,629	$19,710,000	$19,684,444	($2,325,185)	$ (2,325,185)	unfunded amount FY24	
Total	$110,161,135	$104,500,000	$104,372,220		$ (5,788,915)	**total unfunded**	
					$ (4,628,915)	total unfunded - data center risk adjustment removed	descope 1
					$ (3,328,915)	total unfunded - 2-3 operations support positions removed	descope 2
					$ (2,368,915)	total unfunded - reduced transition engineering support	descope 3
					$ (368,915)	total unfunded - no detector replacement or upgrade during FY20-24	descope 4

The proposed profile reflects the best estimates based on current information and a much improved understanding of the cost structure for DKIST Operations. The carry forward from FY 2019 is depleted during FY 2020-2023 to fund the DKIST Operations budget profile. The draw-down profile of carry-forward funds during FY 2020-2023 is indicated in the 'CarryForward' column. According to these budget estimates, a funding deficit exists in FY 2023 and FY 2024. Descope options are discussed below.

In addition, anticipating this shortfall of operations funds in the out years DKIST has taken a very conservative approach to new development activities. A planned start of a second-generation instrument effort was put on hold until the overall budget situation is fully understood. The instrumentation program will be limited to the DKIST MCAO development, and upgrades and improvements to existing instrumentation.

This approach has resulted in the aforementioned significant carry forward. The carry forward funds will be required in the years FY 2020 – FY 2024 to offset the increase in operations cost explained above. However, as is also apparent in Table 10-9, the carry forward is insufficient. The amount of $5.8M remains unfunded.

To fully and adequately fund DKIST Operations, the proposed LRP budget profile is required. The current estimate for the steady-state operations cost amounts to 6% of the DKIST construction cost.

This ratio is on the low end of facility operations cost only (not including a Data Center) for comparable facilities. We emphasize that the presented DKIST Operations budget includes the cost of a Data Center that processes, stores and distributes to the world-wide community on average 6 PB of data per year. The risk-adjusted Data Center budget amounts to about 17% of the annual operations budget.

If de-scopes for the full unfunded amount have to be implemented, the following descope options would have to be considered:

- *Remove funding for Data Center risk.* Impact: Level of effort for calibration effort implementation. Data Center operational readiness will be delayed. Delays in data delivery to users. Reduction of services to users.
- *Reduction in support staff.* Impact: Reduction of services for users. Reduction of operating hours. Longer delivery times for data products. Reduction of service-mode operations.
- *Reduce transition engineering support.* Impact: Extended transition period with low Observatory efficiency. Incomplete knowledge transfer into operations. Higher downtime.
- *Longer hardware replacement cycle, including summit systems and data center hardware.* Effected hardware includes detectors, storage and processing hardware, filters. Impact: Increased risk of hardware failures and subsequent increase in Observatory or Data Center downtime.
- *Delay or cancellation of upgrades and new developments*:
    - *Postpone MCAO purchases and level-of-effort funding of personnel.* Impact: Delay in MCAO implementation. MCAO becomes more expensive due to extended schedule and marching-army cost.
    - *Delay or cancel instrument upgrades.* Impact: Instrumentation will become outdated, limiting science capabilities and long-term viability of DKIST.

We note that development and implementation of a major second-generation instrument is not feasible within the budget constraints. We are constantly pursuing partnerships, in particular, with potential international partners with the goal of augmenting the instrumentation effort.

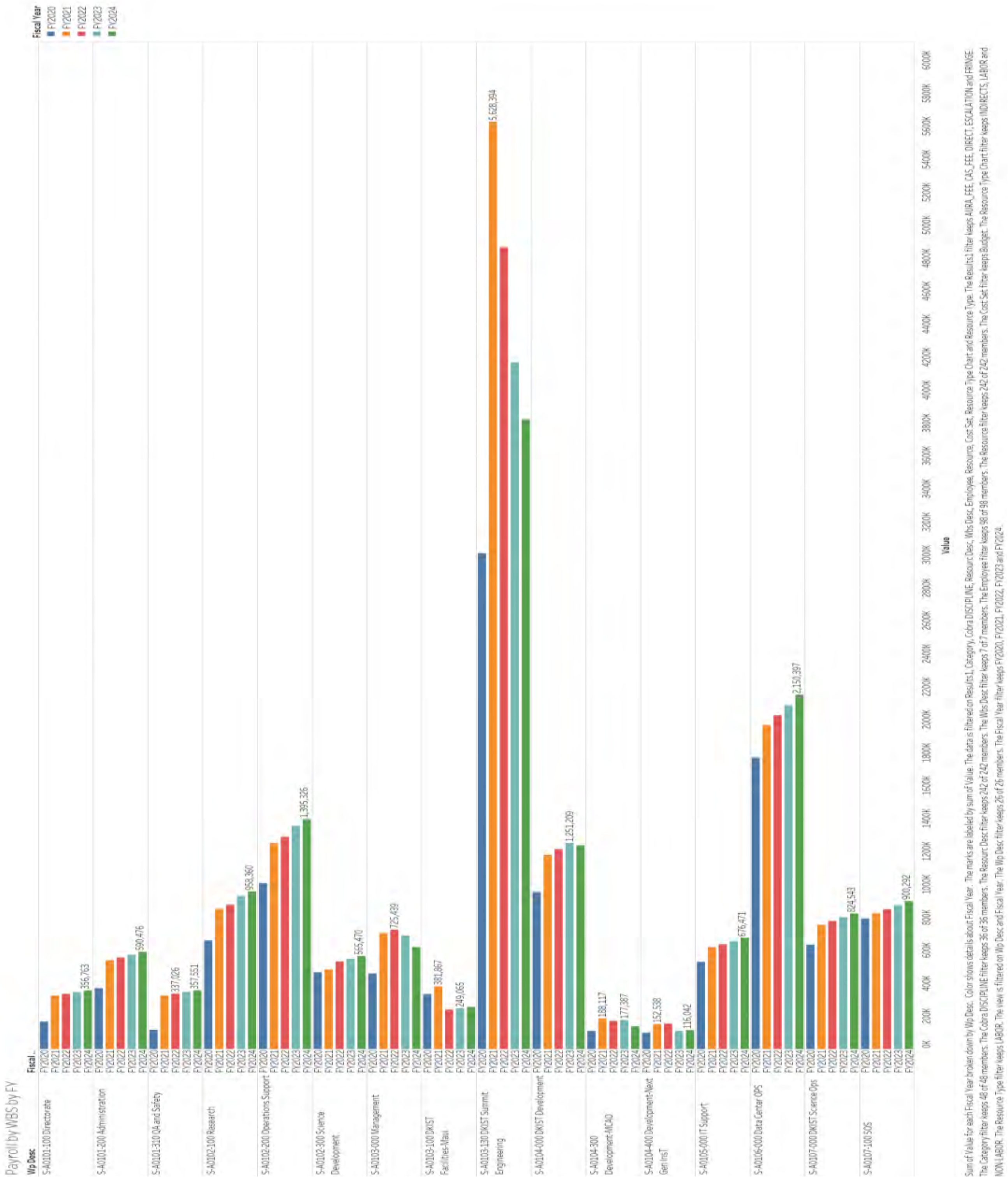


Figure 10-5. Labor budget as a function of work-breakdown-structure element and fiscal year.

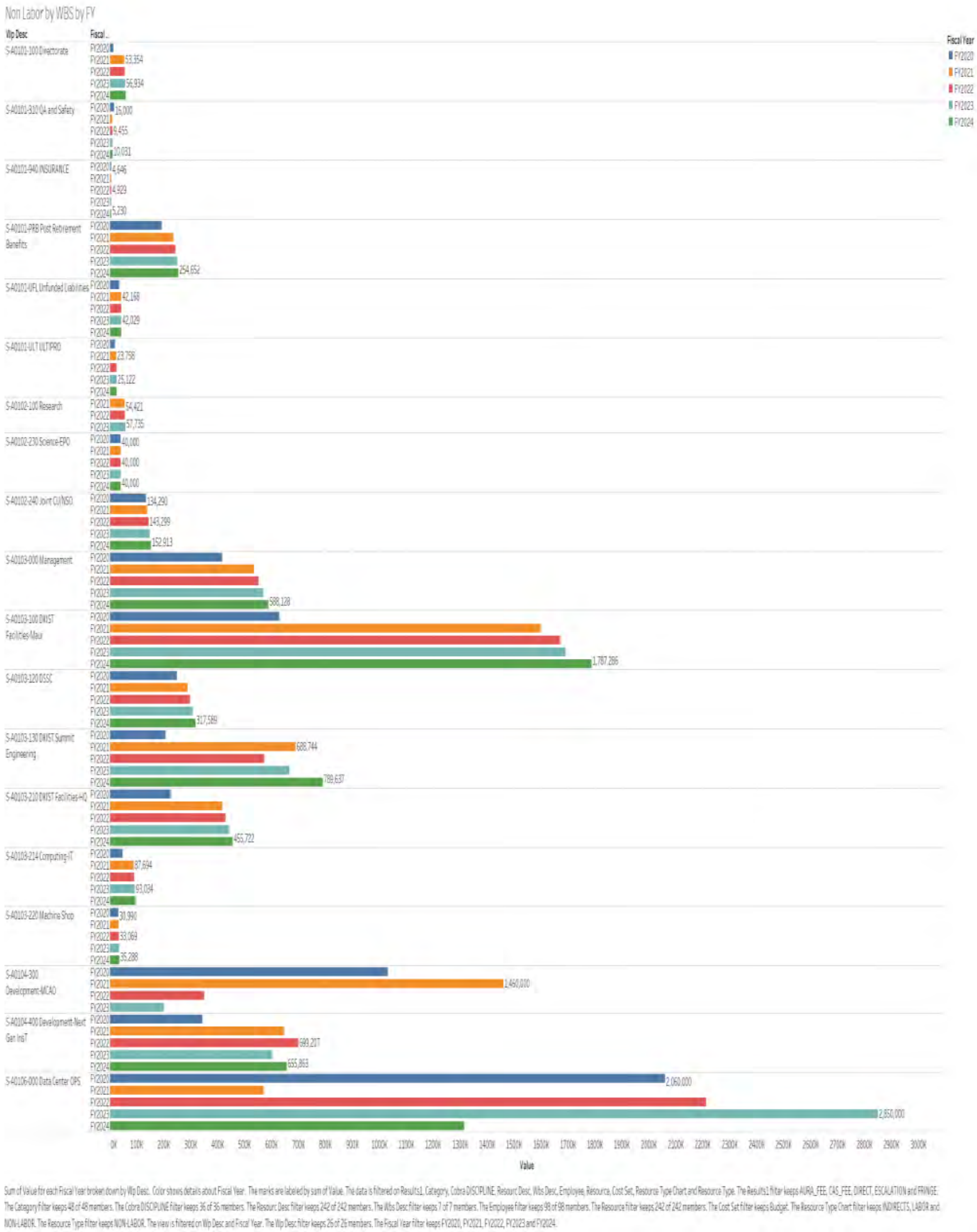


Figure 10-6. Non-Payroll Budget as function of work-breakdown-structure element and fiscal year.

The large fluctuations in the Data Center budget are due to initial hardware purchase in 2020, addition of storage capacity, and hardware refresh cycle in FY 2022 – FY 2023.

Table 10-10. FY 2020 DKIST Operations Program Budget						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	Carry Forward Base Revenue
DKIST Operations	70.6	$10,756,979	$6,656,770	$17,413,749	$0	$17,413,749
Directorate	0.5	$156,867	$24,491	$181,358		$181,358
Observatory Ops Management: Business/Admin.	2.9	$347,708	$23,714	$371,422		$371,422
Safety	0.7	$110,474	$24,626	$135,100		$135,100
Research	4.3	$617,675	$42,125	$659,801		$659,801
Operations Support	6.8	$944,218	$64,396	$1,008,613		$1,008,613
Science - DKIST EPO			$41,705	$41,705		$41,705
Joint CU/NSO			$143,449	$143,449		$143,449
Science - Development	2.8	$436,872	$29,795	$466,666		$466,666
Management	1.6	$430,828	$474,288	$905,116		$905,116
DKIST Facilities-Maui	2.4	$313,095	$693,251	$1,006,346		$1,006,346
DSSC			$251,034	$251,034		$251,034
DKIST Summit Engineering	18.2	$2,817,830	$412,012	$3,229,842		$3,229,842
DKIST Facilities-HQ			$241,579	$241,579		$241,579
Computing - IT			$50,402	$50,402		$50,402
Machine Shop			$33,104	$33,104		$33,104
DKIST Development	5.3	$892,439	$60,864	$953,304		$953,304
Development-MCAO	0.6	$104,606	$1,047,364	$1,151,970		$1,151,970
Development-Next Generation Instruments	0.6	$93,926	$355,604	$449,530		$449,530
IT Support	3.6	$496,737	$33,877	$530,615		$530,615
Data Center Ops	11.0	$1,656,763	$2,252,853	$3,909,617		$3,909,617
DKIST Science Ops	3.5	$594,713	$40,559	$635,273		$635,273
Science Ops Specialist (SOS)	6.0	$742,227	$50,620	$792,846		$792,846
DKIST Ops Post-Retirement Benefits			$205,075	$205,075		$205,075
Historical Unfunded Liabilities			$35,414	$35,414		$35,414
NSO Insurance through AURA			$4,963	$4,963		$4,963
Ultipro			$19,607	$19,607		$19,607
Total:	70.6	$10,756,979	$6,656,770	$17,413,749	$0	$17,413,749
Target:						$16,984,444
Variance:						($429,305)

10.2.3 NSO Integrated Synoptic Program (NISP)

The NISP combines staff from SOLIS and GONG. Following the recommendation of the NSF/AST Portfolio Review Committee, the NSF base funding for NISP was $2M (excluding indirect payments) starting in FY 2016. Beginning in FY 2020, the NISP budget will, for the first time, increase according to the assumed escalation factor. The total budget for the program has been augmented in the past by a NOAA contribution of $800K for GONG operations and by grants at a level slightly below $500K. The program continues to use the one-time contribution received in FY 2016 for GONG refurbishment, and unused funds as part of the program's carry-forward budget.

The NISP budget breakdown for FY 2020 new base funding, NOAA GONG support, and carry forward is presented in Tables 10-11, 10-12, and 10-13, respectively. Currently, NISP has a total of approximately 20 FTEs. The NSF base funding covers about 11 FTEs; 4 FTEs are allocated to GONG operations (NOAA funding) and the remaining 5 FTEs are grant supported (not presented here).

NISP comprises an Atmospheric Section and an Interior Section, each led by a scientist who reports to the NISP Associate Director. The Telescope Operations and Instrument Development staff, supervised by the NISP Head of Engineering, support both SOLIS and GONG instruments and upgrades as needed. Scientific staff support the various NISP data products and respond to the community's need for new data. Both SOLIS and GONG data are processed daily by the NISP Data Center staff and made available for downloading by the solar community. NISP base funding is used to cover scientific support to the program, administrative staff, NISP Data Center activities, and the Big Bear Solar Observatory (BBSO) MOU for SOLIS operations ($260K in Table 10-11).

Table 10-11 shows a base funding deficit of $6K and increases slightly over the out years. The budget was adjusted to a small deficit by allocating most of the NISP scientists to a fraction of their time, as a 100% allocation would have shown a deficit above $300K. This deficit is structural and is not due to the addition of any new personnel or non-payroll commitment. It shows that for the program to operate as it has in the past, the allocation of scientists to external grant funding needs to increase beyond the levels allocated in past years.

Table 10-11. FY 2020 NSO Integrated Synoptic Program Budget

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	11.6	$1,481,336	$793,685	$2,275,021	$0	$275,021
NISP Directorate	0.5	$104,450	$20,096	$124,547		$124,547
Scientific Staff	2.9	$385,789	$50,023	$435,812		$435,812
Data Center	4.3	$556,500	$211,283	$767,783		$767,783
Engineering Operations	2.5	$290,060	$35,127	$325,187		$325,187
SOLIS Ops/Support			$260,415	$260,415		$260,415
Admin	0.7	$68,741	$4,936	$73,677		$73,677
Post-Retirement Benefits			$27,737	$27,737		$27,737
CU IT Connectivity Fees			$9,772	$9,772		$9,772
Unfunded Liabilities			$4,790	$4,790		$4,790
CU and Machine Shop Leaes Fees			$164,336	$164,336		$164,336
NSO IT	0.8	$75,796	$5,169	$80,965		$80,965
Total:	11.6	$1,481,336	$793,685	$2,275,021	$0	$2,275,021
Target:						$2,268,660
Variance:						($6,361)

The $818K from NOAA/SWPC (Table 10-12, 'NISP NOAA/SWPC Budget') covers recurrent operational costs for the GONG network. Payroll includes technical maintenance, scientific validation, and Data Center costs, and totals $405K ('SWPC Payroll'). The remaining $412K ('Non-Staff Cost' column) is used to cover facilities costs at the six stations and the preventive maintenance trips to each site.

Table 10-12. NISP NOAA SWPC Budget						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	3.3	$405,635	$412,695	$818,330	$0	$818,330
SWPC Payroll	3.3	$405,635	$64,699	$470,333		$470,333
SWPC Learmonth (LE)			$47,483	$47,483		$47,483
SWPC Udaipur (UD)			$30,518	$30,518		$30,518
SWPC Tenerife (TD)			$32,597	$32,597		$32,597
SWPC CTIO (CT)			$67,734	$67,734		$67,734
SWPC Big Bear (BB)			$77,251	$77,251		$77,251
SWPC Mauna Loa (ML)			$66,026	$66,026		$66,026
SWPC Boulder			$3,909	$3,909		$3,909
SWPC Network			$22,478	$22,478		$22,478
Total:	3.3	$405,635	$412,695	$818,330	$0	$818,330
Target:						$818,330
Variance:						$0

NISP estimated carry-forward funds in FY 2020 (Table 10-13) total $839K, with $396K allocated for GONG refurbishment and $443K for Data Center equipment.

Table 10-13. FY 2020 NISP Carry Forward						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP			$839,082	$839,082	$0	$839,082
NISP Data Center			$442,626	$442,626		$442,626
GONG Refurbishment			$396,455	$396,455		$396,455
Total:			$839,082	$839,082	$0	$839,082
Target:						$839,082
Variance:						$0

NISP faces considerable challenges over the next years. Several factors have contributed to constrain the budget severely. The continued application of merit increases over four years in a program that is cost capped has created a deficit in the program's payroll. Additionally, the cost of SOLIS relocation to BBSO is now better understood, and it is at least $300K higher than initially expected. To complicate things further, the amount of funds from external grants is smaller than in previous years, and NOAO/CTIO has announced that they will start charging a $50K site fee for the GONG shelter footprint.

To this challenging budget situation, and complicating things further, NISP suffered substantial personnel attrition during the transition to Colorado. The program lost proportionally large fractions of its technical expertise while it was able to maintain a robust scientific group. Going forward, the viability of the program will require rebalancing the existing expertise, in particular as it relates to the allocation of scientists to base funding vs external grants.

10.2.4 NSO Community Science Program (NCSP)

Table 10-14 shows the one-year budget breakdown for the program carry forward in FY 2020 and is budgeted following the guidelines presented in the original DKIST Level-2 proposal.

The program's primary mission is the development of DKIST Level-2 data products. The actual creation of these data products will have to wait until the DKIST starts producing Level-1 data. In preparation for this phase, NCSP is defining in FY 2019 the specific Level-2 data products included in the program and will search for the best existing analogs from other telescopes and instruments to train the Level-2 pipelines. NCSP plans to use the data from the DST service mode that represents a rather unique, readily-available source, with observations of relevant spectral lines taken with instruments that bear similarities with those under construction for DKIST.

The DKIST Level-2 proposal included three interrelated initiatives: a data products initiative; a community-oriented initiative; and a university-oriented initiative that continues in FY 2020. All three initiatives benefit from logistics and outreach support provided by the NSO.

Table 10-14. FY 2020 NSO NCSP Carry Forward Budget

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO Community Science Program	11.5	$1,391,351	$3,315,790	$4,407,141	$0	$4,407,141
Administrative Support	0.5	$52,305	$48,712	$101,017		$101,017
Science Support	5.4	$525,673	$811,738	$1,337,411		$1,337,411
Graduate Students Support			$1,196,063	$1,196,063		$1,196,063
Visitors Program-Short Term			$217,601	$217,601		$217,601
Visitors Program-Long Term	1.1	$161,547	$41,637	$203,184		$203,184
Service Support	2.3	$328,326	$22,392	$350,718		$350,718
Data Center Support	1.8	$271,093	$416,587	$687,677		$687,677
Headquarters Expenditures			$72,863	$72,863		$72,863
Data Triaining Workshop			$468,500	$468,500		$468,500
Curriculum Preparation	0.5	$52,407	$19,701	$72,108		$72,108
Total:	11.5	$1,391,351	$3,315,790	$4,707,141	$0	$4,707,151
Target:						$4,707,324
Variance:						$173

The Data-Products Initiative represents an effort that occurs at NSO and targets Level-2 data products at first light. It represents about 50% of the total funding. The original proposal included two-FTE scientists from NSO and three new postdoc positions to develop the scientific pipelines for producing Level-2 data. NCSP has changed this model to benefit from the existing expertise at NSO in the Level-2 area. Currently, the program includes a more significant number of NSO scientists as part of this effort, and the number of new hires in the form of postdocs is only one. The payroll service support from NSO scientists to NCSP totals $328K ('Service Support'), whereas the research time is $525K ('Science Support') including one postdoc whose research will link to the generation and use of Level-2 data products. Non-payroll scientific support for this initiative includes the cost of the hardware for producing the Level-2 data products. NCSP has performed a tradeoff study and identified a cost-effective way of using the CU Boulder Office of Information Technology services to manage and administer a DKIST Level-2 computer cluster based on two 1296 Core Cluster, Xeon 6150 2.7Ghz, 192 Gb/node from Infiniband. Including the travel for scientists, the cost of this work package is $1,337K. Data Center support for the DKIST Level-2 effort is split into payroll, $271K, and $416K for data-distribution hardware ('Data Center Support').

The Community-Oriented Initiative establishes a visitor program that benefits the broader solar community. It provides support for training and mentoring activities with experts from all over the world. The initiative offers two schemes to participate in these activities, a short-term visiting program with a cost of $217K ('Visitors Program-Short Term'), and a long-term visiting program (that includes stipends) with a budget of $203K ('Visitors Program-Long Term').

The University-Development Initiative helps grow the DKIST community and takes place at graduate programs in the country. Support for graduate students and postdocs ('Graduate Students Support') accounts for $1,196K of the FY 2020 budget. However, only a fraction will be actually spent, while the remaining amount will only be encumbered for future years. NCSP selected in FY 2019 a total of 12 graduate students and postdocs that form the DKIST Ambassadors Program. This program provides a matching-funds opportunity for students that spans over a total of four years, with NCSP and the selected institution covering two years each. Thus, some of the actual expenditures will occur in FY 2021 and FY 2022, depending on the model adopted for the matching funds.

The overall goal of the DKIST Ambassador Program is to create a well-networked cohort of DKIST data experts at US universities who can support and participate in the creation of Level-2 data products for DKIST through the implementation of DKIST Science Use Cases. The University-Development Initiative includes an additional $468K ('Data Training Workshop') for broad community training activities in the creation of Level-2 data products, and that builds on the successful series of DKIST Critical Science Plan Workshops.

NCSP has a sub-award with the High-Altitude Observatory that defines the participation of scientists from this institution into the three initiatives explained above and that continue in FY 2020.

10.2.5 Sacramento Peak

In FY 2020 and FY 2021, NSO plans to operate the Sunspot site and collaborate with the SSOC in the operations of the Dunn Solar Telescope. NSO intends to charge the SSOC for costs that include the DST Chief Observer and telescope and visitor's center utilities and maintenance following the guidelines in the MOU between NMSU and AURA. It should be noted that the funds associated with these charges to the SSOC are outside of the budget presented in this document and are not in WEBUD. For the regular site operations and maintenance, including the site manager, NSO will negotiate each year an SFR with the NSF. Currently, we estimate that we need a slightly more than $300K per year to operate the site (See Table 10-15).

Over the past two years, NSO has used previous funding for improvements of the DST such as the elevator platform, septic system renovations, roof repairs, and existing security contracts. These expenditures have exhausted the Sunspot budget and no carry forward exits; any funding for additional improvements or closeout activities will have to be part of a new SFR negotiation.

Table 10-15. FY 2020 NSO Sacramento Peak Budget						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO SP	3.0	$263,073	$139,126	$402,198	$0	$402,198
Administrative Services	1.0	$118,105	$24,717	$142,822		$142,822
Scientific Staff						
Telescope Operations						
Instrument Develop. &Telescope Maint.						
Computing Support			$4,380	$4,380		$4,380
Facility Maintenance	2.0	$144,967	$110,030	$254,997		$254,997
Housing						
Visitor Center						
Total:	6.0	$263,073	$139,126	$402,198	$0	$402,199
Target:						$300,000
Variance:						($102,198)

10.2.6 AURA Indirect Costs, Fringe Benefit Rate and Fee

Tables 10-16 and 10-17 show the expenses NSO incurs for AURA for Facilities and Administrative (F&A) costs, Central Administrative Services (CAS), and Human Resources (HR) for FY 2020 NSF Funds/DKIST carry forward, and for FY 2020 NSO carry forward, respectively.

The fringe benefit rate for FY 2020 – FY 2024 was applied in accordance with the FY 2019 approved provisional indirect rate agreement letter from the NSF, dated November 8, 2018, remaining constant for all years. The indirect rates for FY 2020 – FY 2021 were applied in accordance with the NCOA Cost Model proposal submitted to the NSF on December 14, 2018, remaining constant for FY 2022 – F Y2024.

The AURA Fee is assumed at the current negotiated amount ($69K/year) per Cooperative Support Agreement Amendment #14. The corresponding budget has been subtracted from the programs that make use of it: HQ, DKIST, and NISP.

Table 10-16. AURA Indirect Costs (FY 2020 NSO Base Funds) + DKIST Carry Forward	
Indirect Cost Type	Charge
AURA CAS & HR Support	$749,889
AURA Corporate F&A	$491,432
Total	$1,241,321

Table 10-17. AURA Indirect Costs NSO Carry Forward	
Indirect Cost Type	Charge
AURA CAS & HR Support	$207,947
AURA Corporate F&A	$136,524
Total	$334,471

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APPENDICES

APPENDIX A. NSO BUDGET EXPENDITURES (FY 2015 – FY 2019)

TABLE A-1

NSO Financial Management Report

FY 2015

	Budget	- Expenditures	- Encumbrance	+ Prior Encumb	= Balance
DKIST OPERATIONS					
Payroll	1,273,098	1,146,478	-	-	126,620
Supplies and Materials	90,742	29,004	4,009	-	57,728
Utilities and Communications	-	21	479	-	(500)
Domestic Travel	116,200	55,093	10,460	15,790	66,437
Foreign Travel	108,400	5,558	-	-	102,842
Contracted Services	200,000	6,374	76,696	-	116,930
Other Services	-	12,023	-	-	(12,023)
Equipment	1,600,000	1,209,747	279,074	-	111,179
Total DKIST OPERATIONS	**3,388,440**	**2,464,298**	**370,719**	**15,790**	**569,213**
DIRECTOR'S OFFICE					
Payroll	843,520	664,973	-	-	178,547
Supplies and Materials	89,907	295,249	30,725	3,238	(232,828)
Utilities and Communications	55,000	53,648	-	-	1,352
Equipment Repair and	-	5,738	4,769	-	(10,508)
Rental and Lease Expense	732,000	597,202	152,870	857	(17,216)
Domestic Travel	99,500	104,826	6,941	6,548	(5,719)
Foreign Travel	15,000	18,958	1,125	2,052	(3,030)
Contracted Services	365,000	52,376	-	14,134	326,758
Other Services	3,441,582	1,268,101	25,712	14,739	2,162,509
Equipment	-	8,537	-	-	(8,537)
G&A Overhead	-	(56,792)	-	-	56,792
Facilities Use Fee	145,000	181,988	-	-	(36,988)
Miscellaneous Revenue	-	(2,420)	-	-	2,420
Total DIRECTOR'S OFFICE	**5,786,509**	**3,192,386**	**222,142**	**41,569**	**2,413,551**
SUNSPOT					
Payroll	2,172,208	2,015,403	-	-	156,805
Supplies and Materials	258,900	176,266	24,985	3,826	61,474
Utilities and Communications	267,000	245,534	52,667	39,995	8,794
Equipment Repair and	2,000	19,817	1,162	-	(18,979)
Domestic Travel	36,500	25,296	933	1,088	11,358
Foreign Travel	16,760	8,181	-	-	8,579
Contracted Services	20,000	9,946	11,068	6,138	5,123
Other Services	30,200	61,737	3,958	5,035	(30,460)
Rent Revenue	(104,000)	(110,906)	-	-	6,906
Meal Revenue	(17,000)	(8,751)	-	-	(8,249)
Sales Revenue	(55,000)	(52,056)	-	-	(2,944)
Miscellaneous Revenue	(336,000)	(371,858)	-	-	35,858
Total SUNSPOT	**2,291,568**	**2,018,609**	**94,775**	**56,082**	**234,266**
TUCSON					
Payroll	296,601	225,994	-	-	70,607
Supplies and Materials	17,000	7,285	500	794	10,009
Utilities and Communications	-	104	-	-	(104)
Equipment Repair and	-	1,032	-	-	(1,032)
Domestic Travel	14,099	14,699	-	-	(600)
Foreign Travel	5,000	-	-	-	5,000
Contracted Services	-	-	-	369	369
Other Services	7,000	4,777	-	-	2,223
Total TUCSON	**339,700**	**253,891**	**500**	**1,163**	**86,472**
NISP					
Payroll	3,239,228	2,178,055	-	-	1,061,173
Supplies and Materials	126,500	93,964	10,342	7,528	29,721
Utilities and Communications	74,900	52,155	22,607	25,024	25,162
Equipment Repair and	4,000	1,005	429	287	2,854
Rental and Lease Expense	-	5,146	-	-	(5,146)
Domestic Travel	42,300	53,158	2,376	5,490	(7,744)
Foreign Travel	22,000	41,675	1,600	7,315	(13,960)
Contracted Services	63,400	27,306	12,000	84,662	108,756
Other Services	99,070	10,716	-	-	88,354
Equipment	74,569	-	250,000	-	(175,431)
Miscellaneous Revenue	(749,600)	-	-	-	(749,600)
Total NISP	**2,996,367**	**2,463,180**	**299,354**	**130,305**	**364,138**
Total NSO	**14,802,584**	**10,392,364**	**987,489**	**244,909**	**3,667,640**

Table A-1 is a reconciliation of the NSO FY 2015 budget, which shows budget, expenditures, encumbrances, adjustments, and final balance by category by Sub-Division. The FY 2015 budget includes the $1.8M carry forward from the prior year, increasing the overall funding levels to $14.8M. Expenditures, including encumbrances, were $11.3M, representing a variance with respect to the original budget of $3.7M, and it is primarily the result of the late start of the Cooperative Agreement.

Due to the uncertainties during the Cooperative Agreement negotiations, many elements of the transition of Headquarters to Boulder, Colorado were put on hold, awaiting final approval of the CA. The FY 2014 Observatory carry forward of $800K was largely unused; the first floor lab remodeling (budget was $119K) was halted; most of the new hires and relocations did not happen ($186K budgeted for Boulder and $64K for Maui).

DKIST Operations

The major components that make up payroll expenditures in the amount of $1.1M consist of $62K DKIST Operational Planning; $200K Scientific Staff Ops Support; $60K DKIST Scientific Support; $64K DKIST Fellowship; $84K AO/MCAO Development; and $598K Data Center Development.

The purchase of the land for the Maui Remote Operations Building (ROB; renamed DKIST Science Support Center, DSSC)) accounts for the $1.2M expenditure in the 'Equipment/Land' category.

Foreign travel expenditures were underspent by $102K, primarily in the areas of DKIST Scientific Staff, $38K, and DKIST Fellowship, $64K. This variance is related to the late approval of the CA.

Contracted Services expenditures were under spent by $116K, primarily due to schedule delays, pending requisite approval, in the Remote Operations Building Support, $67K, as well as Instrument Development, $50K.

Director's Office

The major components that make up the payroll variance of $178K relate to new hire and relocation delays from Sunspot to Boulder, and delays in the start of the EPO program, given the uncertainties with the budget in FY 2015 during the Cooperative Agreement (CA) negotiations.

The major components that make-up Other Services expenditures in the amount of $1.3M consist of $100K Management Fee; $257K AURA CAS Support; $143K AURA Corporate G&A; $147K AURA HR Support; $50K AURA Corporate Direct Charges; $402K NOAO support expenses (i.e., Library, Photo Lab, EPO, CCS). Additional smaller expenditures in the Other Services expenditures are related to HQ Development & Relocation to Boulder, Colorado, IT Support, and conferences. The $2.2M balance in this category primarily relates to expenditures related to the relocation of HQ to Boulder, pending Cooperative Agreement negotiations.

The major components that make up Supplies and Materials, $295K, consist of expenditures related to relocation of HQ to Boulder, Colorado, including, furniture, and network equipment. The negative balance in the Supplies and Materials category ($232K) is offset as some of these items were budgeted in the Contracted Services category.

The major components that make up Rental and Lease, $597K, include CU Boulder lease and lab expenditures, related to the HQ relocation to Boulder, Colorado.

Sunspot

The major components that make-up payroll expenditures in the amount of $2M consist of $200K Scientific Research; $112K User Support/DST; $50K Scientific Support; $61K Telescope Operations; $165K DST Observing; $105K Computing; $227K CCD Integration; $75K Project Administration; $84K General Electronics; $212K Facility Support; and $220K Administrative Support.

NISP

The major components that make-up payroll expenditures in the amount of $2.1M consist of $415K NISP General Activities; $241K NISP Management; $615K NISP Data Management; $155K NISP Science; $392K Scientific Staff; and $134K SOLIS Relocation Activities.

Equipment includes an encumbrance in the amount of $250K that is related to data storage cluster with integrated hardware/software, triple-arity data protection, and 5-year maintenance for the Data Center.

The $750K Misc Revenue carry forward relates to the USAF Support for NISP with a one-year FY 2015 term grant of $750K.

TABLE A-2

NSO Financial Management Report

FY 2016

	Budget	- Expenditures	- Encumbrance	+ Prior Encumb	= Balance
DKIST OPERATIONS					
Payroll	2,893,312	1,746,296	-	-	1,147,016
Supplies and Materials	128,794	32,893	4,521	4,009	95,390
Utilities and Communications	26,774	7,006	447	479	19,800
Domestic Travel	301,811	48,687	12,897	10,460	250,687
Foreign Travel	95,316	30,873	7,000	-	57,443
Contracted Services	233,200	116,806	74,875	76,696	118,215
Other Services	290,317	23,561	8,332	-	258,423
Equipment	3,008,406	280,997	10,386	279,074	2,996,097
Total DKIST OPERATIONS	**6,977,930**	**2,287,119**	**118,458**	**370,719**	**4,943,072**
DIRECTOR'S OFFICE					
Payroll	1,495,521	660,139	-	-	835,382
Supplies and Materials	165,884	257,002	3,944	30,725	(64,337)
Utilities and Communications	14,415	3,491	-	-	10,924
Equipment Repair and	-	4,597	-	4,769	172
Rental and Lease Expense	1,044,351	1,086,458	128,697	152,870	(17,933)
Domestic Travel	174,142	154,888	16,193	6,941	10,002
Foreign Travel	62,198	24,563	-	1,125	38,760
Contracted Services	387,875	82,379	79,731	-	225,765
Other Services	2,556,215	951,066	299,104	25,712	1,331,757
Equipment	1,944,585	85,950	-	-	1,858,635
G&A Overhead	-	(80,909)	-	-	80,909
Facilities Use Fee	24,000	(20,497)	-	-	44,497
Total DIRECTOR'S OFFICE	**7,869,186**	**3,209,125**	**527,668**	**222,142**	**4,354,535**
SUNSPOT					
Payroll	1,559,239	1,581,506	-	-	(22,267)
Supplies and Materials	236,362	171,586	7,532	24,985	82,229
Utilities and Communications	269,146	190,409	71,174	52,667	60,231
Equipment Repair and	22,155	6,344	176	1,162	16,797
Domestic Travel	61,362	19,516	-	933	42,779
Foreign Travel	17,788	5,401	-	-	12,387
Contracted Services	87,358	74,629	-	11,068	23,797
Other Services	34,938	51,722	1,486	3,958	(14,312)
Equipment	46,374	33,035	-	-	13,339
Rent Revenue	(104,000)	(83,536)	-	-	(20,464)
Meal Revenue	(6,500)	(6,252)	-	-	(248)
Sales Revenue	(50,202)	(41,376)	-	-	(8,826)
Miscellaneous Revenue	-	(24,290)	-	-	24,290
Total SUNSPOT	**2,174,020**	**1,978,695**	**80,369**	**94,775**	**209,731**
TUCSON					
Payroll	268,917	284,452	-	-	(15,535)
Supplies and Materials	14,150	4,410	254	500	9,986
Utilities and Communications	40,000	36	-	-	39,964
Equipment Repair and	-	347	-	-	(347)
Domestic Travel	3,776	8,668	4,351	-	(9,242)
Foreign Travel	4,858	-	-	-	4,858
Contracted Services	-	233	-	-	(233)
Other Services	1,560	1,106	-	-	454
Facilities Use Fee	73,000	90,592	-	-	(17,592)
Total TUCSON	**406,261**	**389,843**	**4,604**	**500**	**12,314**
NISP					
Payroll	2,743,119	2,458,925	-	-	284,194
Supplies and Materials	463,030	125,457	24,021	10,342	323,894
Utilities and Communications	37,427	102,499	26,910	22,607	(69,375)
Equipment Repair and	1,824	1,054	519	429	680
Rental and Lease Expense	16,500	7,957	-	-	8,543
Domestic Travel	117,121	49,018	11,570	2,376	58,908
Foreign Travel	235,984	18,021	2,002	1,600	217,560
Contracted Services	-	63,312	78,004	12,000	(129,316)
Other Services	175,650	9,314	2,700	-	163,636
Equipment	949,588	573,982	192,244	250,000	433,361
Total NISP	**4,740,243**	**3,409,541**	**337,971**	**299,354**	**1,292,085**
Total NSO	**22,167,640**	**11,274,323**	**1,069,069**	**987,489**	**10,811,737**

Table A-2 is a reconciliation of the NSO FY 2016 budget, which shows budget, expenditures, encumbrances, adjustments, and final balance by category by Sub-Division.

The significant amount of unspent budget is due to the accumulation, now over two years, of funds allocated for the DSSC and the impacts of its delay. The DKIST Program used in FY 2016 only 26% of its original budget while waiting for the uncertainties created by the DSSC and its final cost to be resolved. The DKIST Program also carries forward additional funds that result from the inability to implement the hires as described in the CA in the absence of a place to accommodate the personnel. This delay has created a total carry forward of almost $7M to which we must add the one-time contribution for the DSSC of $2.5M received in FY 2016. The funds carried forward in the Director's Office are similar to the amount in previous years. For NISP, $1.35M is the balance of GONG refurbishment funds.

DKIST Operations

The major components that make up payroll expenditures in the amount of $1.7M consist of $116K DKIST Operations Management; $257K Scientific Staff Research; $413K Scientific Staff Ops Support; $80K AO/MCAO Development; and $844K Data Center Development. The major components that make up the $1.2M payroll carry forward are $108K DKIST Operations Management; $149K Scientific Staff Research; $136K Scientific Staff Ops Support; $277K Operations Tools Development; $104K DKIST Operations Development; $164K Instrument Development; $119K AO/MCAO Development; and $112K Data Center.

DKIST Operations domestic travel expenditures were underspent by $250K, primarily in the areas of DKIST Operational Planning, $20K; DKIST Scientific Staff, $118K; DKIST Operations Development, $25K; Instrument Development, $15K; and Data Center Development, $60K.

DKIST Operations Contracted Services expenditures were under spent by $118K, primarily in Instrument Development, $193K, offset by expenditures and encumbrances in Scientific Staff Research and Remote Operation Building Support.

Other Services expenditures were under spent by $258K, primarily due to delays in the DSSC Support.

The budget in the 'Equipment/Land' category reflects receipt of upfront payment in the amount of $2.5M for the Maui DSSC. The related carry forward is primarily due to Building support and AO/MCAO development, pending requisite approval.

Director's Office

The payroll carry forward in the amount of $835K is primarily composed of $371K carry forward; $115K ATST ROB Development Recharges; $86K HQ Development and Relocation; $114K Business and Administration; and $172K EPO.

The major components that make up the $1.1M Rental and Lease include CU Boulder lease and lab expenditures related to the HQ relocation to Boulder, Colorado.

The $1.3M carry forward balance in this category primarily relates to expenditures related to the relocation of HQ to Boulder.

The $1.9M Equipment carry forward is primarily related to capital equipment related to the relocation of HQ to Boulder.

Sunspot

The major components that make up payroll expenditures in the amount of $1.6M consist of $49K Scientific Staff; $140K Scientific Research; $87K User Support/DST; $63K Scientific Support; $32K Library; $144K Telescope Operations; $99K Computing; $128K Integration; $106K Project Administration; $56K General Electronics; $209K Facility Support; $42K Housing; $30K Kitchen; and $203K Administrative Support.

NISP

The major components that make-up payroll expenditures in the amount of $2.5M consist of $245K NISP General Activities; $173K NISP Management; $726K Scientific Staff ; $62K NISP Observing; $251K Instrumental Development Project; $121K SOLIS Relocation Activities; $54K GONG Refurbishment; $89K NISP Data Management; and $637K Data Center Operations.

The Supplies and Materials carryforward of $324K primarily relates to NISP General Activities related to GONG Refurbishment. The Other Services carryforward ($163K) relates to NISP Observing. The Equipment carryforward ($433K) relates to GONG Refurbishment.

TABLE A-3

NSO Financial Management Report

FY 2017

	Budget	- Expenditures	- Encumbrance	+ Prior Encumb	= Balance
DKIST OPERATIONS					
Payroll	4,097,252	2,264,767	-	-	1,832,485
Supplies and Materials	159,261	35,550	3,315	4,521	124,917
Utilities and Communications	139,940	9,028	35,231	447	96,128
Rental and Lease Expense	91,888	53,689	-	-	38,199
Domestic Travel	414,887	94,039	14,308	12,897	319,437
Foreign Travel	165,153	30,489	6,127	7,000	135,537
Contracted Services	193,200	3,430,805	5,079,759	74,875	(8,242,489)
Other Services	1,126,849	492,708	223,354	8,332	419,119
Equipment	13,745,588	61,671	-	10,386	13,694,303
Total DKIST OPERATIONS	**20,134,018**	**6,472,746**	**5,362,093**	**118,458**	**8,417,636**
DIRECTOR'S OFFICE					
Payroll	1,362,694	1,106,963	-	-	255,731
Supplies and Materials	111,328	135,286	4,275	3,944	(24,289)
Utilities and Communications	48,932	44,998	3,520	-	414
Equipment Repair and Maintenance	5,000	40	-	-	4,960
Rental and Lease Expense	466,413	612,356	-	128,697	(17,246)
Domestic Travel	348,409	184,224	40,557	16,193	139,821
Foreign Travel	67,210	35,526	13,315	-	18,369
Contracted Services	615,946	108,005	-	79,731	587,673
Other Services	2,098,189	747,539	9,674	299,104	1,640,079
Equipment	62,325	18,403	-	-	43,922
G&A Overhead	-	(62,456)	-	-	62,456
Miscellaneous Revenue	-	(20,000)	-	-	20,000
Total DIRECTOR'S OFFICE	**5,186,446**	**2,910,883**	**71,341**	**527,668**	**2,731,890**
MGMT FEE	-	37,266	-	-	(37,266)
Total MGMT FEE	**-**	**37,266**	**-**	**-**	**(37,266)**
SUNSPOT					
Payroll	1,089,286	1,292,456	-	-	(203,170)
Supplies and Materials	178,700	73,010	363	7,532	112,859
Utilities and Communications	213,265	181,537	92,393	71,174	10,509
Equipment Repair and	14,101	4,258	-	176	10,019
Domestic Travel	39,026	10,468	316	-	28,242
Contracted Services	21,172	18,914	-	-	2,258
Other Services	273,851	141,819	514	1,486	133,004
Rent Revenue	(98,831)	(88,150)	-	-	(10,681)
Meal Revenue	(6,695)	(2,111)	-	-	(4,585)
Sales Revenue	(47,737)	(32,243)	-	-	(15,494)
Miscellaneous Revenue	-	(19,436)	-	-	19,436
Total SUNSPOT	**1,676,138**	**1,580,521**	**93,586**	**80,369**	**82,399**
TUCSON					
Payroll	316,103	269,470	-	-	46,633
Supplies and Materials	21,500	9,963	-	254	11,791
Utilities and Communications	-	27,364	-	-	(27,364)
Equipment Repair and Maintenance	-	92	-	-	(92)
Rental and Lease Expense	146,904	137,175	-	-	9,729
Domestic Travel	8,366	2,856	865	4,351	8,995
Contracted Services	-	-	156	-	(156)
Other Services	33,643	30,050	-	-	3,593
Facilities Use Fee	47,793	47,010	-	-	783
Miscellaneous Revenue	-	(3,040)	-	-	3,040
Total TUCSON	**574,309**	**520,939**	**1,021**	**4,604**	**56,953**
NISP					
Payroll	2,126,085	1,713,611	-	-	412,474
Supplies and Materials	168,942	174,280	3,685	24,021	14,998
Utilities and Communications	17,682	16,006	927	26,910	27,659
Equipment Repair and Maintenance	-	20,141	-	519	(19,622)
Rental and Lease Expense	74,422	46,973	-	-	27,449
Domestic Travel	70,347	68,255	6,675	11,570	6,986
Foreign Travel	89,745	24,217	7,852	2,002	59,678
Contracted Services	2,040	25,681	56	78,004	54,307
Other Services	335,959	203,244	2,320	2,700	133,095
Equipment	855,602	13,169	-	192,244	1,034,677
Total NISP	**3,740,824**	**2,305,578**	**21,515**	**337,971**	**1,751,702**
Total NSO	**31,311,735**	**13,827,933**	**5,549,556**	**1,069,069**	**13,003,315**

Table A-3 is a reconciliation of the NSO FY 2017 budget, which shows budget, expenditures, encumbrances, adjustments, and final balance by category by Sub-Division.

The unspent budget originates primarily from delays in implementing various aspects of the transition. The NSO HQ budget continues its presence in Sunspot and Tucson for the first quarter of FY 2018; closeout costs for those sites have not yet occurred. Relocation expenses to Maui are on hold until the DSSC becomes available. The HQ line also includes the KPVT (SOLIS tower) decommissioning budget; if that amount is subtracted, the total HQ carry forward is similar to carry forward of previous years. The DKIST Program carries forward funds that also result from the inability to implement the hires as described in the CA in the absence of a place to accommodate personnel in Maui. DKIST carry forward also includes costs for the Data Center that are on hold until the project and its scope are defined and
consolidated after this year's scheduled reviews. For NISP, the $1.75M balance results from the SOLIS relocation delays and unused GONG refurbishment funds. All facilities costs in Tucson (including the McMath Joint Use Fee for Q1- FY 2018) are covered from the site's carry-forward funds.

DKIST Operations

The major components that make up payroll expenditures in the amount of $2.3M consist of $97K Directorate/Administration; $436K Scientific Research; $270K Operations Support; $165K FL Data Center Development; $111K MCAO; $73K DSSC Development; $95K Computing-IT; $68K Data Center Ops; ($68K), $770L DC Development; $50K Science EPO; $46K DC Enhancements; $42K Operator Training; and $45K MCAO Development.

The major components that make up the $1.8M payroll carryforward are $381K Science-Research; $178K Operations Support; $108K Computing-IT; $182K DC Development; $139K Operations Tools Development; $136K Operator Training; $303K Development MCAO; $303K Development-Next Generation Instruments; and $83K Development DC Enhancements.

DKIST Operations Supplies and Materials were underspent by $125K, primarily in the areas of DC Development, $90K; Science Research, $17K; and Operations Support, $18K. DKIST Operations domestic travel expenditures were underspent by $319K, primarily in the areas of Operations Support, $72K; Data Center Ops, $83K; Science Research, $30K; FL Data Center Development, $18K; Computing IT, $18K; and DC Development, $83K. DKIST Operations foreign travel expenditures were underspent by $135K, primarily in the areas of Directorate, $21K; Science-Research, $32K; Operations Support, $31K; and DC Development, $20K.

DKIST Operations Contracted Services expenditures were overspent by $8.2M, primarily in DSSC development encumbrances (offset by budget which resided in Other Services and Land/Equipment). Other Services expenditures were under spent by $419K, offset by expenditures which resided in Contracted Services. The $13.7M budget in the 'Equipment/Land' category reflects receipt of upfront payment for the DSSC. The related carry forward is primarily due to Data Center Development, $216K); Ops Support, $163K; Development-MCAO, $2.2M; Development Next Generation Instruments, $1.3M); Development – DC Enhancements, $102K; and DSSC, $9.6M.

Director's Office

The major components that make up payroll expenditures in the amount of $1.1M primarily consist of $502K Directorate; $219K Business Administration; $100K NSO Management-Carry Forward; $137K NSO EPO; $61K Boulder-Computing IT; and $50K Research Assistants. The payroll carry forward in the amount of $255K is primarily composed of $179K NSO Management Carry Forward; $115K NSO EPO offset by -$50K Research Assistants. The Director's Office domestic travel expenditures were underspent by $140K, primarily in the areas of Directorate, $31K; AURA Committees, $53K; and Research Assistants, $47K. The Director's Office Contracted Services were underspent in the amount of $588K, primarily in the areas of SOLIS Tower Demolition, $492K; Boulder Computing IT, $50K; and Boulder HQ, $51K. The Director's Office Other Services were underspent in the amount of $1.6M, primarily in the areas of Management, $578K; Science Research, $270K; NSO Development, $690K; and EPO, $114K.

Sunspot

The major components that make-up payroll expenditures in the amount of $1.2M consist of $273K Scientific Staff; $131K Directorate; $727K Sunspot Facilities; and $126K Project Administration.

NISP

The major components that make-up payroll expenditures in the amount of $1.7M consist of $241K Management; $763K Science; $355K Facilities; and $355K Development New Programs. The $1M Equipment carry forward primarily consists of $31K SOLIS; $120K Data Center Data Storage; $192K GONG Refurbishment; $123K Workstation Replacement; $41K Instrument Computer Upgrade; $39K Weather Station; $21K UPS; $15K HVAC Upgrades; $69K Camera Upgrade; $56K Modulator (Tunable); $133K H-Alpha; and $140K Optical Upgrade.

TABLE A-4

NSO Financial Management Report

FY 2018

	Budget	- Expenditures	- Encumbrance	+ Prior Encumb	= Balance
DKIST OPERATIONS					
Payroll	6,245,168	3,512,576	-	-	2,732,592
Supplies and Materials	225,343	317,932	44,787	3,315	(134,062)
Utilities and Communications	232,985	75,902	48,634	35,231	143,680
Equipment Repair and	20,000	-	-	-	20,000
Rental and Lease Expense	94,645	104,559	-	-	(9,914)
Domestic Travel	666,210	106,099	2,390	14,308	572,029
Foreign Travel	225,552	46,782	9,675	6,127	175,222
Contracted Services	9,045,861	5,019,194	3,200,953	5,079,759	5,905,474
Other Services	9,452,762	604,660	303,330	223,354	8,768,127
Equipment	4,027,635	340,248	1,178,606	-	2,508,782
Facilities Use Fee	-	(50,992)	-	-	50,992
Total DKIST OPERATIONS	**30,236,162**	**10,076,960**	**4,788,374**	**5,362,093**	**20,732,921**
DIRECTOR'S OFFICE					
Payroll	1,613,634	2,058,700	-	-	(445,066)
Supplies and Materials	117,636	125,355	13,763	4,275	(17,207)
Utilities and Communications	31,229	46,857	-	3,520	(12,108)
Equipment Repair and	2,600	2,866	1,134	-	(1,400)
Rental and Lease Expense	489,687	474,619	-	-	15,068
Domestic Travel	283,839	250,521	24,681	40,557	49,194
Foreign Travel	63,724	120,169	772	13,315	(43,902)
Contracted Services	549,351	66,733	1,701	-	480,917
Other Services	5,314,829	470,943	8,705	9,674	4,844,855
Equipment	55,000	25,966	7,560	-	21,474
Center F&A	-	(307,965)	-	-	307,965
Miscellaneous Revenue	-	20,000	-	-	(20,000)
Total DIRECTOR'S OFFICE	**8,521,529**	**3,354,764**	**58,316**	**71,341**	**5,179,790**
MGMT FEE	69,012	41,633	-	-	27,379
Total MGMT FEE	**69,012**	**41,633**	**-**	**-**	**27,379**
SUNSPOT					
Payroll	440,672	296,386	-	-	144,286
Supplies and Materials	101,140	28,018	-	363	73,485
Utilities and Communications	167,505	117,708	77,986	92,393	64,204
Equipment Repair and	18,587	5,031	31,213	-	(17,657)
Rental and Lease Expense	2,420	-	-	-	2,420
Domestic Travel	17,781	6,670	-	316	11,427
Contracted Services	91,076	26,470	1,471	-	63,135
Other Services	240,515	38,687	30,598	514	171,744
Rent Revenue	(44,400)	(32,815)	-	-	(11,585)
Meal Revenue	-	(35)	-	-	35
Sales Revenue	(3,318)	(7,417)	-	-	4,099
Miscellaneous Revenue	-	(2,345)	-	-	2,345
Total SUNSPOT	**1,031,978**	**476,357**	**141,268**	**93,586**	**507,939**
TUCSON					
Payroll	-	6,320	-	-	(6,320)
Supplies and Materials	6,910	1,909	-	-	5,001
Utilities and Communications	-	22,828	-	-	(22,828)
Rental and Lease Expense	13,000	29,864	-	-	(16,864)
Domestic Travel	-	5,724	-	865	(4,858)
Contracted Services	-	147	-	156	9
Other Services	25,000	4,214	-	-	20,786
Facilities Use Fee	11,948	13,085	-	-	(1,137)
Total TUCSON	**56,858**	**84,090**	**-**	**1,021**	**(26,211)**
NISP					
Payroll	1,798,831	1,764,261	-	-	34,570
Supplies and Materials	175,916	62,123	4,200	3,685	113,278
Utilities and Communications	41,480	3,279	-	927	39,128
Equipment Repair and	-	30,212	-	-	(30,212)
Rental and Lease Expense	112,490	112,764	-	-	(274)
Domestic Travel	59,207	47,543	7,283	6,675	11,056
Foreign Travel	91,467	18,290	6,050	7,852	74,979
Contracted Services	312,150	218,070	21,225	56	72,911
Other Services	328,382	168,002	1,700	2,320	160,999
Equipment	987,885	93,069	20,625	-	874,190
Total NISP	**3,907,807**	**2,517,612**	**61,083**	**21,515**	**1,350,627**
Total NSO	**43,823,347**	**16,551,416**	**5,049,041**	**5,549,556**	**27,772,445**

Table A-4 is a reconciliation of the NSO FY 2018 budget, which shows budget, expenditures, encumbrances, adjustments, and final balance by category by Sub-Division.

DKIST Operations

The major components that make up payroll expenditures in the amount of $3.5M consist of $100K Directorate; $844K Science Research; $265K Operations Support; $124K FL Data Center Development; $97K MCAO; $90K DC Enhancements; $301K Computing-IT; $36K Data Center Ops; $951K DC Development; $43K Ops Support; $243K Operations Tools Development; $272K Operator Training; and $78K DSSC Development.

DKIST Operations Contracted Services expenditures in the amount of $5M primarily consist of Development of the DSSC.

Director's Office

The major components that make up payroll expenditures in the amount of $2.1M primarily consist of $487K Directorate; $344K Business Administration; $229K Post-Retirements Benefits; $266K Science Research; $33K Research Assistants; $227K HQ Development & Relocation; $60K CMAG; $321K NSO EPO; and $90K Boulder-Computing IT.

The payroll deficit in the amount of $445K is primarily composed of Post-Retirement Benefits ($257K), and HQ Development & Relocation-related to severance/terminal vacation payout ($227K), and CMAG ($59K), offset by under expenditures of $121K in the areas of CSP Activities.

The $4.9M carry forward in the Director's Office Other Services primarily consists of carry forward to the Supplemental Funding received in FY18 for the new NSO Community Science Program (NCSP-DKIST Level 2 products, $3.5M; Recruiting/Relocation, $232K; and SOLIS Tower Demolition, $500K; Indirect Cost Credits, $166K; CSP Activities, $180K; HQ Development and Relocation, $354K; and NSO EPO, $94K.

NISP

The major components that make-up payroll expenditures in the amount of $1.8M consist of $190K Directorate; $87K Administration; $725K Science Research; $84K Management; $40K SOLIS Relocation; $33K Boulder HQ Computing IT; $335K Facilities-Data Center; $126K GONG Refurbishment; $40K GONG Refurbishment Management; $38K GONG Refurbishment Engineering; and $50K GONG Refurbishment Scientific.

The $874K Equipment carry forward primarily consists of SOLIS, $43K; Data Center Data Storage, $240K; Data Center Data Processing, $31K; GONG Refurbishment Workstation Upgrade, $30K; GONG Refurbishment Workstation Replacement $41K; GONG Refurbishment Instrument Computer Upgrad, $37K; GONG Refurbishment Weather Station, $35K; GONG Refurbishment Camera Upgrade, $129K; GONG Refurbishment H-Alpha, $131K; and GONG Refurbishment Optical Upgrade, $139K.

TABLE A-5

NSO Financial Management Report

FY 2019 Through Q2

	Budget	- Expenditures	- Encumbrance	+ Prior Encumb	= Balance
DKIST OPERATIONS					
Payroll	5,733,060	1,876,361	-	-	3,856,699
Supplies and Materials	143,000	198,416	92,231	44,787	(102,859)
Utilities and Communications	6,446,425	49,568	80,378	48,634	6,365,114
Equipment Repair and	20,600	-	-	-	20,600
Rental and Lease Expense	149,484	98,950	82,731	-	(32,198)
Domestic Travel	571,261	42,732	32,401	2,390	498,518
Foreign Travel	228,364	23,236	24,587	9,675	190,216
Contracted Services	12,198,366	368,394	2,858,754	3,200,953	12,172,170
Other Services	1,714,505	484,866	332,864	303,330	1,200,104
Equipment	2,002,299	358,261	946,160	1,178,606	1,876,483
Facilities Use Fee	-	(152,976)	-	-	152,976
Total DKIST OPERATIONS	**29,207,365**	**3,347,809**	**4,450,107**	**4,788,374**	**26,197,823**
NCSP					
Payroll	1,136,082	221,555	-	-	914,527
Supplies and Materials	33,128	107	1,892	-	31,129
Rental and Lease Expense	50,845	-	-	-	50,845
Domestic Travel	231,806	-	-	-	231,806
Foreign Travel	82,428	-	2,095	-	80,333
Contracted Services	681,589	-	-	-	681,589
Other Services	578,255	15,788	-	-	562,467
Equipment	700,899	-	415,469	-	285,430
Total NCSP	**3,495,032**	**237,450**	**419,455**	**-**	**2,838,127**
DIRECTOR'S OFFICE					
Payroll	1,303,332	664,727	-	-	638,605
Supplies and Materials	90,283	73,768	14,930	13,763	15,348
Utilities and Communications	7,673	2,415	-	-	5,258
Equipment Repair and	4,000	-	5,134	1,134	-
Rental and Lease Expense	286,701	178,511	132,892	-	(24,702)
Domestic Travel	247,328	57,108	43,211	24,681	171,689
Foreign Travel	148,998	25,819	17,335	772	106,617
Contracted Services	606,419	545,926	121,162	1,701	(58,967)
Other Services	760,704	183,275	34,994	8,705	551,140
Equipment	62,496	7,900	-	7,560	62,156
Center F&A	-	(60,431)	-	-	60,431
Total DIRECTOR'S OFFICE	**3,517,934**	**1,679,017**	**369,658**	**58,316**	**1,527,575**
MGMT FEE					
Supplies and Materials	-	135	-	-	(135)
Other Services	96,391	8,079	-	-	88,312
Total MGMT FEE	**96,391**	**8,214**	**-**	**-**	**88,177**
SUNSPOT					
Payroll	202,879	248,481	-	-	(45,602)
Supplies and Materials	16,796	18,175	8,170	-	(9,549)
Utilities and Communications	70,223	69,483	69,612	77,986	9,114
Equipment Repair and	3,801	-	31,213	31,213	3,801
Domestic Travel	-	7,266	857	-	(8,123)
Contracted Services	1,012	87,179	81,682	1,471	(166,378)
Other Services	513,228	95,104	50,213	30,598	398,509
Interest Exp & Analysis Fees	-	11	-	-	(11)
Rent Revenue	-	(15,775)	-	-	15,775
Miscellaneous Revenue	-	(1,928)	-	-	1,928
Total SUNSPOT	**807,939**	**507,996**	**241,747**	**141,268**	**199,465**
TUCSON					
Payroll	-	257	-	-	(257)
Supplies and Materials	-	26	-	-	(26)
Utilities and Communications	-	11,870	-	-	(11,870)
Other Services	-	777	-	-	(777)
Total TUCSON	**-**	**12,931**	**-**	**-**	**(12,931)**
NISP					
Payroll	1,595,290	857,337	-	-	737,953
Supplies and Materials	50,720	23,227	481	4,200	31,212
Utilities and Communications	39,151	309	-	-	38,842
Equipment Repair and	-	3,274	-	-	(3,274)
Rental and Lease Expense	179,267	93,780	73,909	-	11,577
Domestic Travel	61,135	2,899	1,250	7,283	64,270
Foreign Travel	48,102	15,609	-	6,050	38,543
Contracted Services	372,321	9,900	26,125	21,225	357,521
Other Services	252,343	65,980	7,300	1,700	180,763
Equipment	949,459	10,125	10,500	20,625	949,459
Total NISP	**3,547,789**	**1,082,440**	**119,565**	**61,083**	**2,406,866**
Total NSO	**40,672,450**	**6,875,857**	**5,600,532**	**5,049,042**	**33,245,102**

Table A-5 is a reconciliation of the NSO FY 2019 mid-year budget through March 2019, which shows budget, expenditures, encumbrances, adjustments, and balance by category by Sub-Division.

DKIST Operations

The major components that make up payroll expenditures in the amount of $1.9M consist of $92K Directorate; $113K Post-Retirement Benefits; $31K Unfunded Liabilities; $306K Science Research; $111K Operations Support; $62K FL Data Center Development; $70K MCAO; $43K DC Enhancements; $123K Computing-IT; $493K DC Development; $30K Ops Support; $111K Operations Tools Development; $240K Operator Training; and $19K Development-Next Generation Instruments.

The significant carry forward includes $8M of FY19 forward funding the NSF provided at the end of FY18.

As stated previously, DKIST carry forward originates from the project's diligent efforts to retain construction staff with the goal of transferring many of them with their invaluable expertise into operations. This reduces to a significant extent the need for initial hiring and cross-training of an operations crew in parallel with the ongoing construction effort. The operations staffing ramp up has been slower than was projected in the original CA proposal plan, which assumed an approximately linear ramp up of operations staff in parallel with the ongoing construction effort. The actual situation is a much slower ramp up in years before the end of construction and a very steep ramp up (transfer of construction staff) in FY 2020 (final year of construction).

The DKIST project is proposing a reprofiling of the significant carry-forward funds for the operational phase in Section 5 of this LRP.

Director's Office

The major components that make up payroll expenditures in the amount of $665K primarily consist of $248K Directorate; $152K Business Administration; $17K Post-Retirements Benefits; $60K Boulder-Computing IT; $23K CMAG; and $146K NSO EPO. The deficit in Rental and Lease expense in the amount of $24K will be relieved by accounting reallocations of the CU lease currently in process. The $551K of remaining funds in the Other Services category primarily consist of $75K Directorate; $52K Post- Retirement Benefits; $92K Recruiting/Relocation; $46K Research Assistants; $24K Science Research; $29K NISP Operation Service; $38K CSP Activities; $28K Hale Postdoc; $104K HQ Development and Relocation; and $67K NSO EPO.

NISP

The major components that make up payroll expenditures in the amount of $857K primarily consist of $91K Directorate; $42K Administration; $139K Science Research; $20K External Committee Assignments; $54K Data Product Support; $33K Proposal Preparation; $20K NISP Data Center; $82K SOLIS Relocation; $25K Boulder HQ Computing IT; $164K Facilities-Data Center; $33K Post-Retirement Benefits; $10K Unfunded Liabilities; $12K Management; $11K Paper Refereeing; and $77K GONG Refurbishment.

The major components that make up remaining expenditures in the $357K Contracted Services account primarily consist of $167K SOLIS; $126K SOLIS Relocation; $19K GONG Refurbishment Camera Upgrade; and $45K GONG Refurbishment Optical Upgrade.

NSO Community Services Program (NCSP)

The $914K balance in Payroll primarily consists of $51K Administrative Support ; $261K Science; $81K Visitor's Program Long Term; $222K Service; $253K Data Center Support; and $48K Curriculum Prep. The $682K balance in Contracted Services primarily consists of $60K Science and $621K Graduate Students Support. The $562K balance in Other Services primarily consists of $264K Graduate Students Support; $143K Data Training Workshop; and $158K related indirect costs associated with all balances. The $285K balance in Equipment primarily consists of $54K Science-Computers; $53K Graduate Students Support-Computers; and $179K Data Center Support-Computers.

Sac Peak

The FY19 Sac Peak budget comprises:

The program's carry forward budget of $508K. NSO plans to use these funds primarily for site reparations, and closeout activities such as improvements of the DST elevator platform, septic system renovations, roofs repairs, and existing security.

The program's base NSF funds budget in the amount of $300K. The Payroll deficit ($45K) will be relieved by billings to NMSU, currently pending subcontract amendment. The Contracted Services deficit ($166K) is offset by the $399K balance in Other Services. A detailed reconciliation of the Sac Peak budget is currently in process to determine the projected expenditures, encumbrances, billings to NMSU, and the projected balance at the end of FY19.

APPENDIX B.
NSO OPERATIONS BUDGET CHANGE CONTROL PROCESS

March 28, 2018

Process Overview

The budget change request process for NSO Operations allows for the traceability of the current NSF approved FY Budget back to the original NSF approved FY Budget. The process ensures all changes to the NSO approved FY Budgets are controlled, documented and managed in a consistent manner.
After the initial budget baseline is finalized and submitted to NSF, although there may be changes in respective Area budgets, the NSO bottom line budget amount should not change without the Director's approval.
All budget change requests for NSO Operations will go through the NSO Center "Budget Coordinator" (currently assigned to Carolyn Watkins, Business Manager) for processing. The Budget Coordinator obtains approval from the affected Associate Directors. The Budget Coordinator then coordinates with CAS for Webud and Casnet implementation. The Budget Coordinator maintains an "audit trail"/log with all budget changes.

Initiation of Budget Change Process

The change request process will be initiated if one or more of the following situations are requested:

- Budget moves from one work package/account to another (e.g., within or between divisions).
- Correction of errors in the Division budget/plan

Budget Change Request Submission

Budget change requests are to be submitted to the Budget Coordinator via email.
The change request should contain the following:

- Explanation of Requested Change
- Budget Funding Source (i.e. Base, Carryforward, etc.)
- To and From Account
- Amount
- Supporting Documentation:

  Any relevant files should be submitted along with the change request.

Budget Change Request Approval

The Budget Coordinator will obtain approval from the affected Associate Director(s). Budget request changes coming from the Center and Associate Director(s) to the Budget Coordinator which only affect that Area will be considered as approved.

Budget Change Implementation

Upon receipt of approval from all affected Associate Director(s), the Budget Coordinator will coordinate with CAS to implement the change into WEBUD and CASNET. The Budget Coordinator will review and verify that the requested changes are implemented as requested. The Budget Coordinator will have the sole ability to update WEBUD/CAS with the change request modifications.

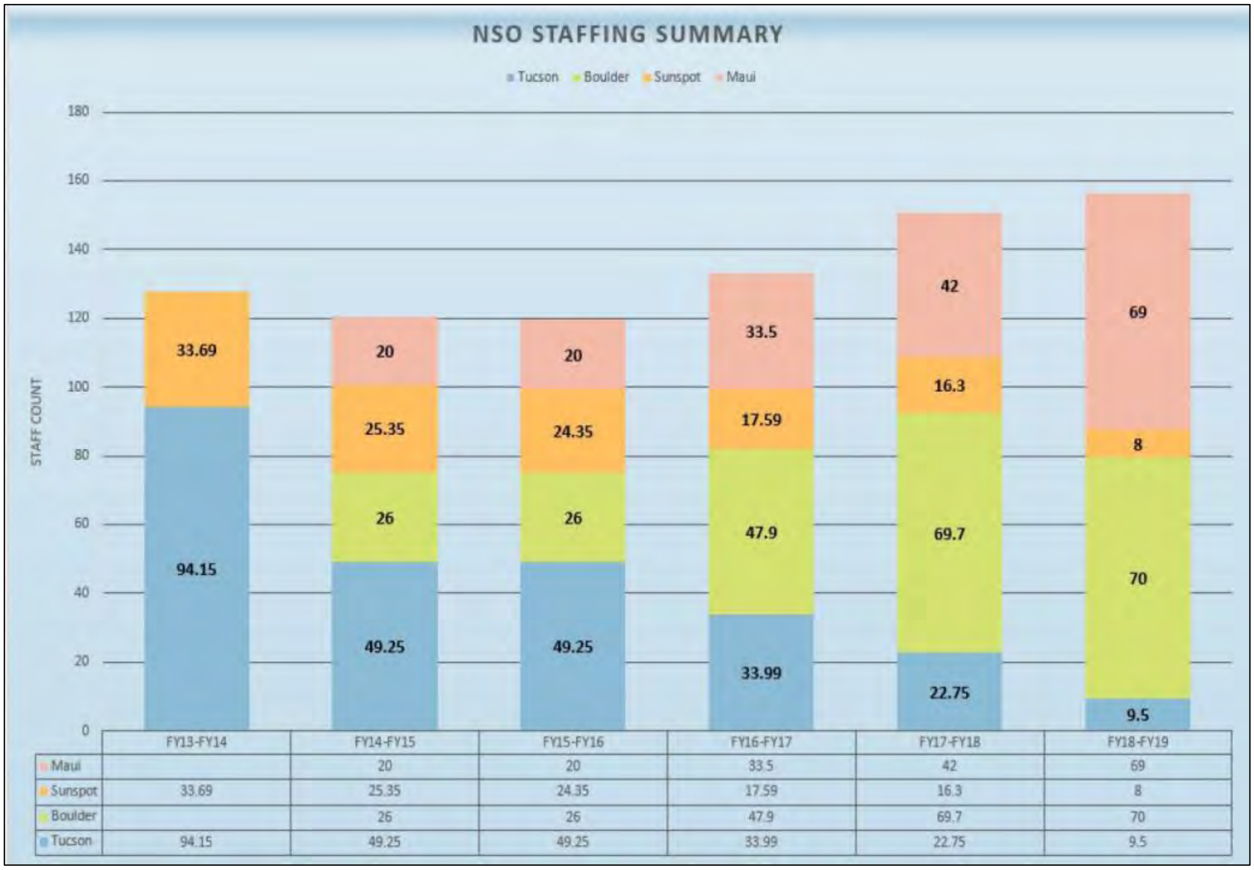
Detailed Method of Implementation

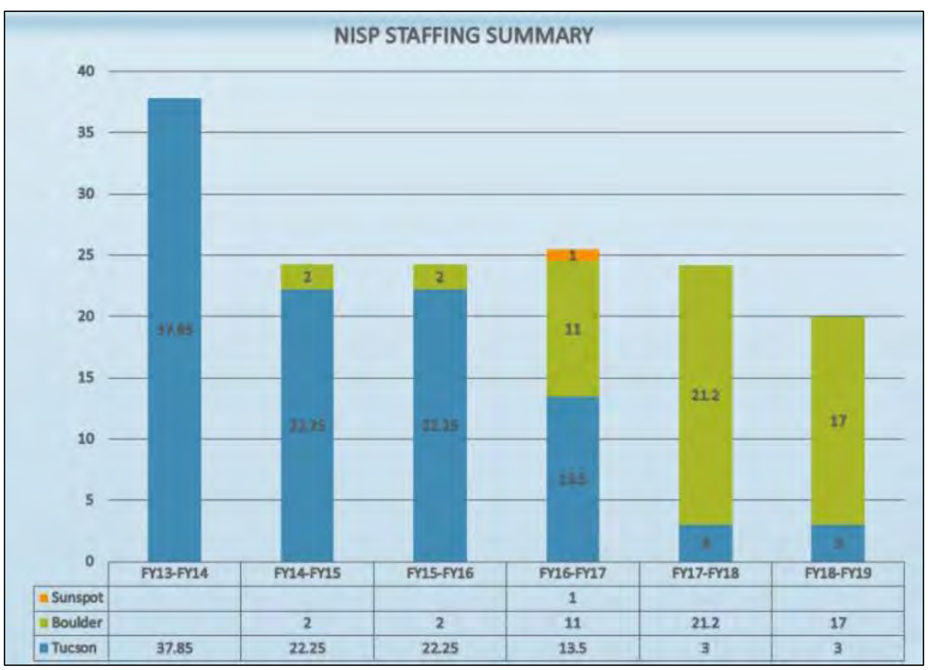
1. The Budget Coordinator will make the approved budget changes in Webud.
2. On the 6th working day of each month, CAS will run a program to compare the most current amounts in Webud to the budget amounts in the last month-end published Casnet financial report.
3. Any differences would appear in the “My Budget Transfer Batches” tab of the Casnet Budget Ledger program as an “Unfinished” batch.
4. An email will be sent to the Budget Coordinator advising that a transfer needs to be reviewed.
5. In Budget Ledger, the Budget Coordinator will open the unfinished transfer using “Edit” to review. If it looks correct the Budget Coordinator will “Submit for Approval.”
6. At this point the Budget Coordinator will review the batch and save to Excel or PDF for the record.

Tracking Budget Change Requests

The Budget Coordinator will maintain an “audit trail”/ log of all budget changes (spreadsheet tracking form). A report will also be available in CASNET.

APPENDIX C. NSO STAFFING SUMMARY (FY 2013 – FY 2019)





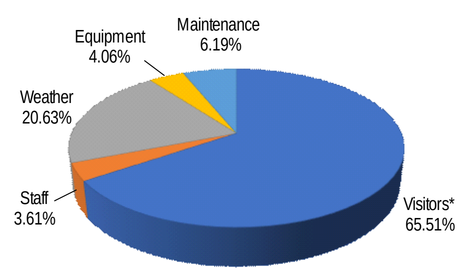
APPENDIX D.
OBSERVING AND USER STATISTICS (FY 2013 – FY 2017)

NSO TELESCOPES
Percent Distribution of Telescope Hours
(Scheduled vs. Downtime)
FY 2013 - FY 2017
01 October 2012 - 30 September 2017

Telescope	Hours Scheduled	% Hours Used By: Visitors[a]	Staff	% Hours Lost To: Weather	Equipment	% Hrs. Lost To: Scheduled Maintenance
Dunn Solar Telescope/SP	14,564.1	29.5%	19.2%	34.5%	4.2%	12.6%
McMath-Pierce*	19,592.0	21.8%	40.5%	21.8%	10.4%	5.5%
KP SOLIS Tower &"Farm"[a,b]	18,233.0	54.7%	0.0%	31.6%	13.7%	0.0%
Evans Solar Facility	5,313.5	42.7%	0.0%	47.4%	9.7%	0.2%
All Telescopes	**57,702.6**	**65.5%**	**3.6%**	**20.6%**	**4.1%**	**6.2%**

[a]Includes synoptic programs for which all data are made available immediately to the public and scientific community at large.
[b]SOLIS was relocated from Kitt Peak to the University of Arizona agricultural campus (or "Farm") in Tucson in 2014.
*Totals include both day and night hours. (All others are day only.)

ALL NSO TELESCOPES
% DISTRIBUTION OF TELESCOPE HOURS



*Includes synoptic/archival data made immediately available to scientific community at large.

Institutions Represented by Visiting Users

	US	Non-US	Total	% Total
Academic	30	23	53	65%
Non-Academic	13	16	29	35%
Total Academic & Non-Academic	**43**	**39**	**82**	**100%**

Users of NSO Facilities by Category

VISITORS:	DST	MCMP	DST & MCMP	KPST*	ESF	Total
US PhDs	49	47	2		3	**101**
Non-US PhDs	61	6				**67**
US Grad Students	8	13				**21**
Non-US Grad Students	16	5				**21**
US Others		8				**8**
Non-US Others	0	0				**0**
US Undergrads		9				9
TOTAL Visiting Users	**134**	**88**	**2**	**0**	**3**	**227**
% of Total	59.0%	38.8%	0.9%	0.0%	1.3%	100.0%
AURA Staff:						
PhDs	15	6	2	5	1	29
Other	22	4	0	2		28
TOTAL AURA Staff	**37**	**10**	**2**	**7**	**1**	**57**

*KPST/SOLIS: Synoptic program for which all data are made available immediately to the public and scientific community at large.

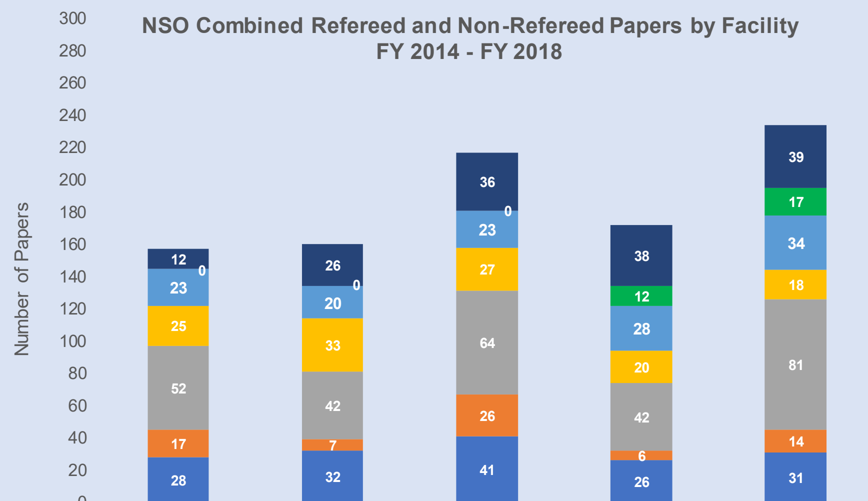
Number of Users by Nationality			
Australia	1	Italy	18
Belgium	3	Japan	8
Brazil	2	Mexico	1
England, UK	2	Poland	2
France	8	Scotland, UK	1
Germany	16	Spain	4
India	4	United States	139
Ireland, UK	18		

US Demographics			
Number of Users by State			
Alabama	3	New Hampshire	1
Arizona	12	New Jersey	7
California	36	New Mexico	9
Colorado	12	New York	4
Florida	11	Oregon	1
Hawaii	3	Pennsylvania	2
Massachusetts	5	Texas	2
Maryland	19	Washington DC	1
Montana	2	Wisconsin	9

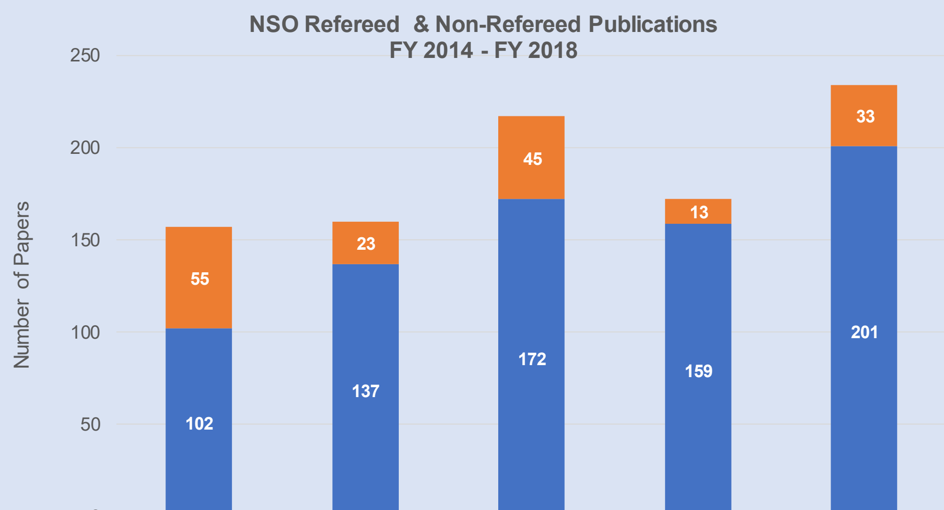
Foreign Institutions (39)	US Institutions (43)
Armagh Observatory, Univ. Sheffield	Alfred University
Belgian Institute for Space Aeronomy	Boston University
Catania Univ. Catania Astrophys. Observatory	California Institute of Technology
Ibaraki University	California Polytechnic State University
Indian Space Res. Organisation (ISRO)	California State Univ, Northridge
Instituto de Astrofisica de Canarias	Catholic Univ., NASA GSFC
Katholieke Universiteit Leuven	Dickinson College
Kiepenheuer Institute, Univ. Freiburg	Dublin School, NH
Monash University	Edinboro University
Oxford University	Embry Riddle Aeronautical University, Daytona
Queen's University	George Mason University
Univ of Naples, Osserv Astron di Capodimonte	Johns Hopkins University
Universidad de Monterrey	Montana State University
Universidade Presbiteriana Mackenzie, Sao Paolo	New Jersey Institute of Technology
Universitat de les Illes Balears	New Mexico State University
University of Florence	Oregon State University
University of Glasgow	Salpointe Catholic High School, Tucson
University of Koeln	Stanford University
University of Nice-Sophia Antipolis	University of Arizona
University of Rome "Tor Vergata"	University of California, Berkeley
University of Sheffield	University of Central Florida
University of St. Andrews	University of Colorado, Boulder
University of Wroclaw	University of Florida
INAF - Arcetri Astrophysical Observatory	University of Hawaii, IFA
INAF - Catania Astrophysical Observatory	University of Kansas
INAF, Instituto di Fisica dello Spazio Interplanetario	University of Texas, Brownsville
Indian Institute of Astrophysics	University of Texas-Austin, McDonald Obs.
Insti d'Astrophysique de Paris (CNRS)	University of Wisconsin, Madison
Institut D'Astrophysique Spatiale, Orsay	Vail High School
Instituto Nacional de Pesquisas Espaciais	Williams College
Laboratoire Atmosphères, Milieux, Obs. Spatiales	Briggs LLC
Leibniz Inst. for Astrophysics, Potsdam	Brilliant Sky Observatory
Max Planck Inst. for Solar System Res.	Harvard Smithsonian Center for Astrophysics
Nagoya University	High Altitude Observatory, NCAR, Boulder
National Astronomical Observatory of Japan	Lockheed Martin Solar & Astrophysics Lab
Observatoire de Bordeaux	Lowell Observatory
Observatoire de Cote d'Azur	NASA Ames Research Center
Observatoire de Paris, CNRS	NASA Goddard Space Flight Center
University of Tokyo, Dept. of Astronomy, NAOJ	NASA Marshall Space Flight Center
	New Jersey Institute of Technology, BBSO
	Northrup Grumman Corp.
	Planetary Science Institute (PSI)
	PlanetWave Instruments

APPENDIX E. PUBLICATIONS (FY 2014 – FY 2018)

The following are data of *known* refereed papers, conference proceedings and non-refereed papers published during FY 2014 through FY 2018 by NSO staff, REU program participants, graduate students, and non-REU undergraduates, as well as papers resulting from the use of NSO facilities. Table E-1 provides the detailed publications count by year and facility.



	2014	2015	2016	2017	2018
OTHER	12	26	36	38	39
VSO	0	0	0	12	17
SOLIS	23	20	23	28	34
MCMP	25	33	27	20	18
GONG	52	42	64	42	81
DKIST	17	7	26	6	14
DST	28	32	41	26	31



	2014	2015	2016	2017	2018
Non-Refereed	55	23	45	13	33
Refereed	102	137	172	159	201

Table E-1. NSO Publication Count by Year and Facility (2014-2018)						
	2014	2015	2016	2017	2018	Total
Refereed Staff DST	4	5	6	3	6	24
Refereed Staff McMP (including FTS & nighttime)	1	1	5	1		8
Refereed Staff GONG	9	10	6	3	7	35
Refereed Staff VSO					0	0
Refereed Staff DKIST			4	2	3	9
Refereed Staff SOLIS (includes KPVT)	3	1	7	6	4	21
[a]Refereed Staff Other NSO Instruments	0	1	1	1		3
[b]Refereed Staff No NSO Data	4	2	7	6	8	27
Refereed Staff Papers SubTotal	21	20	36	22	28	127
Refereed Visitor DST	17	27	29	22	18	113
Refereed Visitor McMP (Solar, including FTS)	24	30	20	19	16	109
Refereed Visitor GONG	20	31	51	39	68	209
Refereed Visitor VSO				12	17	29
Refereed Visitor DKIST				1	4	5
Refereed Visitor SOLIS (includes KPVT)	15	11	13	19	29	87
[a]Refereed Staff Other NSO Instruments			2	1	1	4
[b]Refereed Visitor No NSO Data	5	18	21	24	20	88
Refereed Visitor Papers SubTotal	81	117	136	137	173	644
					TOTAL REFEREED PAPERS	771
Non-Refereed Staff DST	3	0	2	1	2	8
Non-Refereed Staff McMP (Solar, including FTS)						0
Non-Refereed Staff GONG	9	1	2		1	13
Non-Refereed Staff VSO						0
Non-Refereed Staff DKIST	11	7	18	3	6	45
Non-Refereed Staff SOLIS (includes KPVT)	4	7	3	3	1	18
[a]Non-Refereed Staff Other NSO Instruments		2				2
[b]Non-Refereed Staff No NSO Data	1		1	2	3	7
Non-Refereed Staff Papers SubTotal	28	17	26	9	13	93
Non-Refereed Visitor DST	4	0	4		5	13
Non-Refereed Visitor McMP (Solar, including FTS)		2	2		2	6
Non-Refereed Visitor GONG	14		5		5	24
Non-Refereed Visitor VSO						0
Non-Refereed Visitor DKIST	6		4		1	11
Non-Refereed Visitor SOLIS (includes KPVT)	1	1				2
[a]Non-Refereed Visitor Other NSO Instruments			1	1		2
[b]Non-Refereed Visitor No NSO Data	2	3	3	3	7	18
Non-Refereed Visitor Papers SubTotal	27	6	19	4	20	76
					TOTAL Non-REFEREED PAPERS	169
						Total Papers
						940

Non-Refereed = Conference Proceedings & Other Publications.
Staff papers = NSO staff is first author.
Visitor papers = Visitor first author; includes NSO staff participation as co-author.
[a]Other NSO instruments: e.g., ESF, CATE.
[b]e.g., Theory papers, which generally address how to interpret data in general, not just from a specific facility.

APPENDIX F.
NSO Educational Outreach
Undergraduate, Graduate, Teacher & Postdoctoral Program Participants (2013 – 2018)

Akamai = Akamai Workforce Initiative
Hale = George Ellery Hale Graduate Fellowship
SRA = Summer Research Assistantship
RET = Research Experiences for Teachers
REU = Research Experiences for Undergraduates
IRES = International Research Experiences for Students
INSPIRE = Integrated Support Promoting Interdisciplinary Research and Education
**Masters or PhD Thesis partially supported by NSO during summer and/or academic year.

Table F-1. Number of Participants in NSO Educational Outreach Programs (2013-2018)

Year	*Graduate (SRA)*	*Undergrad (SRA)*	*Undergrad (REU)*	*Teachers (RET)*	*Postdoctoral Fellows*
2018	5	2	7		3
2017	7	6	2		2
2016	5	5	8		1
2015	2	1	8		1
2014	2	4			2
2013	11	1	6	1[a]	5

[a]*2013 final year of NSO RET Program.*

Table F-2. NSO REU Gender & Ethnicity Statistics (2013-2018)

Year	*2018*	*2017*	*2016*	*2015*	*2014*	*2013*	*%*
Male	1	1	5	1	-	4	37.5
Female	6	1	3	7	-	3	62.5
Minority*	1		1			1	9.3

**Includes only students from underrepresented minorities.*

Table F-3. NSO Undergrad[b] & Grad SRA Gender & Ethnicity Statistics (2013-2018)

Year	*2018*	*2017*	*2016*	*2015*	*2014*	*2013*	*% Participants*
Male	5	6	5	1	2	9	54.9
Female	2	7	5	2	4	3	45.1
Minority*	1	2	2			4	17.6

[b]*Excludes REU participants.*
**Includes only students from underrepresented minorities.*

Complete 2013-2018 List of NSO Educational Outreach Related Program Participants, Including Current Status

2018

NSO Program	Participant Name	Advisor(s)	Institute	**What they are doing now …**
Akamai Undergrad	Alexander Meyer	Bill McBride & Mackenzie Stratton	U. Hawaiʻi at Maui College	
Akamai Undergrad	Erik Svetin	Brialyn Onodera and Chriselle Galapon	Syracuse U.	2nd-yr UG at Syracuse U.
REU	Chantelle Kiessner	Christian Beck & Sanjay Gosain	U. Hawaiʻi, Hilo	
REU	Kara McDonough	Andy Ferayorni	Colorado School of Mines	Senior, Colorado School of Mines, Engineering Physics

2018 **(Cont.)**

NSO Program	Participant Name	Advisor(s)	Institute	**What they are doing now …**
REU	Katherine Lee	Kevin Reardon	Montana State U.	Senior, Montana State U, Physics
REU	Eden Harris	Gordon Petrie	U. Washington	2nd-yr UG U. Washington Physics & Astronomy
REU	Zeb Keith-Hardy	Sushanta Tripathy	Colby College, Maine	Senior, Colby College, Physics & Computer Science
REU	Sarah Szczepanski	Serena Criscuoli	UC Berkeley	Senior, UC Berkeley, Astrophysics
REU	Alexis Vizzerra	Han Uitenbroek	U Arizona	Senior, U. Arizona, Physics & Astronomy
Grad SRA	Elizabeth Butler**	Adam Kowalski	U. Colorado Boulder	Graduate Student, APS Department, U. Colorado Boulder
Grad SRA	Ryan Hofmann**	Kevin Reardon	U. Colorado Boulder	Graduate Student, APS Department, U. Colorado Boulder
Hale Grad SRA	Momchil Molnar**	Kevin Reardon	U. Colorado Boulder	Graduate Student, APS Department, U. Colorado Boulder
Grad SRA	Gary Simons**	Adam Kowalski	U. Colorado Boulder	Received Masters Degree, U. Colorado Boulder
Hale Grad SRA	Amanda White**	David Harrington	U. Colorado Boulder	Graduate Student, APS Department, U. Colorado Boulder

2017

NSO Program	Participant Name	Advisor(s)	Institute	**What they are doing now …**
INSPIRE Undergrad	Pierre Aka	Predrag Sekulic	Iowa State U	Sales Development Representative, Western Digital, Longmont, CO
Akamai Undergrad	Nicolas Colon	David Harrington & Stacey Sueoka	U. Arizona	Grad Student, MS Program, U. Arizona Optical Sciences
Akamai Undergrad	Chantelle Kiessner	David Harrington & Tom Schad	U. Hawaiʻi, Hilo	
Undergrad SRA	Brian Healy	Alexandra Tritschler	Boston U.	Grad Student, Dept of Physics & Astronomy, Johns Hopkins U.
Undergrad SRA-NASA	Honor Hare	Matthew Penn	Western Kentucky U./Gatton Academy	2nd-yr Undergrad, Western Kentucky U.
REU	Logan Jensen	Matthew Penn	U. Wyoming	Grad Student, School of Earth & Space Exploration, Arizona State U.
REU	Sarah Kovac	Matthew Penn	Southern Illinois U. Carbondale	Grad Student, Dept of Astronomy, New Mexico State U.
Undergrad SRA-NASA	Adriana Maciera Mitchell	Matthew Penn	U. Arizona Optical Sciences	Undergrad (Optics Ambassador), U. Arizona College of Optical Sciences
Grad SRA	Elizabeth Butler**	Adam Kowalski	U. Colorado Boulder	Graduate Student, APS Department, U. Colorado Boulder
Hale Grad SRA	Lily Kromyda**	Adam Kowalski	U. Colorado Boulder	Graduate Student, APS Department, U. Colorado Boulder
Hale Grad SRA	Momchil Molnar**	Kevin Reardon	U. Colorado Boulder	Graduate Student, APS Department, U. Colorado Boulder
Grad SRA	Courtney Peck**	Mark Rast (CU Boulder); Serena Criscuoli, Freidrich Woeger	U. Colorado Boulder	Postdoctoral Research Fellow, CIRES, U. Colorado Boulder
Grad SRA	Gary Simons**	Adam Kowalski	U. Colorado Boulder	Received Masters Degree, U. Colorado Boulder
Hale Grad SRA	Amanda White**	David Harrington	U. Colorado Boulder	Graduate Student, APS Department, U. Colorado Boulder
Grad SRA	Yan Xu	Matthew Penn	New Jersey Institute of Technology	Research Professor, New Jersey Institute of Technology

2016

NSO Program	Participant Name	Advisor(s)	Institute	**What they are doing now …**
REU	Emalee Couture	V. Martinez Pillet & Christian Beck	U. Maine	Technology Licensing Associate, Massachusetts Institute of Technology
REU	Lucas Guliano	Serena Criscuoli	Connecticut College	Electro-Optics Observation Engineer, Applied Optimization, Dayton, OH
REU	Jacob Hamer	Brian Harker	City U. of New York (CUNY)	Grad Student, Dept of Physics & Astronomy, Johns Hopkins U.
REU	Brian Healy	Alexandra Tritschler	Boston U.	Grad Student, Dept of Physics & Astronomy, Johns Hopkins U.
REU	Logan Jensen	Matthew Penn	U. Wyoming	Grad Student, School of Earth & Space Exploration, Arizona State U.
REU	Sarah Kovac	Matthew Penn	Southern Illinois U. Carbondale	Grad Student, Dept of Astronomy, New Mexico State U.
REU	Tyler McMaken	Gordon Petrie	Case Western Reserve U.	Grad Student, Dept of Physics, CU Boulder
REU	Adriana Maciera Mitchell	Matthew Penn	U. Arizona Optical Sciences	Undergrad (Optics Ambassador), U. Arizona College of Optical Sciences
Undergrad SRA-NASA	Robert Bosh	Matthew Penn	Western Kentucky U./Gatton Academy	2nd-yr Undergrad, Western Kentucky U.
Undergrad SRA-NASA	Honor Hare	Matthew Penn	Western Kentucky U./Gatton Academy	2nd-yr Undergrad, Western Kentucky U.
Undergrad SRA-NASA	Myles McKay	Matthew Penn	South Carolina State U.	Grad Student, Dept of Astronomy, U. Washington, Seattle
Grad SRA	Courtney Peck**	Mark Rast (CU Boulder); Serena Criscuoli, Freidrich Woeger	U. Colorado Boulder	Postdoctoral Research Fellow, National Solar Observatory
Grad SRA	Yan Xu	Matthew Penn	New Jersey Institute of Technology	Research Professor, New Jersey Institute of Technology
Undergrad SRA	Zachary Watson	Matthew Penn	U. Arizona	Staff Engineer, Hart Scientific Consulting International (HartSCI), Tucson, AZ
Akamai Undergrad	Kari Noe	Tom Schad, David Harrington, Kevin Reardon	U. Hawaiʻi, Mānoa	Grad Student, Lab for Advanced Visualization & Applications, U. Hawaiʻi, Mānoa
Akamai Undergrad	Brialyn Onodera	William McBride	U. Hawaiʻi, Mānoa	2017 BS Mechanical Engineering; Assistant Engineer, NSO/DKIST
Akamai Undergrad	Keanu Makoto Paikai	LeEllen Phelps & Guillermo Montojo Jr.	U. Alaska Fairbanks	2017 BS Mechanical Engineering; Current status ??
Akamai Undergrad	Christine J. Rioca	John Hubbard & Steve Wampler	U. Hawaiʻi, West Oahu	

2015

NSO Program	Participant Name	Advisor(s)	Institute	**What they are doing now …**
REU	Carina Alden	Han Uitenbroek	Lyndon State College, VT	BS 2018; Solar Physics, Student Intern NASA GSFC 2018; Mar-2019 Student Loan Fellow, Savi
REU	William P. Bowman	Alexandra Tristchler	Indiana U.	BS 2016 Indiana U; Grad Student, Dept Astronomy & Astrophysics, Penn State U.

2015 **(Cont.)**

NSO Program	Participant Name	Advisor(s)	Institute	**What they are doing now …**
REU	Alysa Derks	V. Martinez-Pillet & Christian Beck	U. Colorado, Boulder	Grad Student, Dept of Physics , Montana State U.
REU	Taylor Whitney	Serena Criscuoli	U. Nebraska, Lincoln	2016 started 2-year commission as ROTC 2nd Lieutenant, Air Force
REU	Charlotte Guthery	Matthew Penn	Rochester Institute of Technology	Grad student, U. Arizona Optical Sciences
REU	Jessica Hankes	John Leibacher & SushantaTripathy	Denison U., Granville, OH	2017 BS, Physics; Systems Engineer, ASSETT, Inc., Manassas, VA
REU	Stella Ocker	Gordon Petrie	Oberlin College, OH	Fall 2018 Grad Student, Dept of Astronomy, Cornell U.
REU	Kaitlin Evans	Brian Harker	U. Maryland, College Park	Middle School Science and Math Teacher, Archdiocese of Cincinnati
Grad SRA	Courtney Peck**	Mark Rast (CU Boulder); Serena Criscuoli, Freidrich Woeger	U. Colorado, Boulder	Postdoctoral Research Fellow, National Solar Observatory
Grad SRA	Kseniya Tlatova	Alexei Pevtsov	St. Petersburg State U., Russia	Kislovodsk Mountain Astronomical Station, Pulkovo Observatory, Russian Academy of Sciences, Kislovodsk, Russia
Akamai Undergrad	Michael Gorman	Chriselle Galapon, LeEllen Phelps, Guillermo Montijo Jr.	Syracuse U.	Mechanical Quality Engineer, Apple, Cupertino, CA

2014

NSO Program	Participant Name	Advisor(s)	Institute	**What they are doing now …**
Undergrad SRA	Sophie Ettinger	Gordon Petrie	U. Chicago	Grad Student, Dept Physics & Astronomy, U. Pennsylvania
Undergrad SRA	Isaac McQuillen	LeEllen Phelps	Santa Clara U., Engineering School	MS 2018 Mechanical Engineering, Stanford U.; Aero-Thermal Engineer, Lucid Motor, Newark, CA
Undergrad SRA	Sarah C. Blunt	Serena Criscuoli	Brown U.	NSF Graduate Research Fellow, Dept of Astronomy, Harvard U.
Undergrad SRA	Sierra N. Ferguson	Christian Beck	Northern Arizona U.	Grad Student, Arizona State U. School of Earth and Space Exploration
Grad Akamai	Stacey R. Sueoka**	David Elmore	U. Arizona Optical Sciences	PhD 2016; Optical Systems Engineer, NSO/DKIST
Grad SRA	Sanjay Dmello	Andy Ferayorni	U. Colorado Boulder, Engineering	MS 2014 CU Boulder; Sr. Firmware Engineer, BYTON, Santa Clara, CA

2013

NSO Program	Participant Name	Advisor(s)	Institute	**What they are doing now …**
REU	Daniel Cohen	Serena Criscuoli	UC Berkeley	Graduate Student, Division of Astronomy & Astrophysics, UCLA
REU	Natalie Foster	Christopher Richards	U. Florida	3rd-yr NSF Graduate Research Fellow at U. Texas at Austin Department of Physics

2013 **(Cont.)**

NSO Program	Participant Name	Advisor(s)	Institute	What they are doing now …
REU/Akamai	Mark Miyazaki	Igor Suarez Sola & Niles Oien	U. Hawaiʻi, Hilo	Obtained Bachelor's degree in Mechanical Engineering, U. Hawaiʻi, Manoa
REU	Elora Salway	J. Lewis Fox	Brigham Young U.	Product Specialist, Qualtrics, Provo, UT January 2015 - Present
REU	Darryl Seligman	Gordon Petrie	U. Pennsylvania	Grad Student (Class of 2021), Dept of Astronomy, Yale U. Co-Founder of a science outreach organization called OpenLabs (http://theopenlabs.org).
REU	Tyler Sinotte	Brian Harker	U. Wisconsin, Madison	Grad Student, Clark Doctoral Fellow, U. Maryland College Park, Aerospace, Aeronautical & Astronautical/Space Engineering
RET	Pia Denzmore	Han Uitenbroek	DeBakey High School for Health Professions, Houston	Audit Staff, Plante Moran, Denver, CO; Professional Tutor, Math, Physics & Astronomy, Front Range Community College, Longmont, CO
Grad Akamai	Stacey R. Sueoka**	David Elmore	U. Arizona Optical Sciences	PhD. 2016, Optical Systems Engineer, NSO/DKIST
Grad SRA	Teresa Monsue**	Frank Hill & Keivan Stassun (Vanderbilt U.)	Fisk U./Vanderbilt U.	PhD. 2018 Physics, Vanderbilt U.; Catholic U. of America Intern at NASA Sciences & Exploration Directorate, Solar Physics Laboratory
Grad SRA	Matthew Richardson**	Frank Hill & Keivan Stassun (Vanderbilt U.)	Fisk U./Vanderbilt U.	Postdoctoral Research Scientist, Planetary Science Institute
Grad SRA	Tyler Behm	Steve Keil	Texas A&M U.	
Grad SRA	Thomas Schad**	Matthew Penn	U. Arizona	Assistant Scientist, National Solar Observatory
Grad SRA	Alexander Pevtsov	Thomas Berger	New Mexico State U.	Research Assistant, National Solar Observatory; Industrial Engineering Grad Student New Mexico State U.
Grad SRA	Michael Kirk**	K.S. Balasubramaniam & Irene Gonzalez-Hernandez	New Mexico State U.	Research Astrophysicist, Catholic U. of America & NASA Heliophysics Science Division
Grad SRA	Cedric (Eric) Ramesh	Alexei Pevtsov & Serena Criscuoli	New Mexico State U.	2017: Math & Astronomy Teacher, Socorro High School
Grad SRA	Gregory Taylor**	Thomas Rimmele	New Mexico State U.	PhD 2014; Adaptive Optics Scientist, Large Binocular Telescope Observatory
Undergrad SRA	Christopher Moore	Thomas Rimmele & Mark Rast (CU Boulder)	U. Colorado Boulder	PhD 2017; Postdoctoral Fellow, Harvard CfA
Grad IRES	John R. Hodgson II	Firoza Sutaria	California State U. Northridge	Sr. Manager, Sales Planning & Technology, Viking Cruises
Grad IRES	Filis Coba	Mousumi Das	Hunter College City of NY (CUNY)	DataKind Data Science Fellow at Flatiron School, Washington DC

APPENDIX G. NSO IT SECURITY PLAN

NSO is in the process of developing an IT security program that takes into consideration the specificities of the existing sites in Colorado, Hawai'i, and New Mexico and that takes advantage of the integration of the NSO HQ in the cyber University of Colorado IT system. The security program requires approval by the NSO's Directorate and will consider the following items:

- Cybersecurity and Acceptable Use Policy
- Backup Policy
- Computer and Network Room Access Policy
- Internet Privacy Policy
- Privileged Account Access Policy
- Remote Access Policy
- Security Camera Policy
- Security Incident Response Policy
- Wireless Access Policy
- Acceptable Encryption Use Policy
- Guidelines for Choosing a Good Password
- Network Audit Policy
- Server Security Policy
- Websites Terms and Conditions of Use
- Laptop Security Tips

APPENDIX H. 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
APRPP	Annual Progress Report and Program Plan (NSF)
APS	Astronomy and Planetary Science (CU Boulder Department)
AR	Active Region
ARRA	American Recovery and Reinvestment Act
ASP	Advanced Stokes Polarimeter
APDA	Astronomical Photographic Data Archives (PARI)
ATI	Advanced Technology Instrumentation (NSF)
ATM	Atmospheric Sciences (Division of NSF)
ATRC	Advanced Technology Research Center (University of Hawai‘i)
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
BLNR	Bureau of Land and Natural Resources
BBSO	Big Bear Solar Observatory
BOE	Basis of Estimate
BO/ITL	Biological Opinion/Incidental Take License (U.S. Fish & Wildlife Service)
BSA	Boulder Solar Alliance
CA	Cooperative Agreement
CAS	Central Administrative Services (AURA)
CATE	Citizen Continental America Telescopic Eclipse (NSO Project)
CAM	Cost Account Manager (DKIST)
CCD	Charge Coupled Device
CCMC	Community Coordinated Modeling Center
CDAW	Coordinated Data Analysis Workshop

CD-ROM	Compact Disk – Read Only Memory
CDR	Critical Design Review
CDUP	Conservation District User Permit
CES	Coudé Environmental System
CfA	Center for Astrophysics (Harvard Smithsonian)
CfAO	Center for Adaptive Optics
CGEM	Coronal Global Evolutionary Model
CGEP	Collaborative Graduate Education Program (University of Colorado, Boulder)
CHU	Critical Hardware Upgrade
CISM	Center for Integrated Space Weather Modeling
CJS	Commerce, Justice, Science (Subcommittee, US House Appropriations Committee)
CLEA	Contemporary Laboratory Exercises in Astronomy
CMAG	Compact Magnetograph (NISP)
CMEs	Coronal Mass Ejections
CNC	Computer Numerical Controlled
CNSF	Coalition for National Science Funding
CoDR	Conceptual Design Review
COLLAGE	COLLAborative Graduate Education (University of Colorado, Boulder)
COS	College of Optical Sciences (University of Arizona)
CoRoT	COnvection ROtation and planetary Transits (French Space Agency CNES)
CoSEC	Collaborative Sun-Earth Connection
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
CTL	Center-to-Limb
CU Boulder	University of Colorado, Boulder
CYRA	Cryogenic Infrared Spectrograph (NJIT, Big Bear Solar Observatory)
DA	Diversity Advocate
DAG	Directed Acyclic Graphs
DAS	Data Acquisition System
DB-P	Dual-beam Polarizer (McMath-Pierce Telescope)
DC	Data Center
D&D	Design & Development
DASL	Data and Activities for Solar Learning
DC	Data Center
DCAP	Data Center Action Plan (NSO)
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)
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
EIS	Extreme-ultraviolet Imaging Spectrometer (*Hinode*)
EIS	Environmental Impact Statement
EIT	Extreme ultraviolet Imaging Telescope (SOHO)
EMR	Experience Modifier Rate (OSHA)
EPA	Environmental Protection Agency
EPD	Energetic Particle Detector
EPO	Educational and Public Outreach
ESA	European Space Agency
ESF	Evans Solar Facility
ESO	European Southern Observatory
EST	European Solar Telescope
EU	European Union
EUI	Extreme Ultraviolet Imager (Solar Orbiter)
EUV	Extreme Ultraviolet
EVMS	Earned Value Management System (DKIST)
FAA	Federal Aviation Administration
FAT	Factory Acceptance Test
FDP	Full-Disk Patrol (SOLIS)
FDR	Final Design Review
FEIS	Final Environmental Impact Statement
FIDO	Facility Instrument Distribution Optics (DKIST)
FIP	First Ionization Potential
FIRS	Facility Infrared Spectro-polarimeter
FMS	Flexible Manufacturing System
FLC	Ferroelectric Liquid Crystal

FOCS	Feed Optics Control Software
FOV	Field of View
FPGA	Field Programmable Gate Array
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
GNAT	Global Network of Astronomical Telescopes, Inc. (Tucson)
GOES	Geostationary Operational Environmental Satellites (NASA and NOAA)
GONG	Global Oscillation Network Group
GOS	Gregorian Optical System
GSFC	Goddard Space Flight Center (NASA)
GST	Goode Solar Telescope (Big Bear Solar Observatory, California)
GUI	Graphical User Interface
HAO	High Altitude Observatory
HASO	Historical Archive of Sunspot Observations
HCP	Habitat Conservation Plan (HI State Division of Forestry & Wildlife)
HIDEE	Heliophysics Infrastructure and Data Environment Enhancements (NASA)
HIS	Heavy Ion Sensor
HLS	Higher Level Software
HMI	Helioseismic and Magnetic Imager
HO	Haleakalā Observatory
HOAO	High-Order Adaptive Optics
HPCF	High Performance Computing Facility (CU Boulder)
HQ	Headquarters
HR	Human Resources
HSG	Horizontal Spectrograph
HST	Hubble Space Telescope
HXR	Hard X-Ray
IAA	Instituto de Astrofísica de Andalucía (Spain)
IAC	Instituto de Astrofísica de Canarias (Spain)
IAU	International Astronomical Union
IBIS	Interferometric BIdimensional Spectrometer (Arcetri Observatory)
ICD	Interface Control Document
ICM	Inversion by Central Moments
ICME	Interplanetary Coronal Mass Ejections
ICS	Instrument Control System
IDL	Interactive Data Language
IEF	Inverse Evershed Flow
IfA	Institute for Astronomy (University of Hawai`i)
IFU	Integrated Field Unit (McMath-Pierce Solar Telescope Facility)

IHY	International Heliophysical Year
IMAP	Interstellar Mapping and Acceleration Probe (NASA)
IMaX	Imaging Magnetograph eXperiment (SUNRISE)
IMF	Interplanetary Mean Field
INAF	Istituto Nazionale di Astrofisica (National Institute for Astrophysics, Italy)
IPC	Integration Progression Criteria (DKIST)
IPS	Integrated Project Schedule
IR	Infrared
IRES	International Research Experience for Students (NSF)
IRIS	Interface Region Imaging Spectrograph
IRIS SMEX	Interface Region Imaging Spectrograph Small Explorer Mission (NASA)
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)
IT	Information Technology
ITAR	International Traffic in Arms Regulations
IT&C	Integration, Testing, & Commissioning
JPL	Jet Propulsion Laboratory (NASA)
JSOC	Joint Science Operations Center (SDO)
JTTS	Journey to the Sun (NSO Teacher Workshop and Telescope Program)
KAOS	Kiepenheuer Adaptive Optics System
KCE	KC Environmental (Maui)
KIS	Kiepenheuer Institute for Solar Physics (Freiburg, Germany)
KPNO	Kitt Peak National Observatory
KPVC	Kitt Peak Visitor Center
KPVT	Kitt Peak Vacuum Telescope
KS	Kamehameha Schools
LAPLACE	Life and PLAnets Center (University of Arizona)
LASCO	Large Angle and Spectrometric Coronagraph (NASA/ESA SOHO)
LASP	Laboratory for Atmospheric and Space Physics (University of Colorado, Boulder)
LAT	Lab Acceptance Test
LCROSS	Lunar CRater Observation and Sensing Satellite
LCVR	Liquid-Crystal Variable Retarder
LESIA	Laboratoire d'études patiales et d'instrumentation en astrophysique (Paris Observatory)
LFM	Large Facilities Manual (NSF)
LIC	Local Interlock Controller
LMSAL	Lockheed Martin Solar and Astrophysics Laboratory
LoHCo	Local Helioseismolgy Comparison Group
LOS	Line Of Sight
LRP	Long-Range Plan
LTE	Local Thermodynamic Equilibrium
LWS	Living With a Star
M1CA	Primary Mirror Cell Assembly (DKIST)
MAG	Magnetometer
MagEX	Magnetic Explorer (LASP CU-Boulder Mission)

MBP	Magnetic Bright Point
McMP	McMath-Pierce
MCAO	Multi-Conjugate Adaptive Optics
MCC	Maui Community College
MDI	Michelson Doppler Imager (SOHO)
ME	Milne-Eddington
MEDB	Maui Economic Development Board
METIS	Coronagraph (onboard Solar Orbiter)
MHD	Magnetohydrodynamic
MKAOC	Mauna Kea Astronomy Outreach Committee
MKIR	Mauna Kea Infrared
MOU	Memorandum of Understanding
MLSO	Mauna Loa Solar Observatory (HAO)
MOI	Memorandum of Intent
MPI	Message Passing Interface
MPR	Midterm Progress Review
MREFC	Major Research Equipment Facilities Construction (NSF)
MRI	Major Research Instrumentation (NSF)
MSAC	Math and Science Advisory Council (State of New Mexico)
MSFC	Marshall Space Flight Center (NASA)
MSIP	Mid-Scale Instrumentation Program (NSF)
MWO	Mt. Wilson Observatory (California)
NAC	NSO Array Camera
NAI	NASA Astrobiology Institute
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NCAR	National Center for Atmospheric Research
NCOA	National Center for Optical-Infrared Astronomy
NPR	National Public Radio
NCSP	NSO Community Science Program
NDSC	Network for the Detection of Stratospheric Change
ngGONG	Next Generation GONG
NHPA	National Historic Preservation Act
NHWG	Native Hawaiian Working Group
NIR	Near Infrared
NISP	NSO Integrated Synoptic Program
NJIT	New Jersey Institute of Technology
NLFFF	Non-Linear Force-Free Field
NLTE	Non-Local Thermodynamic Equilibrium
NMDOT	New Mexico Department of Transportation
NMSU	New Mexico State University
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NPDES	National Pollutant Discharge Elimination System (EPA/HI Dept of Health)
NPFC	Non-Potential Field Calculation
NPR	National Public Radio

NPS	National Park Service
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NSBP	National Society of Black Physicists
NSF	National Science Foundation
NSF/AST	National Science Foundation, Division of Astronomical Sciences
NSF/ATM	National Science Foundation, Division of Atmospheric Sciences
NSHP	National Society of Hispanic Physicsts
NSO	National Solar Observatory
NSO/SP	National Solar Observatory Sacramento Peak
NSO/T	National Solar Observatory Tucson
NST	New Solar Telescope (NJIT Big Bear Solar Observatory)
NSTC	National Science Technology Council
NTT	New Technology Telescope (ESO)
NWNH	New World New Horizons (Astro2010: Astronomy & Astrophysics Decadal Survey)
NWRA/CoRA	NorthWest Research Associates/Colorado Research Associates
O&M	Operations and Maintenance
OCD	Operational Concepts Definition (DKIST)
OCP	Operations Commissioning Phase (DKIST)
OCS	Observatory Control System
OEO	Office of Education and Outreach (NSO)
OFCM	Office of the Federal Coordinator for Meteorology
OMB	Office of Management and Budget
OP	Observing Program
OPMT	Operations Planning & Monitoring Tool
OSHA	Occupational Safety and Health Administration
O-SPAN	Optical Solar Patrol Network (formerly ISOON)
OSTP	Office of Science and Technology Policy (US Office of the President)
PA	Programmatic Agreement (State Historic Preservation Office/Federal Historic Preservation Office)
PA	Proposal Architect
PAARE	Partnerships in Astronomy & Astrophysics Research & Education (NSF)
PA&C	Polarization Analysis & Calibration
PAEO	Public Affairs and Educational Outreach (NOAO)
PB	Peta Bytes
PBR	President's Budget Request
PARI	Pisgah Astronomical Research Institute
PCA	Principal Component Analysis
PDR	Preliminary Design Review
PFSS	Potential Field Source Surface
PhET	Physics Education Technology (CU Boulder)
PHI	Polarimetric and Helioseismic Imager (Solar Orbiter)
PI	Principal Investigator
PLA	Project Labor Agreements
PM	Project (or Program) Manager (NSO)

PMCS	Project Management Control System
PRC	Portfolio Review Committee (NSF)
PRD	Partial Frequency Redistribution
PRI	Public Radio International
ProMag	PROminence Magnetometer (HAO)
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
ROSA	Rapid Oscillations in the Solar Atmosphere
RPW	Radio and Plasma Wave
SACNAS	Society for the Advancement of Chicanos an Native Americans in Science
SAN	Storage Area Network
SASSA	Spatially Averaged Signed Shear Angle
SAT	Sight Acceptance Testing
SCB	Sequential Chromospheric Brightening
SCM	Small Complete Mission (NASA)
SCOPE	Southwest Consortium of Observatories for Public Education
SDO	Solar Dynamics Observatory (NASA)
SDR	Solar Differential Rotation
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)
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)
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
SPC	Scientific Personnel Committee (NSO)
SPD	Solar Physics Division (AAS)
SPICE	Spectral Imager of the Coronal Environment (Solar Orbiter)
SPINOR	Spectro-Polarimeter for Infrared and Optical Regions
SPRING	Solar Physics Research Integrated Network Group (European Union)
SPSC	Space Science Center (University of Colorado, Boulder)
SRA	Summer Research Assistant
SRD	Science Requirements Document
SREC	Southern Rockies Education Centers
SSA SWE	Space Situational Awareness – Space Weather Segment (European Space Agency)
SSEB	Source Selection Evaluation Board (Federal Government)
SSL	Space Sciences Laboratory (UC Berkeley)
SSOC	Sunspot Solar Observatory Consortium
SSP	Source Selection Plan (DKIST)
SST	Swedish Solar Telescope
SSWG	Site Survey Working Group (DKIST)
STARA	Sunspot Tracking and Recognition Algorithm
STEAM	Science, Technology, Education, Arts, and Mathematics
STEM	Science, Technology, Engineering and Mathematics
STEP	Summer Teacher Enrichment Program
STEREO	Solar TErrestrial RElations Observatory (NASA Mission)
STIC	Stockholm *Inversion* Code
STS	Science for a Technological Society (2013 Solar and Space Science Decadal Survey)
SUC	Science Use Case
SUCR	Summit Control Room (DKIST)
SUMI	Solar Ultraviolet Magnetograph Investigation (NASA, MSFC)
SUP	Special Use Permit
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)

TAC	Telescope Time Allocation Committee
TB	Tera Bytes
TBD	To Be Determined
TCS	Telescope Control System
TEOA	Top End Optical Assembly (DKIST)
TMA	Telescope Mount Assembly
ToO	Target of Opportunity
TOP	Technical Operations
TRC	Technical Review Committee
TRACE	Transition Region and Coronal Explorer
UA	University of Arizona
UH	University of Hawai'i
UBF	Universal Birefringent Filter
UK	United Kingdom
UPS	Uninterruptible Power Supply
USAF	United States Air Force
USF&WS	US Fish and Wildlife Service
USNO	United States Naval Observatory
UV	UltraViolet
UVCS	UltraViolet Coronagraph Spectrometer (SOHO)
VBI	Visible-light Broadband Imager (DKIST)
VCCS	Virtual Camera Control System (Dunn Solar Telescope)
VFD	Variable Frequency Drive
VFISV	Very Fast Inversion of the Stokes Vector (Inversion Code, HMI)
ViSP	Visible Spectropolarimeter (DKIST)
VLA	Very Large Array
VSM	Vector SpectroMagnetograph (SOLIS)
VSO	Virtual Solar Observatory
VTF	Visible Tunable Filter (DKIST)
VTT	Vacuum Tower Telescope (Tenerife, Spain)
WBS	Work Breakdown Structure
WCCS	Wavefront Correction Control System
WDC	Workforce and Diversity Committee (AURA)
WFC	Wavefront Correction (DKIST)
WHI	Whole Heliospheric Interval
WISPR	Wide-Field Imager (Parker Solar Probe)
WIT	Women In Technology (MEDB)
WOW	World of Work (Patsy T. Mink Summit, Hawaii)
WSA	Wang-Sheeley-Arge (Solar Wind Model)
WSDL	Web Service Description Language
WWW	World Wide Web