NSO National Solar Observatory

2018 Annual Progress Report

2019 Program Plan

Unlocking the mysteries of the Sun and its effects on Earth

AURA

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The National Solar Observatory is operated by the
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MISSION

The mission of the National Solar Observatory (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 mission includes the operation of cutting-edge facilities, the continued development of advanced instrumentation both in-house and through partnerships, conducting solar research, and educational and public outreach.

NSO accomplishes this mission by:

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

RESEARCH OBJECTIVES

The broad research goals of NSO are to:

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

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1 EXECUTIVE SUMMARY

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

Major components of the National Solar Observatory strategic planning include:

- Developing and operating the National Science Foundation's 4-meter Daniel K. Inouye Solar Telescope (DKIST) on behalf of, and in collaboration with, the solar and heliospheric community.
- Developing the DKIST operations team based in Maui.
- Operating a suite of instruments comprising the NSO Integrated Synoptic Program (NISP). This Program includes the Synoptic Optical Long-term Investigation of the Sun (SOLIS) and the Global Oscillation Network Group (GONG).
- Developing partnerships to establish a concept for a future network (Solar Physics Research Integrated Network Group, SPRING) that replaces GONG and SOLIS and provides ground-based solar data adapted to the demands of Space Weather modeling.
- An orderly transition to a new NSO structure that efficiently operates DKIST and NISP and continues to advance the frontiers of solar physics. This structure establishes a matrix organization of the NSO that promotes a unified culture at the Observatory and allows for optimizing resource allocations. NSO will describe the matrix structure in the five-year Long Range Plan (LRP) due in FY 2019. The proposed matrix organization resembles the consolidation of the night-time ground-based observatories under AURA in the National Center for Optical-Infrared Astronomy (NCOA).

In parallel with these major components, NSO will continue:

- Expanding interagency collaborations for NISP following the guidance in the National Space Weather Strategy and Action Plan.
- Upgrading the GONG network to adapt it to the needs of the Space Weather research community, ensuring its competitive continuation for another solar cycle.
- Developing the adaptive optics (AO) and multi-conjugate AO (MCAO) needed for the DKIST.
- Helping the transition of operations of the Dunn Solar Telescope (DST) to a consortium led by New Mexico State University (NMSU). NSO will continue operating the Sacramento Peak site facilities in FY 2019.
- Increasing diversity of the solar workforce.

Some of the programmatic highlights of the NSO Program in FY 2019 include:

- Continuation of DKIST construction on Haleakalā. In FY 2019, the DKIST first-light initiative combining the Visible-light Broadband Imager (VBI) and the Wavefront Correction (WFC) system will take place.
- Start DKIST's instruments integration and science verification.

- Continue forming the core teams for DKIST operations in Boulder and Maui, including the DKIST Data Center (DC).
- Establish the DKIST Science Policy Advisory Committee (DSPAC) charged with advising the National Solar Observatory (NSO) and the DKIST Time Allocation Committee (TAC) on the optimum strategies and priorities, consistent with NSF policy, for the operations of the DKIST to maximize its scientific productivity. The primary task of the DSPAC is to implement a data and access policy responsive to the Astronomy and Astrophysics Advisory Committee (AAC) recommendations on principles for access to large federally funded astrophysics projects and facilities.
- Resume operations of the SOLIS suite of instruments at Big Bear Solar Observatory (BBSO).
- Advance the GONG refurbishment project in its main components: acquisition and characterization of new detectors, new polarization modulators, and tunable Hα filters.
- In the context of the newly created NSO's Community Science Program (NCSP), accelerate NSO's capability to apply spectro-polarimetric inversions to generate enhanced DKIST Level-2 data products routinely, along the lines of the NSF Big Idea: *Harnessing the Data Revolution*.

A few of the major actions to advance solar physics that NSO will undertake in FY 2019 include:

- End the first series of DKIST Critical Science Plan (CSP) workshops targeted at training the community with its capabilities and with the generation of detailed Science Use Cases (SUC).
- Implement through the NCSP a series of activities aimed at preparing the DKIST community on data manipulation and Level-2 data products generation. Grow the DKIST user base with particular attention to the US university system.
- As the operational phase of DKIST nears, continue seeking international participation in the project.
- Establish an outreach plan to publicize the early science phase of DKIST, starting with the first-light initiative.
- Continue integrating NSO research activities into the CU Boulder system.

In FY 2019, the anticipated observatory funding is $21M, split into $17M for the DKIST operations funding wedge, reaching its planned maximum level, and $4M for base-program actions including HQ operations and NISP non-grant activities. Of the $17M for DKIST operations, NSO has already received $0.5M for the construction of the ROB (Remote Office Building; renamed the DKIST Science Support Center (DSSC)) and $8M for the timely completion of the DKIST Data Center. Thus, the expected remaining funds for the DKIST Operations Program in FY 2019 total $8.5M.

NSO received in FY 2018 two supplemental fundings, one for the continued operations of the Sunspot facility ($325K) and another for the production of DKIST Level-2 data products ($3.5M). This last supplement will be channeled through the NCSP as carry-forward funds in FY 2019. NSO expects to receive approval for a second, and similar, contribution to the NCSP to support the continued production of Level-2 data products.

In FY 2019, and after integration of the Primary Mirror, M1, DKIST will continue adding the optical components of the telescope and testing their overall performance and alignment. The most imminent activity will be the first night-time measurements using the M1 system, the night-time acquisition telescope, and the prime focus Shack-Hartmann wavefront sensor. Progressing to the integration of the optical subsystems, DKIST will then proceed with mounting and aligning the Top-End Optical Assembly (TEOA) subsystem containing the secondary mirror. These activities will continue integrating all mirrors and optical elements all the way down to the first folding mirror at the Coudé Lab, M7. The rotating Coudé optical room is being prepared to incorporate the VBI and the wavefront correction in preparation for the first-light initiative in the summer of 2019, a construction Level 1 milestone.

The Polarization, Analysis and Calibration (PA&C) team is starting lab assembly and testing in Boulder. PA&C is currently the primary schedule driver for the project. The team is assembling the lower Gregorian optical station components and has started fabrication of the upper elements. PA&C summit integration will occur during the spring of 2019.

Preparations for DKIST operations continue in FY 2019. The NSO personnel on the island moved to the Pukalani-based DKIST Science Support Center in the summer of 2018. The delays incurred in the construction and availability of the DSSC are responsible for the relatively large amounts of funds the DKIST Program carries forward. These funds mainly stem from an operational crew that is lagging behind the plans described in the Cooperative Agreement proposal. DKIST is adjusting its transition from construction to operations plan to distribute these funds in a cost-effective manner and minimize 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.

The DKIST Data Center architecture and design have continued its detailed definition and refinements in FY 2018 and has reached a point where the actual construction of the system can start in earnest. FY 2019 will see the ramp-up of DC personnel to its planned full capacity of about 10 FTEs. With the hires that occurred in FY 2018, there has been significant progress in the development of the operational tools including a functional release of the experiment architecture. These architectures will allow the creation of detailed observational programs that feed the summit operations and the Data Center metadata.

A total of nine Critical Science Plan (CSP) workshops have occurred in FY 2018. The workshops have increased the number of participants in the DKIST Critical Science Plan to about 150 scientists, and the number of Science Use Cases (SUC) has reached more than 200. This training activity has provided an opportunity for the community to familiarize itself with DKIST capabilities and the science that it enables. Particular emphasis was made on describing the unique coronal capabilities of the telescope that attract a much broader community than the traditional users of ground-based facilities. The workshops have also served as a platform for the community to test the tools needed to define an observing run compatible with the current instrument and telescope capabilities. In this manner, the various instrument performance calculators and the light distribution (FIDO) tool have been extensively validated. The project is using the expanded list of SUCs to understand the most demanded Coudé configurations. This list is also useful in identifying the most popular Level-2 data products. Two additional CSP workshops are planned for FY 2019.

FY 2019 will see the start of a new science program at the Observatory: the NSO Community Science Program (NCSP). NCSP will be under a new Associate Director (AD) reporting to the NSO Director. 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. Nurturing this scientist pool by focusing on research priorities demanded by the community is the primary task of the NCSP. NCSP fosters synergies between the operational programs (DKIST and NISP) by promoting activities with a research impact extending to both programs. In FY 2019, the funding for NCSP will come from the recently approved supplemental funding for the production of DKIST Level-2 data products. While this represents an activity specific for DKIST, the SOLIS facility generates data that use similar pipelines. By concentrating Level-2 data generation in the NCSP, we aim at efficiently exchanging the existing expertise on spectral inversions at the Observatory. NCSP will also use the supplemental funding to develop broad community-focused initiatives oriented at providing training on the use of DKIST data and the creation of higher-level data products. These intiatives range from broad data-training workshops to graduate-student support with dedicated training opportunities that include experts from all over the world and focuses on students' research interests.

In the context of the preparations for the DKIST early-science phase, NSO will start in FY 2019 the DKIST Science Policy Advisory Committee (DSPAC). The committee's charge is the definition of detailed guidance on DKIST data rights, data types (instrument's science verification data, guaranteed time data, CSP data, target-of-opportunity data, etc.), and data publication. It will also provide high-level guidance on facility access following the open skies policy described in the NSF Astronomy and Astrophysics Advisory Committee (AAAC) recommendations. The DSPAC will include the DKIST Co-Investigators along with other members of the community.

NISP relocation to the Boulder HQ is complete, including the GONG shelters that are located within walking distance of the NSO HQ on campus. The accessibility of the GONG engineering units offers a unique outreach opportunity, from VIP visits to student training. In FY 2019, NISP needs to make critical progress on the two top priorities of the program: refurbishment of the GONG network and the relocation of SOLIS. Specific milestones in FY 2019 for GONG refurbishment continue to be testing of the new detectors and the acquisition, calibration, and deployment of new polarization modulators. Validation of the Hα tunable filters concept continues to suffer significant delays due to a lack of interested vendors; as a solution, NISP is focusing on testing the existing filters in a motorized unit this year. The SOLIS facility is already at BBSO, but its deployment is suffering from delays in obtaining the construction permit. All of the required environmental and cultural studies have been successfully performed, but recent concerns with the SOLIS support structure are delaying the permit for onsite construction. In spite of these uncertainties, we expect SOLIS to resume operations sometime in FY 2019.

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 SPRING network is the most advanced concept that meets these needs and has broad international and national support. SPRING is a ground-based network of telescopes capable of spatially-resolved 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.

SPRING 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. Helioseismological techniques have now been assimilated by the blossoming field of asteroseismology, where they provide essential data key to the theory of stellar structure and evolution. Through this improved understanding of the parent stars enabled by asteroseismology, a more accurate characterization of the environment existing in orbiting exoplanets becomes possible. We anticipate the breadth of knowledge that SPRING will provide about the magnetic linkages in the solar system to transfer into the developing field of exo-weather and its impact on the habitability of other worlds.

In FY 2019, NSO will continue the multi-agency discussions to seek funds for the definition phase of the SPRING network.

To continue the diversification of NISP activities and expand the potential of future resources, in FY 2018 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. Using the GONG shelters' optical setup, the CMAG concept has been proven with satisfactory results. NSO will propose a CMAG as one of the payloads for a mission to the Lagrange Point L5, using the Small Complete Mission (SCM) opportunity that utilizes the IMAP ESPA Grande Access to Space option in the NASA 2018 Heliophysics Science Mission call for proposals. The mission to L5, MagEx, is led by the CU-Boulder Laboratory for Atmospheric and Space Physics (LASP) and includes other collaborating institutions. NSO contributes to the mission project scientist and the CMAG instrument. Other teams defining concepts for future missions have expressed an interest in the CMAG concept.

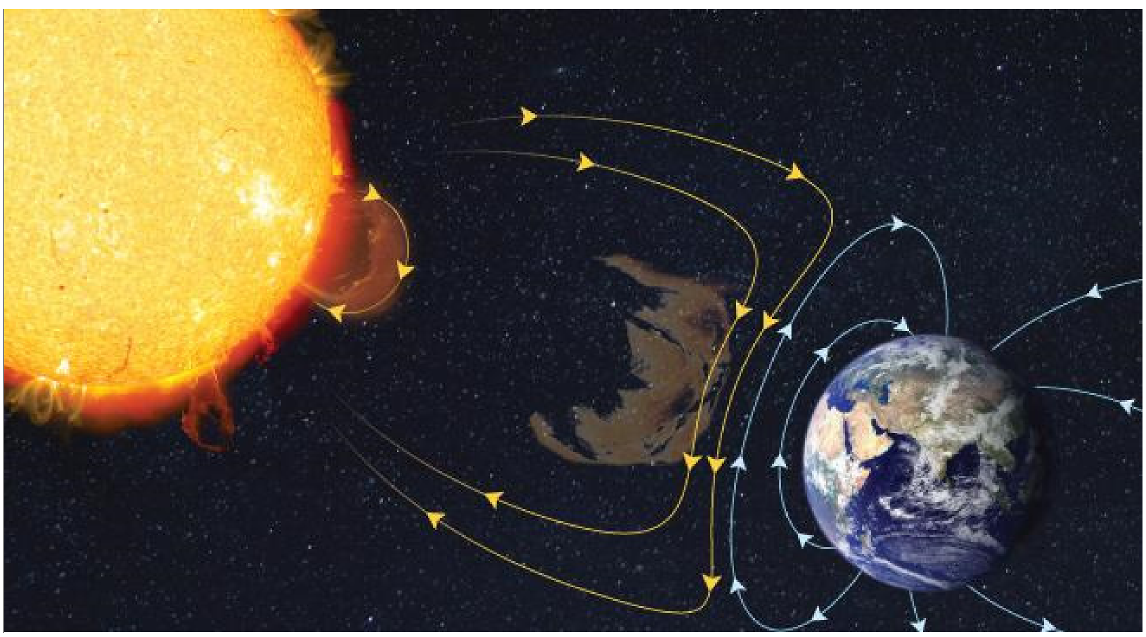


Figure 1-1. *SPRING observations will provide the necessary boundary data required to propogate magnetized coronal mass ejections (CME's) and track the orientation of the CME's magnetic field when it arrives at the Earth.*

In Sunspot, NSO activities concentrate on training of the NMSU staff that will operate the DST. This training has continued in FY 2018. To maximize the training time, no open calls to the community for observing proposals at the DST are regularly made, and the available time is mostly used to prepare the NMSU-led consortium's synoptic observations. The telescope continues to be accessible to the community for target of opportunities such as rocket launches from the nearby White Sands facility and to coordinate with space-mission observations. The DST will support the encounter phases of NASA's Parker Solar Probe mission starting in early November 2018. In FY 2019, NSO will operate the facility while NMSU efforts concentrate on the DST and the Visitor Center. An MOU between NMSU and AURA has been signed and will provide the legal framework for continued operations of the site.

Since FY 2016, NSO has been reinvigorating our education and public outreach (EPO) program by hiring a Boulder-based Head of EPO and an assistant in Maui. The team has been augmented with a graphics designer and webmaster. Our EPO team played a vital role during the 2017 eclipse when the presence of NSO was visible to the general public, the solar community, and the funding agencies. We are using the experience obtained during the 2017 eclipse to define the activities planned for the 2019 total solar eclipse that crosses the Chile-based observatories managed by AURA. NSO will provide scientific guidance to AURA during these activities. Leveraging on this success, NSO plans to continue publicizing the research performed at our facilities and its importance for our technological society, with particular emphasis on preparing for the beginning of DKIST operations in Maui. The EPO team at NSO will also provide support to the NCSP DKIST Level-2 project by enabling networking activities, online contents, and ensuring educational best practices.

NSO 2019 Program

- Daniel K. Inouye Solar Telescope (DKIST)
  - Continue construction on Haleakalā. Continue IT&C phase.
  - Conduct DKIST first-light initiative.
  - Start integration and science verification of first-light instruments.
  - Start execution of the DKIST Data Center implementation plan.
  - Finalize five-year DKIST Operations plan.
  - Define DKIST access and data policies.
  - Further recruitment of national and international collaborations.
- NSO Integrated Synoptic Program (NISP)
  - Operate GONG.
  - Resume SOLIS operations at BBSO.
  - Continue the refurbishment of the GONG network.
  - Continue the exploration of new funding opportunities for the SPRING network.
  - Continue the definition of a space-based compact magnetograph (CMAG).
  - Continue to seek outside funding for operations.
- NSO Community Science Program (NCSP)
  - Roll out the NCSP.
  - Specify DKIST Level-2 data products.
  - Start community training activities on DKIST data products.
- Sacramento Peak Observatory
  - Operate the site.
  - Continue training the NMSU personnel as needed.
- NSO Directorate
  - Prepare NSO five-year Long Range Plan and conduct Mid-term Review.
  - Continue definition of the NSO matrix structure.
  - Submit a white paper on future priorities for ground-based solar astronomy to the A&A Decadal Survey.
- Education and Outreach and Broadening Participation
  - DKIST first-light initiative outreach plan.
  - Continue the renovation of NSO's website.
  - Train the next generation of solar astronomers.

Figure 1-2. *Planned and ongoing programs and projects at NSO.*

2 FY 2018 SCIENTIFIC RESEARCH & DEVELOPMENT HIGHLIGHTS

2.1 Temporal Patterns of Zonal Flows as Precursors of Magnetic Activity in Solar Cycle

The two large-scale flows on the Sun are its rotation about its axis, and the meridional flow. The solar rotation is noticeable, for example, in the way sunspots move across the solar disk. The solar differential rotation shows a small variation of about 5 m/s with the solar cycle, the so-called torsional oscillation, which is small compared to the average rotation rate with, for example, about 2000 m/s at the equator near the surface. This variation moves from mid-latitudes toward the equator during the solar cycle noticeable as bands of faster- and slower-than-average rotation.

This pattern of migrating zonal flow bands has been monitored since 1995 for nearly two solar cycles with continuous global helioseismic observations by the Global Oscillations Network Group, together with those made by the Michelson Doppler Imager onboard the Solar and Heliosepheric Observatory and its successor the Helioseismic and Magnetic Imager onboard the Solar Dynamics Observatory. Earlier this year, a group of scientists with NSO scientists (Howe et al., *ApJ*, 2018) among them reported that the flows now show traces of the mid-latitude acceleration that is expected to become the main equatorward-moving branch of the zonal flow pattern for Cycle 25. Extrapolating from the current position of this branch, the onset of widespread activity for Cycle 25 is expected to be likely after the middle of 2019, **near the time when DKIST comes online.**

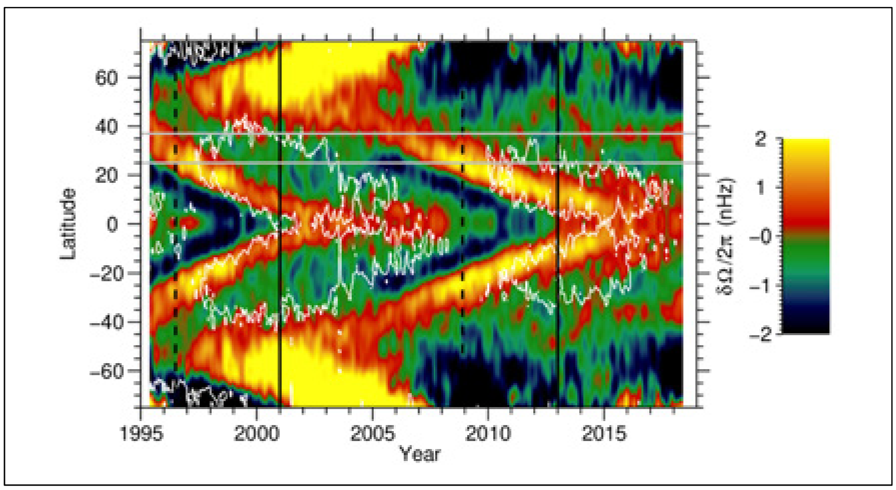


Figure 2.1-1. *The rotation-rate residuals at a target depth of 0.99 solar radius as a function of latitude and time, from RLS inversions of GONG, MDI, and HMI data. The mean to be subtracted was taken separately over the whole data set for GONG and for the combined MDI and HMI set. The vertical black lines represent the times of solar minimum (dashed) and solar maximum (solid). The horizontal gray lines indicate the 25- and 37-degree latitudes. The white contours represent 10% of the maximum level of the synoptic unsigned magnetic field strength.*

2.2 New Solar Chromosphere Temperature Diagnostics with ALMA and IBIS

Exploring a new diagnostic of the solar chromosphere can provide novel insights and raise intriguing questions. The Atacama Large Millimeter Array (ALMA) has recently opened a new window on the chromosphere with observations of the millimeter-wavelength continuum of the Sun. With its array of 66 antennas, ALMA has already provided groundbreaking results on astrophysical topics such as stellar formation and galactic dynamics. On the Sun, ALMA can achieve the highest spatial and temporal resolution to date at these wavelengths (500 km and two seconds). The exciting diagnostic capability of ALMA for solar physics is based on the expected linear relationship between the observed continuum brightness at the millimeter wavelengths and the local electron temperature, which can't be so easily measured in any other region of the spectrum.

In 2016, NSO scientists were awarded observing time on ALMA during its first round of regular solar observations (Cycle 4). In April 2017, they coordinated these observations from Chile with simultaneous observations from the Dunn Solar Telescope (DST) using IBIS, ROSA, and FIRS. They also organized observations with IRIS, BBSO, and *Hinode*. Working with two CU graduate students, Momchil Molnar and Ryan Hofmann, and in collaboration with Yi Chai and Dr. Dale Gary at the New Jersey Institute of Technology, they processed this complicated set of observations to provide a unique and comprehensive view of the solar atmosphere around an active region plage.

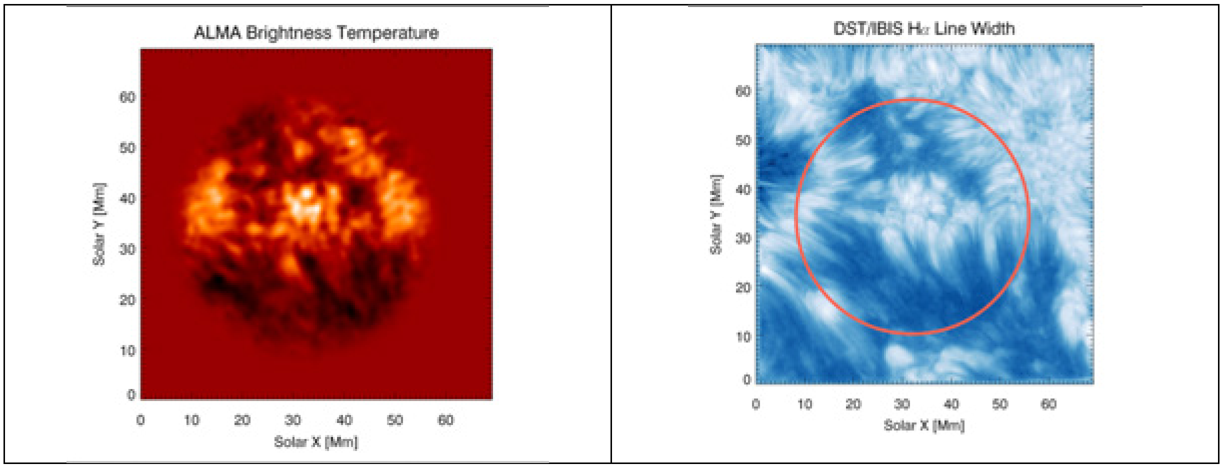


Figure 2.2-1. *Left: High-resolution, interferometric image obtained with the ALMA interferometer in the wavelength interval 2.8-3.3 mm (92-108 GHz; Band 3), which characterizes the temperatures in the chromospheric plasma, ranging from 6,800-10,800 K. Right: Map of line widths measured from the H-alpha line profile obtained with IBIS at the Dunn Solar Telescope, ranging from 0.95 to 1.25 Ångstroms. After applying blurring to match the ALMA spatial resolution, the line widths show a better that 0.85 correlation with the ALMA temperatures.*

The most intriguing result so far is the finding that the ALMA brightness temperatures (Band 3) are most strongly correlated with the width of the H-alpha line, the canonical signature of the solar chromosphere. This indicates that the millimeter wavelengths are indeed providing information on the chromospheric plasma. More importantly, the H-alpha line width is an easily accessible diagnostic, making it a powerful proxy for chromospheric temperatures for a wide range of observations. This may guide new interpretations of the profiles of this line.

The more curious finding is that the temperatures measured by ALMA, after careful calibration, are significantly higher than the temperatures previously predicted using calculations from three dimensional magnetohydrodynamic simulations. Instead of the 5000-6000 K expected based on those works, the ALMA temperatures were significantly higher, with an average of 7000-8000 K. This indicates that the ALMA radiation is formed in plasma that is closer to transition region temperatures, perhaps due to incorrect estimates of electron density in the numerical models.

This work will be extended, with the goal to prepare for joint observations between ALMA and DKIST, where additional information on the chromospheric magnetic field can be routinely measured. The combination of these different new diagnostics will be a powerful new tool in understanding the chromosphere.

2.3 Reconstructing Solar Magnetic Fields from Historical Observations

The widely accepted phenomenological concept of the solar cycle, the so-called Babcock-Leighton model (Babcock 1961; Leighton 1969), describes the solar cycle as a transformation of poloidal field, which is concentrated in polar areas at the beginning of each cycle, into toroidal field. As the cycle progresses, increase in toroidal field gives rise to active regions in mid to low latitudes. The magnetic field of dissipating active regions is dispersed by near-surface motions and transported across the solar surface by meridional flows. The trailing polarity fields are transported poleward, where they rebuild the poloidal field for the next solar cycle. The Babcock-Leighton model assumes that the magnetic flux of the leading polarity fields of active regions cancels out across the solar equator. This leaves several important questions open. What would be the effect on the solar cycle if sunspot activity was strongly asymmetric hemispherically, or was even completely restricted to one hemisphere only? Would we still see the build-up of the poloidal field in polar areas in both hemispheres, or would the alternation of the polarity of polar fields as a signal of the solar 22-year magnetic (Hale) cycle be disrupted?

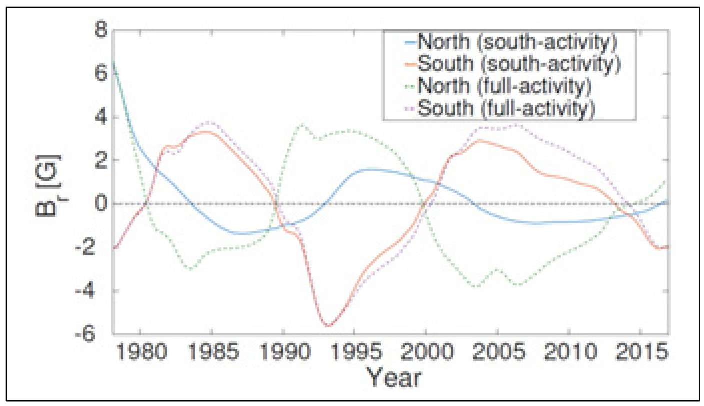


Figure 2.3-1. *Average field strength above 60° and below −60° latitude from the simulations that include sunspot activity in both hemispheres (dashed lines) and the activity only in one (southern) hemisphere (solid lines).*

In a search for answers to these important questions, the team of scientists from NSO and the University of Oulu, Finland (Virtanen et al. *A&A*, 2018) employed the surface flux transport model (SFT) and modern observations of solar magnetic fields from the (now defunct) Kitt Peak Vacuum Telescope and the SOLIS Vector Spectromagnetograph (VSM from 1978 till 2016. The SFT model includes the meridional circulation, differential rotation, diffusion, and a term describing the emerging flux. For this work, the model has been extended with the decay term, which is based on the diffusion of the radial field in the convection layer. The introduction of additional decay term solves the known problem related to the inability of SFT models to reverse the polarity of polar fields correctly during weak cycles, such as Cycle 24. To demonstrate that the model successfully reproduces the behavior of polar magnetic fields during 1978 - 2016, the team, first, compared the outcome of the model with the observations. They found a good agreement in overall amplitude of (observed and modelled) polar fields and the time of reversals. Next, they repeated the calculations but with sunspot activity in the Northern hemisphere turned off. The team found that even without any new flux emerging in the northern hemisphere, polarity reversals of polar fields can still be observed in both hemisphere due to flux transport across solar equator. Since the meridional flows are directed poleward in either hemisphere, the only mechanism that can transport magnetic flux across the solar equator is diffusion. The simulation showed that cross-equatorial flux transport is quite efficient, and once the magnetic flux has crossed the equator, it can be transported towards the northern pole also by the meridional flow.

Figure 2.3-1 shows the average intensity of polar fields below -60° and above 60° latitude in the two simulations with normal activity in both hemispheres (dashed lines) and the sunspot activity only in one (southern) hemisphere. The northern polarity reversals of Cycles 21–23 occur three to four years later in the south-activity simulation than in the full-activity simulation. For Cycle 24, this difference is about two years. The southern polarity reversals happen slightly earlier in the south-activity simulation. The difference is a few months for Cycles 21–23 and about a year for Cycle 24. Moreover, because of the delayed reversal of the northern pole in the south-activity simulation, both poles have the same polarity for three to four years during the early declining phase of each cycle.

The team also investigated the effect of the reduced level of sunspot activity and found that reducing the number of active regions by a factor of three does not prevent the polar fields from reversing their polarity, but simply scales them down. Because of the decay term, the model does not have a long-term memory, and the effect of the earlier, more active sunspot cycle disappears rather quickly. Therefore, the simulation maintains polar fields that are weaker, but reverse their polarity regularly, even after an initial cycle with strong polar fields.

The results of this study are important for understanding the magnetic cycle on the Sun. During the Great (Maunder) minimum of solar activity, the direct observations of sunspots indicate a very low level of sunspot activity. Moreover, the sunspot activity was highly asymmetric with nearly all sunspots observed in the southern hemisphere. These observations were interpreted as if the solar cycle was not operating during the Maunder minimum. On the other hand, the derivations based on the cosmogenic isotopes imply that the magnetic cycle in the heliosphere had continued. The results reconcile this apparent disagreement as it is found that even with a highly asymmetric and low level of sunspot activity, the polar field reversals can still occur in both hemispheres thus maintaining the 22-year magnetic cycle.

2.4 An Assessment of and Solution to the Intensity Diffusion Error Intrinsic to Short-Characteristic Radiative Transfer Methods

Computational radiative transfer is critical for inferring the physical properties of the Sun by comparing the synthesized spectra from model atmospheres with observed spectra. Moreover, radiative transfer modeling plays an important role in determining the solution of the energy equation in hydrodynamic and magnetohydrodynamic (MHD) simulations of the solar surface. A reliable computational solution of the radiative transfer equation is therefore required to accurately compare model results with observations.

Solution of the radiative transfer equation often employs the short-characteristic method due to its straightforward domain decompo-sition when synthesizing 3D MHD simulations. The most significant draw-back of the short-characteristic method is numerical diffusion resulting from interpolation when propagating rays at slanted angles through the simulation domain. While the diffusive error introduced by the short-characteristics method has been known since the foundational work, no work had assessed the error introduced when calculating the radiative transfer solution on 3D MHD simulations.

C. L. Peck et al. (*ApJ*, 2017) presented a detailed analysis of the effective reduction in spatial resolution that results when employing the short-characteristic radiative transfer method to calculate the emergent intensity at inclined viewing angles. In this work, they derived a closed form analytical model for the specific intensity of a beam at each point of the grid as a function of beam angle when the beam is initiated as a delta function at the bottom of the computation domain. The emergent intensity at the top of the domain therefore represented the effective point-spread function of the numerical scheme. They then validated the analytic model by comparing the intensity obtained by a short-characteristics numerical solution of the radiation emerging from a 3D MHD simulation snapshot with that predicted by the analytic model. Most importantly, they demonstrated that the diffusive error is readily avoided by interpolating the simulation atmosphere onto a viewing-angle aligned grid (or pre-tilting) prior to computing the radiative transfer solution. The difference in spatial resolution for the emergent intensity of a 3D MHD simulation calculated using the short characteristics method and the pre-tilting method can be seen in Figure 2.4-1.

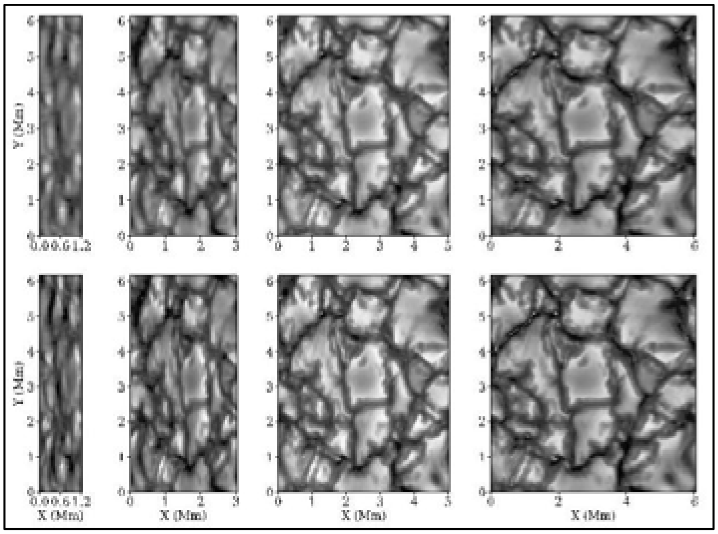


Figure 2.4-1. *Emergent intensity synthesized in the standard short-characteristics method at inclination values of μ = 0.20, 0.49, 0.82, and 0.99 (top row from left to right). Note the smearing in the direction of the tilt due to the short-characteristic intensity diffusion and is more prominent for larger inclination angles. Bottom row shows the emergent intensity for the same inclination when synthesized on a pre-tilted domain (grid aligned with the ray propagation direction). The pre-tilting method maintains the spatial resolution of the simulation, which can be seen most clearly in the small-scale magnetic structures.*

Without such pre-tilting, the short-characteristic scheme introduces errors that challenge comparisons between numerical solutions and observations. For simulations and observations with matching native resolution, any nongrid-aligned viewing angle yields a fundamental mismatch in the effective spatial resolution. For example, the spatial resolution of the simulation shown in Figure 2.4-1 is reduced from 16 km to 80 km when viewed at μ = 0.49 due to the numerical diffusion. This change is equivalent to the difference in spatial resolution of observations obtained in the visible with telescope apertures of 4 m (e.g., DKIST and EST) and ~0.8 m (e.g., the Dunn Solar Telescope). While Peck and colleagues demonstrated that employing higher-order interpolation schemes yields an improvement to 28 km resolution (when employing cubic monotonic in the previous example), this comes at the expense of nonconservation of the specific intensity. These results therefore demonstrate the importance of a robust solution to the radiative transfer equation when comparing 3D MHD simulations to observations and will be critical for the upcoming observations with DKIST.

2.5 Thermodynamic Properties of the Inverse Evershed Flow at its Downflow Points

Mass motions inside and in the vicinity of sunspots are mostly organized as flows along penumbral filaments in the photosphere and along super-penumbral fibrils in the chromosphere. The direction and strength of the flows along different channels depend on the thermodynamic and magnetic properties of the regions connected by the magnetic field lines. The determination of the flow speed, the flow direction and the temperature of the plasma in these flow channels is critical for understanding the underlying physical mechanisms.

The photosphere in sunspots shows the regular Evershed flow (EF), a radial outflow that is roughly parallel to the solar surface. At chromospheric heights, a radial inflow is observed that was termed the "inverse" Evershed flow (IEF). Both EF and IEF are structured in elongated, thin flow fibrils. The chromospheric IEF is generally believed to be caused by siphon flows along arched magnetic field lines connecting footpoints with a different magnetic field strength and gas pressure. In a series of papers, Thomas & Montesinos (1989, 1990, 1991, 1993) developed theoretical models of photospheric siphon flows.

Using observations of the Ca II IR line at 854 nm acquired with the SPINOR spectropolarimeter at the NSF's Dunn Solar Telescope, D. P. Choudhary and C. Beck (*ApJ*, 2018) determined the thermodynamic properties of chromospheric flow fibrils. They derived the line-of-sight (LOS) velocity as a measure of the flow speed and inverted the spectra with the CAISAR code (Beck et al. 2015) to obtain temperature stratifications.

Figure 2.5-1 shows a typical example of an IEF flow fibril. The LOS velocity drops from a supersonic speed of 5-15 km/s to about zero at the location where the fibril returns to the photosphere as indicated by the temperature stratifications. The temperature at the downflow point is enhanced at mid photospheric layers, which suggests the existence of a shock front with significant heating of the atmosphere.

Using the statistics of the 100 flow fibrils identified in the data, Choudhary and Beck found that the thermodynamic properties of individual flow fibrils and on average comply with the scenario of a super-sonic siphon flow that decelerates at its footpoint through a standing shock as depicted in scenario A of Figure 2.5-2. Other potential drivers of chromospheric flows such as mass shedding of rising magnetic field lines (scenario B) or coronal rain (scenario C) do not match the spatial and temporal behavior of the chromospheric flow fibrils harboring the IEF. They thus suggest that the IEF is driven by siphon flows that attain chromospheric heights at their apex.

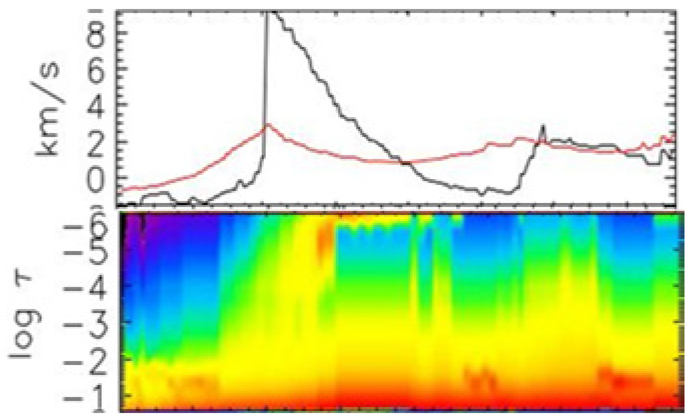


Figure 2.5-1. *Top panel: line-of-sight velocity (black) and line-core intensity (red) along a chromospheric flow fibril. Bottom panel: temperature along the flow fibril. The umbra of the sunspot is at the left. The velocity drops abruptly to zero at the hot fibril head. Taken from Choudhary & Beck (2018).*

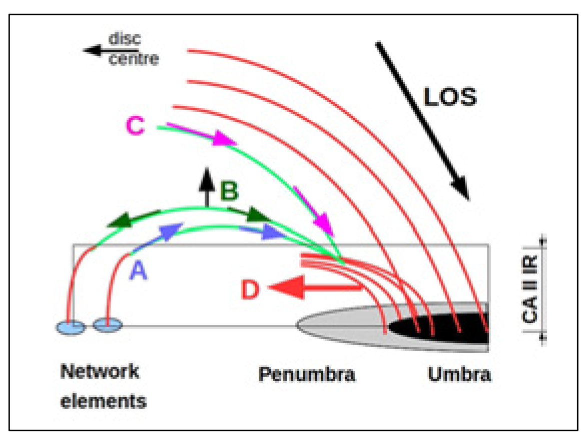


Figure 2.5-2. *Sketch of different flow scenarios. A: Inverse Evershed flow (IEF) through a siphon flow mechanism. B: IEF caused by mass shedding of rising magnetic field lines. C: IEF through coronal rain. D: photospheric Evershed flow. The black rectangle indicates the formation height of the Ca II IR line at 854.2 nm from the continuum-forming layers to a height of about 1 Mm. Taken from Choudhary & Beck (2018).*

2.6 Modeling the Global Coronal Field with Simulated Synoptic Magnetograms from Earth and the Lagrange Points L3, L4, and L5

The Sun is the only star that directly impacts us on Earth from our climate to short-term effects collectively known as space weather. Some of this impact is dangerous: energetic particles (radiation) and induced electric currents from flares and coronal mass ejections (CMEs) can do great harm to astronauts, satellites, communication systems and electric power distribution systems.

To forecast and model the effects of space weather, we rely on full-surface maps of the Sun's photospheric magnetic field to drive near-real-time models for the global solar atmosphere. This is because the solar photospheric flux distribution is key to structuring the global corona and heliosphere. In particular, the polar fields play a leading role in defining this global structure. However, we can only observe the Sun from a single vantage point—Earth and its vicinity. Multi-vantage observations were available from NASA's STEREO mission but, unfortunately, the STEREO spacecraft did not have magnetograph instruments on board. From Earth (or the Lagrange point L1; see below), we can only see the side of the Sun facing us at any given time and, since the Sun's rotation period is about 27 days on average, it takes nearly a month to build a full-surface map of the Sun's field. These synoptic maps do not represent well the evolution of magnetic fields in areas that cannot be observed from Earth/L1 viewing direction. Moreover, because the Earth's orbit is tilted only very slightly (7.25 degrees) with respect to the Sun's rotation axis, the Sun's poles are very difficult to observe. From Earth/L1, we cannot see one or other pole for about half a year and, even under optimal conditions, we observe that pole with a very large viewing angle. This is particularly unfortunate because the Sun's polar magnetic fields are globally influential: they supply most of the interplanetary magnetic field and channel most of the fast solar wind—some of the most important ingredients of space weather.

One possible solution to this is to send telescopes to other locations in the solar system. A natural choice would be a gravitational equilibrium point around the Earth's orbit, such as one of the Lagrange points (see image at *https://wmap.gsfc.nasa.gov/media/990528/index.html*). In particular, the Lagrange points L5 and L4 are located 60 degrees behind and ahead of Earth, and L3 is 180 degrees from Earth, where the far (from us) side of the Sun is visible. However, launching and operating spacecraft is expensive, and it would be useful to evaluate the benefits of the additional data. Here, G.J.D. Petrie et al. (*SoPh*, 2018) modeled the possible effect of full-disk magnetogram data from the Lagrange points L4 and L5, each extending longitudinal coverage by 60 degrees, and from the more distant point L3, extending the longitudinal coverage much further. The additional vantage points also improve the visibility of the polar fields because the tilt angles of the Sun's rotation axis with respect to the different vantage points have different phases, and so each pole goes unobserved for a smaller portion of the year as more vantage points are added. This additional information should therefore improve the accuracy of global field models.

To test this idea, Petrie and colleagues used a simulated surface magnetic field from flux-transport simulation for a full solar activity cycle (11 years), and modeled daily observations of the Sun's surface magnetic field over the full cycle from Earth and from L3, L4 and L5. They then constructed the best full-surface solar field maps as if they were observed from various locations on Earth's orbit (Lagrange L1/Earth, L3, L4, and L5) and their combination. Synoptic maps are constructed at NSO by projecting full-disk magnetograms taken from Earth (GONG and SOLIS/VSM), over a full rotation covering the range of solar longitudes, onto a common Carrington coordinate (longitude, latitude) grid, combining them in a

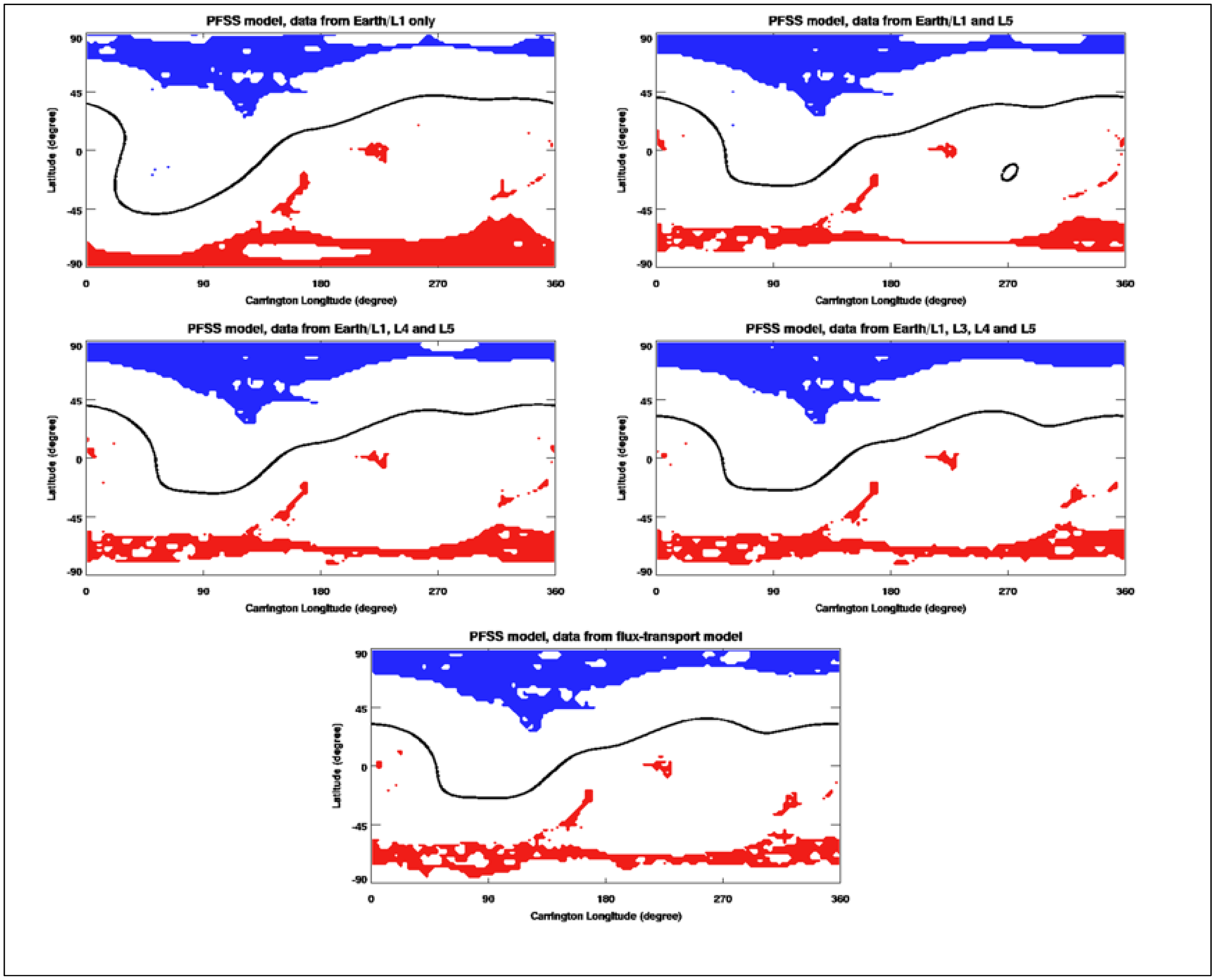


Figure 2.6-1. *Longitude–latitude plots of five coronal magnetic field models. The five models are based on synthetic observations from Earth/L1 only (top left), Earth/L1 and L5 (top right), Earth/L1, L4, and L5 (middle left), Earth/L1, L3, L4, and L5 (middle right), and from the corresponding full-surface snapshot of the original solar surface field simulation (bottom). The positive- and negative-polarity footpoints, representing coronal holes (solar wind sources), are plotted in red and blue. The thick black line represents the heliospheric current sheet.*

weighted average with higher weighting for data observed nearer central meridian. Here, to accommodate data from the additional viewpoints, they modified this weighting scheme to allow new data from a given viewpoint to overwrite older data for the same solar locations taken from a different viewpoint.

Petrie et al. estimated the effect of additional observations and found that adding L5 observations to the Earth/L1 observations reduces the mean error by about 17%, and the further addition of L4 data reduces the error by a further 17%. L3 data produce a further reduction in the error by 23-24%. As the example in the figure demonstrates, the improvements in the coronal field modeling are more evident at the poles than at low latitudes. This reflects the sensitivity of the Potential Field Source Surface (PFSS) model, particularly the coronal holes (solar wind sources), to polar field data. The correct answer, the model based on a snapshot of the original solar surface field simulation, is shown in the bottom panel. There are key differences between the model based on data from L1/Earth (top left) and the bottom panel, and these differences are most obvious at the poles. Adding data from L5 (top right), then L4 (middle left) and then L3 (middle right), brings the model progressively closer to the correct answer. It is clear that, even without leaving the ecliptic plane, observing from multiple viewpoints such as the Lagrange points significantly enhances our coverage of the polar fields, which is key to improving Petrie and colleagues' near-real-time modeling of the solar atmosphere and their forecasting of the effects of dangerous solar phenomena.

2.7 Towards DKIST Cool Coronal Magnetometry: Establishing Polarimetric Diagnostics of Cooled Coronal Loops Through Novel Off-Limb Neutral Helium Imaging Spectroscopy

Our finest probe of coronal magnetism may be when it undergoes runaway cooling events. When the corona cools, condensed material embedded in the corona radiates via strong spectral lines from more abundant ions, i.e., hydrogen and helium. The boost in line radiance helps alleviate some of the observational difficulties of observing the corona via highly ionized metals, albeit for plasma that has cooled from megakelvin to kilokelvin temperatures. Coronal polarimetry, in particular, is a photon-starved endeavour that may greatly benefit from adapting and applying polarimetric techniques typically used for chromospheric plasmas directly for remote sensing the coronal magnetic field.

Establishing polarimetric diagnostics of cooled coronal loops requires knowledge of the formation of cooled spectral species during episodes of coronal rain. This poses the secondary challenge of conduc-ting rapid imaging spectroscopy of dynamically evolving material. Tom Schad's recent article (*ApJ*, 2018) is the culmination of work with prototype instrumentation at the Dunn Solar Tele-scope (Schad & Lin, *SoPh*, 2017*)* and newly developed machine vision analysis techniques (Schad, *SoPh*, 2017) to study the neutral helium triplet lines at 10830 Å in dynamic phenomena. The He I triplet is an important polarized diagnostic of magnetic fields. The recent *ApJ* article reports on coordinated observations of coronal run using SDO/AIA, IRIS, and the hybrid, massively-multiplexed (17-slit) grating-based spectrograph with simultaneous narrowband imaging deployed at the DST.

Figure 2.7-1 shows a snapshot of the coordinated data set targeting coronal rain observed off-limb in NOAA AR 12468. Coronal rain is readily identified in all channels as downflowing material (better seen in the associated movie), and is spatial coherent among all channels. Schad (2018) concludes that, despite its neutral character, the material seen in the He I triplet is well coupled to the ionized gas and therefore likely traces out the coronal magnetic field. The corresponding statistical analysis of more than 120,000 coronal rain He I spectral profiles established that the median He I line radiances are on order of 10^5 photons cm^{-2} s^{-1} $arcsec^{-2}$, or approximately two orders of magnitude brighter than the most promising polarized diagnostics of hot coronal material. The He I profiles also show signatures consistent with optically thin formation.

Using the observed characteristics of the neutral helium triplet, Schad (2018) goes on to estimate the sensitivity that DKIST provides for inferring the cool coronal magnetic field via simultaneous polarimetric observations of the He D3 5876 Å and the He I 10830 Å multiplets with the Visible Spectropolarimeter (ViSP) and the Diffraction-Limited Near-Infrared Spectropolarimeter (DL-NIRSP). Using a monte-carlo error simulation and custom inversions of profiles synthesized with the HAZEL code (Asensio Ramos et al. 2008), this work predicts that DKIST can provided inverted field errors of +/-3.5 Gauss (2σ) for ~360 km scales (~0.5 arcsec) within an integration time of 5.5 seconds. In addition, the analysis indicates that the

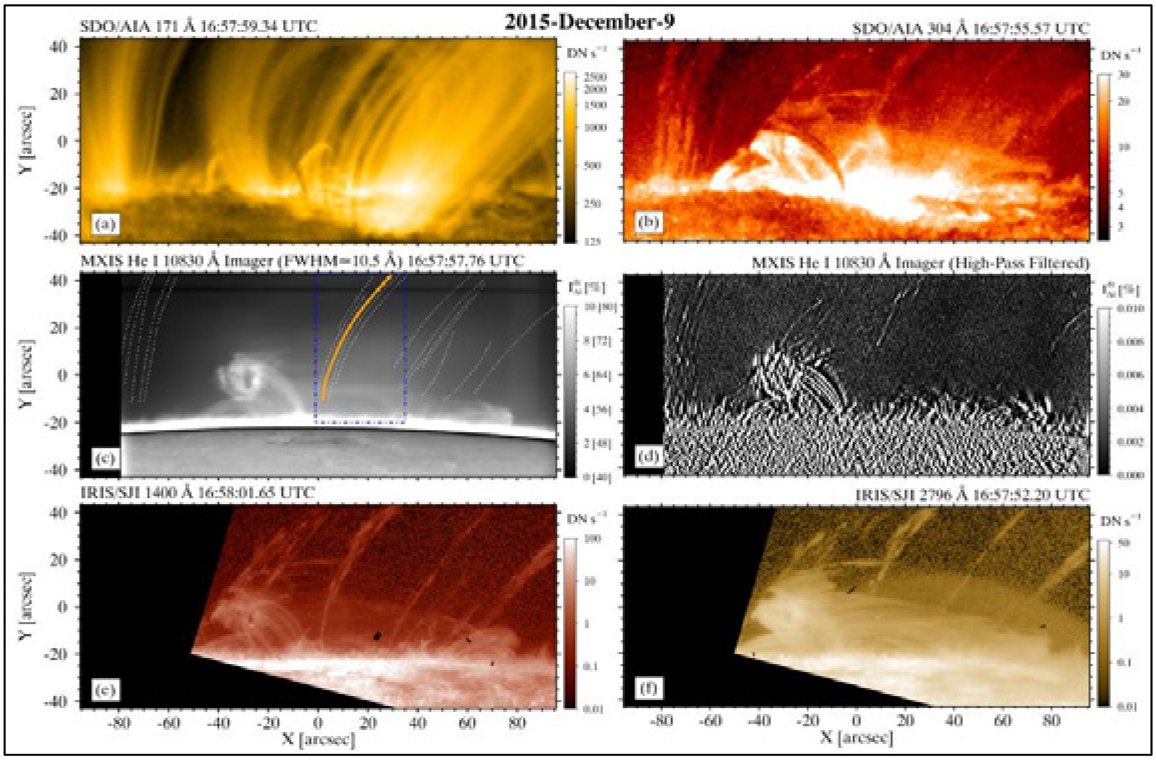


Figure 2.7-1. *Coordinated observations of coronal rain in NOAA AR 12468 on December 9, 2015. The top panels show the SDO/AIA 171 Å and 304 Å channels, respectively dominated by Fe^{+10} and He^{+1} formed near 0.6 MK and 50,000 K. Narrowband observations centered on He I 1083 nm, observed using the prototype DST multiplexed spectrograph's imaging channel, are shown in the middle panels (left: scaled, right: high-pass filtered). IRIS slit-jaw images in the 1400 Å and 2796 Å channels are on the bottom, respectively dominated by Si^{+3} (T~60,000 K) and Mg^{+1} (T ~ 10,000 K).*

scattering angle and magnetic field vector can be simultaneously recovered, which means the location of the coronal rain material along the line-of-sight can be directly inferred.

Table 2.7-1 compares the results of this new study and hot coronal diagnostics to further highlight the importance of realizing cool coronal polarimetry at DKIST. See Schad (*ApJ*, 2018) for more details.

Table 2.7-1. Comparison of required integration times for hot and cool coronal magnetic field diagnostics.

	Hot Corona	Cool Corona
Spectral Line	Fe XIII 10747 Å	He I 10830 Å / He I D3 5876 Å
Temperature	~ 1.6 Megakelvin	< 50,000 K
Angular Scales	1" × 1"	0.5" × 0.5"
Line Radiance	10^3 photons cm^{-2} s^{-1} $arcsec^{-2}$	10^5 photons cm^{-2} s^{-1} $arcsec^{-2}$
Polarization Mechanisms	Zeeman Effect + Saturated Hanle Effect	Zeeman Effect + J-level Crossings + (Un-) saturated Hanle Effect
Minimum DKIST integration time for < 1 G magnetic field error	7.6 minutes	5.5 seconds

2.8 Formation of the UV Spectrum of Molecular Hydrogen in the Sun

Molecular hydrogen is able to form in great abundance in the temperature minimum region of the solar atmosphere, and in cool regions, such as in sunspots, it may account for as much at 10% of the total particle population. Detecting hydrogen molecules in the Sun is difficult because the traditional rotation-vibration lines typically used in astrophysical situations are forbidden at the high densities in the Sun's photosphere. However, H_2 molecules can produce fluorescent emission at ultraviolet wavelengths through electronic transitions in response to irradiation by bright emission lines produced by high temperatures above the chromosphere. To understand the UV spectrum of H_2, Jaeggli, Judge, & Daw (*ApJ*, 2018) carried out modeling using realistic radiative inputs and carried out a detailed calculation of the wavelength-dependent opacity between the excitation source and the molecules in the lower atmosphere using an advanced radiative transfer code.

Jaeggli et al. found that although the chromosphere is thought to be highly structured thermally, the H_2 emission forms in a fairly uniform layer. Figure 2.8-1 shows the H_2 number density calculated in dissociative equilibrium for a vertical slice through the 3D simulation (en024048 hion from *http://sdc.uio.no/vol/simulations*) made with the Bifrost code. The top panel is shown on a physical height scale, while the bottom panel is in terms of the optical depth at 140 nm in the ultraviolet. The dashed line in both panels shows the height where the optical depth is equal to unity and consequently where most of the H_2 UV emission originates. The figure demonstrates that even in a realistic 3D model of the Sun, the structure of the low chromosphere is dominated by the density stratification. The tau=1 surface closely follows the H_2 density and is closer to horizontal than to vertical. This means H_2 irradiance and fluorescence can be successfully modeled using a 1D radiative transfer calculation.

The detailed modeling of Jaeggli et al. was carried out with improved line lists for H_2, and many previously unidentified lines of H_2 were discovered in UV spectral atlases of the Sun. This modeling also demonstrates that the fluorescent emission from H_2 actually originates somewhat higher than the temperature minimum due to the steeply increasing UV opacity of the lower solar atmosphere, and that H_2 emission is able to be seen in the quiet-Sun in measurements with sufficient signal to noise or when there is bright transition region emission, such as during flares.

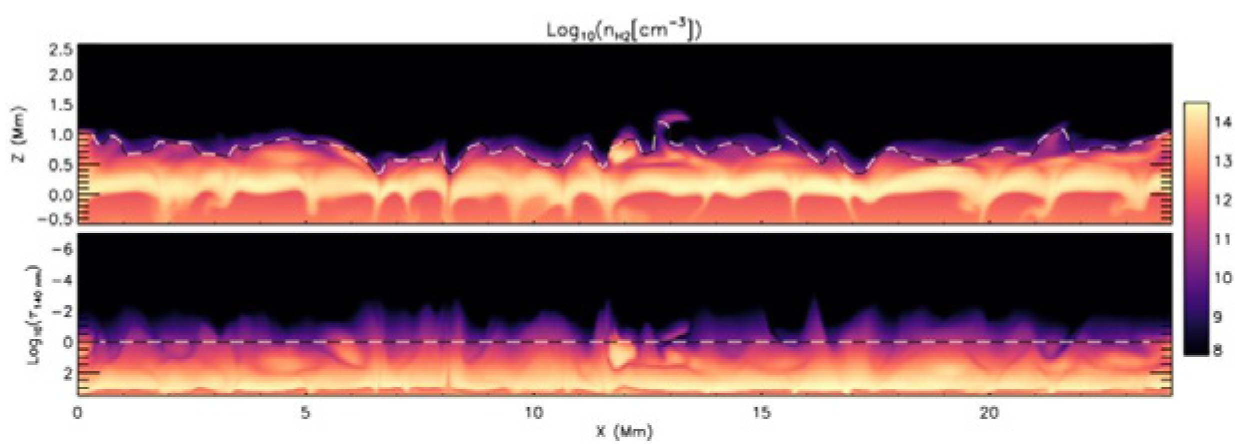


Figure 2.8-1. *The H_2 number density calculated in dissociative equilibrium for a vertical slice through the 3D simulation made with the Bifrost code.*

2.9 Detection of a Millimeter Flare from Proxima Centauri

The nearest star beyond the Sun is Proxima Centauri, an M-type dwarf that was recently found to harbor an Earth-mass planet in the habitable zone where liquid water could potentially exist. This exciting discovery has spurred follow-up studies to search for other potential similarities to our own solar system, such as features that are analogous to our Kuiper belt and the zodiacal dust. Anglada et al. 2017 presented far-IR measurements with ALMA of the Proxima Centauri system and claimed detections of three dust belts around the central star: at 0.4 a.u. beyond the orbit of the planet and analogous to zodiacal dust; at 1-4 a.u. analogous to an asteroid belt; and at 30 a.u. analogous to a Kuiper belt.

In a follow up study, Meredith MacGregor (postdoc at Carnegie-DTM) analyzed the time-evolution of the ALMA data and found that the innermost two sources of emission were of stellar origin. MacGregor and collaborators, including University of Colorado associate professor Steve Cranmer and assistant professor Adam Kowalski, reported on the properties of the stellar emission in an *ApJ Letter* (MacGregor et al. 2018). The 1-4 a.u. source was explained as a large flare event on Proxima Centauri, not thermal emission from circumstellar dust. The innermost ring may be explained as basal coronal emission from the star, as described in Cranmer et al. 2013.

Finding similar features to our own solar system around M stars—like Proxima Centauri—allows us to better understand planet formation in the solar system at various stages of evolution. Though the two innermost features around Prox Cen can be attributed to stellar emission, the detection of an outermost ring is being investigated with more ALMA data (led by MacGregor). The flare that was detected in ALMA (and mistaken for an asteroid belt-like ring) was unique in being the first M dwarf flare observed at these far-IR mm wavelengths. Because these wavelengths are in the optically thin part of the gyrosynchrotron spectrum, the authors were able to derive the power-law of mildly relativistic electrons accelerated during an M dwarf flare for the first time. In contrast to solar flares, radio detections are the only way to directly probe the properties of accelerated particles during flares on other stars. The nature of accelerated particles is important for understanding the space weather and potential habitability of the Earth-mass planet in the Proxima Centauri system.

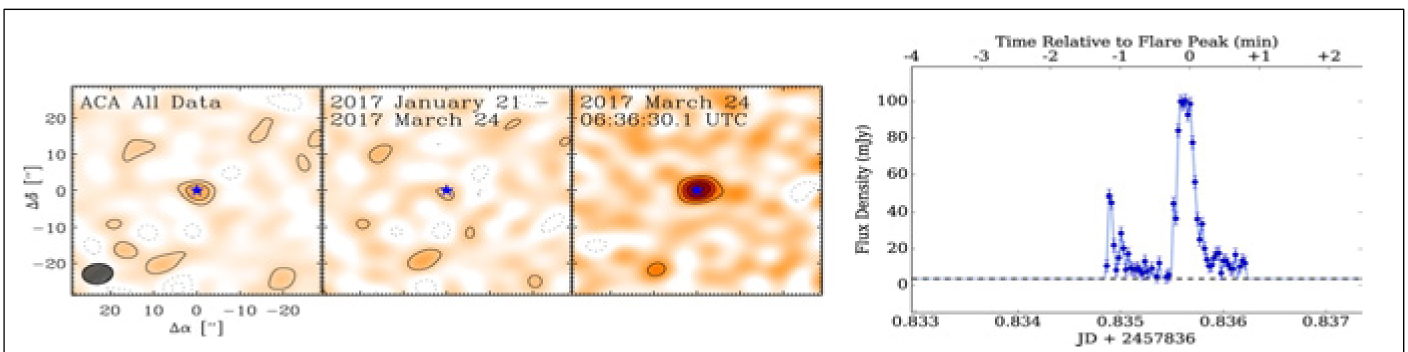


Figure 2.9-1. *Millimeter emission from Proxima Centauri is detected only in a small subset of data taken with the Atacama Compact Array (ACA, part of ALMA). Left: the left panel shows the natural weight image that results from combining all 13 observations together. The middle panel shows the first 12 observations combined, while the right panel shows the final observation imaged separately. From these images, it is clear that a point source is only detected at the stellar location in the final observation. In all three images, contour levels are in steps of [−2, 2, 4, 6, ...]× the rms noise of 47, 68, and 150 μJy beam⁻¹, respectively. The stellar position is marked by the blue star symbol, and the 7.27″ × 5.51″ synthesized beam is indicated by the hatched ellipse in the lower-left corner of the first panel. Right: a light curve of the transient point source detected in the second to last scan of the observation on 2017 March 24 from 06:36:30.1 to 08:10:27.2 UTC. A series of several small oscillations in flux density followed by a much larger flare-like event are seen at JD 2457836.8349–2457836.8355. Figure from MacGregor et al. 2018.*

2.10 Improved Analysis Tools and Metrology for System-Level Polarization Performance at DKIST

Two publications this year by D. Harrington and S. Sueoka (SPIE *JATIS*, 01/2018(a) & *JATIS*, 11/2018(b)) show detailed polarization performance modeling for calibration and modulation optics. New spatial retardance mapping techniques have been developed and applied to the suite of DKIST telescope and instrument retarders to assess the field-dependent calibration errors. Harrington and Sueoka show how DKIST can achieve calibration efficiency and also high accuracy within arc-minute fields as well as tools to optimize further upgraded calibration optics. Using retardance mapping at scales much finer than DKIST beam, they can calculate errors introduced in various calibration and modulation techniques as functions of wavelength, field angle, orientation, manufacturing errors and other variables. This allows a realistic estimate of errors in trade studies when comparing various duration sequences. An important system-level trade is efficiency vs redundancy when performing calibration of all DKIST AO-assisted instrumentation with all cameras operating simultaneously with the optic under thermal loading of the 300 Watt beam. Harrington and Sueoka also built on their 2017 publication (Harrington et al., *JATIS*, 048001, 2017) of the Berreman calculus applied to polarization fringes to show in *JATIS* 2018(a) how fringes depend on beam focal ratio, choices about coatings and bonding materials and on thermal perturbations. The unprecedented thermal loads on the DKIST polarization calibration optics have been assessed from the perspective of fringes as well as bulk thermal drifts. With these new estimates of optical performance, they show that DKIST will be stable and accurate over the intended first-light use cases. They also use these new tools to identify and pursue upgrades to various DKIST polarization optics.

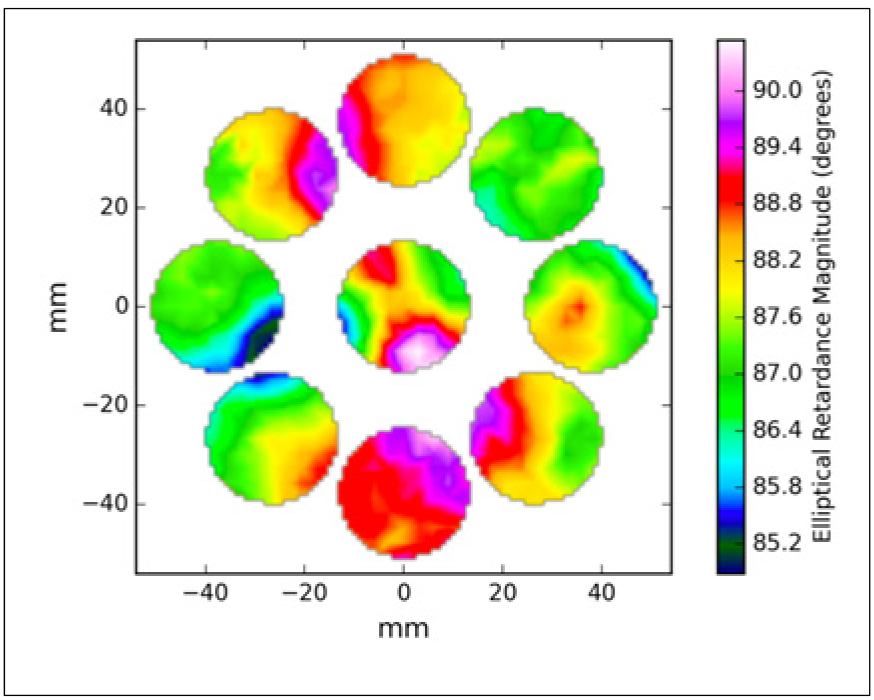


Figure 2.10-1. *The spatially variable retardance for a specific DKIST calibration retarder for a specific sequence of calibration optic orientations. The reference computes depolarization and systematic errors for this optic when averaging over a variable field angle. Also shown in the reference is an example estimate of calibration efficiency and systematic errors introduced by averaging flux over a variable field.*

3 SCIENTIFIC AND KEY MANAGEMENT STAFF

The NSO staff provide support to users including observational support, developing and supporting state-of-the-art instrumentation to ensure that users obtain the best data, and maintaining data archives and the means to accessing the data. Members of the scientific staff are defining how DKIST will be operated and how NSO will handle the data. In addition, both scientific and engineering staff serve as mentors for undergraduate and graduate students and postdoctoral fellows. They also organize community workshops on critical areas of solar research and planning. Staff science and instrument development allow NSO to stay at the forefront of solar physics and play a crucial role in fulfilling user support.

The current NSO scientific and management staff, as well as affiliated scientific staff, are listed below with their primary areas of expertise and key observatory responsibilities.

Scientific Staff

Christian Beck	Post-focus instrumentation; data reduction pipelines; high-resolution spectroscopy and spectro-polarimetry of the photosphere and chromosphere; development of inversion tools for chromospheric spectral lines; polarimetric calibration techniques; DKIST instrumentation and polarimetric calibration approaches.
Luca Bertello	NISP/SOLIS Data Scientist; solar variability at different temporal, spectral, and spatial scales; calibration of the observed solar magnetic field data to enhance the database that supports analysis of conditions in the corona and heliosphere; long-term synoptic observations in the resonance line of Ca II K for retrospective analyses of solar magnetism on multi-decade time scales; analysis of helioseismological data for better understanding solar interior structure and dynamics.
Serena Criscuoli	High-spatial resolution spectroscopy and spectropolarimetry of the photosphere and chromosphere; radiative transfer; numerical simulations; solar irradiance variations.
Alisdair Davey	CMEs and associated phenomena; acceleration and heliospheric propagation of SEPs during solar flares and CMEs; use of computer vision/AI in identifying solar features and events; development of the VSO and the heliospheric data environment, including integration of data and modeling efforts.
Andre Fehlmann	DKIST infrared instrumentation specialist; IR instrumentation; precision spectro-polarimetry; coronal magnetic fields; student engagement and community outreach.
Sanjay Gosain	Astronomical instrumentation: optical design of instruments for polarimetry and spectroscopy. Solar Physics: flares, eruptive filaments and coronal mass ejections; chromospheric magnetic field of solar active regions; solar cycle evolution of magnetic field.
David M. Harrington	DKIST polarimetry scientist; instrumentation; spectropolarimetry, adaptive optics, novel optical systems, detector systems, applied research, community workforce development.

Scientific Staff (cont.)

Frank Hill	NSO Associate Director for NISP; helioseismology; asteroseismology; fluid dynamics of the solar convection zone; the solar activity cycle; virtual observatories; solar magnetic fields; space weather.
Sarah A. Jaeggli	3D structure of sunspot magnetic fields; atomic and molecular physics of the photosphere and chromosphere; radiative transfer modeling and spectral synthesis; instrumentation for spectroscopy and spectropolarimetry, including DKIST facility instrument development; engaging the community to perform multi-facility observations.
Kiran Jain	Helioseismology: oscillation mode characteristics; multi-wavelength helio-seismology; subsurface dynamics; active regions; solar activity; Sun-Earth connection.
Maria Kazachenko	Inversion techniques to derive the electric fields and Poynting fluxes on the surface of the Sun using magnetic field measurements; data-driven simulations of the solar coronal magnetic fields; statistical properties of solar flares.
Rudolf W. Komm	Helioseismology; dynamics of the solar convection zone; solar activity and variability.
Adam F. Kowalski	Flare observations and radiative-hydrodynamic modeling; white-light flare radiation and continuum properties; connection between magnetic activity and flares on the Sun and younger M dwarf stars; teaching physics of stellar atmo-sphere modeling and observational astronomy and spectroscopic analysis.
Jose Marino	DKIST wavefront correction; image restoration; solar adaptive optics and multi-conjugate adaptive optics; solar adaptive optics modeling and simulation; high-resolution solar observations; atmospheric tomography; point spread function estimation.
Valentín Martínez Pillet	NSO Director; solar activity; Sun-heliosphere connectivity; magnetic field measurements; spectroscopy; polarimetry; astronomical instrumentation with an emphasis on spectropolarimetry.
Gordon J. D. Petrie	NISP; solar magnetism; the polar magnetic fields and their responses to activity; magnetic restructuring and associated Lorentz force changes during flares; coronal magnetic field extrapolations; CMEs; DKIST critical science planning.
Alexei A. Pevtsov	NISP; Chair, NSO Scientific Personnel Committee; solar magnetic fields; corona; sunspots; chromosphere; solar-stellar research; space weather and space climate.
Kevin P. Reardon	Dynamics and structure of the solar chromosphere, transition region, and corona; implementation of modern techniques for data archiving, processing, and discovery; application of imaging spectroscopy techniques; post-focus instrumentation development; spectropolarimetry of the solar atmosphere; transit studies of inner planets; history of solar astronomy.

Scientific Staff (cont.)

Thomas R. Rimmele	NSO Associate Director for DKIST; DKIST PI and Project Director; sunspots; small-scale magnetic surface fields; active region dynamics; flares; acoustics waves; weak fields; adaptive optics; multi-conjugate adaptive optics; instrumentation.
Thomas A. Schad	Chromospheric and coronal magnetic field dynamics; precision spectro-polarimetry; infrared instrumentation, including DKIST facility instrument development; student engagement and community outreach; scientific lead, DKIST Instrument Control System.
Dirk Schmidt	DKIST adaptive optics, high spatio-temporal resolution observation techniques; development of adaptive optics systems, in particular multi-conjugate adaptive optics systems.
Sushanta C. Tripathy	NISP Interior Program Scientist; magnetoseismology of active regions; global and local helioseismology; solar activity cycle; ring-diagram analysis, sub-surface flows, cross-spectral analysis of oscillation time series.
Alexandra Tritschler	DKIST Operations Scientist; DKIST operations development; DKIST Observatory Control System Scientist; DKIST Target Acquisition System Scientist; DKIST Visible Broadband Imager; solar fine structure; magnetism; Stokes polarimetry.
Han Uitenbroek	Associate Director for NSO Community Science Program; atmospheric structure and dynamics; radiative transfer modeling of the solar atmosphere; DKIST Visible Broadband Imager.
Friedrich Wöger	DKIST Instruments Project Scientist. Image reconstruction techniques; adaptive optics; two-dimensional spec-troscopy, and spectro-polarimetry; DKIST instrumentation, in particular the visible broadband imager; DKIST wavefront correction system; DKIST data handling system.

Grant-Supported Scientific Staff

Shukirjon S. Kholikov	Helioseismology; data analysis techniques; time-distance methods.

Postdoctoral Fellows

Tetsu Anan	Solar chromospheric heating; high-energy non-thermal particles; integral-field-unit spectro-polarimetry.
Gabriel Dima	Coronal magnetic field measurements; polarimetry; infrared emission line diagnostics.
Courtney Peck	High spatial resolution spectroscopy of the solarphotosphere; solarirradiance; radiative transfer; numerical simulations; speckle image reconstruction.

Key Management Staff

Gregory Card	NISP Engineering & Technical Manager.
Jennifer L. Ditsler	NSO Director's Office Administrator.
Rex G. Hunter	DKIST Construction Business Manager.
Andrew R. Marble	NISP Data Center Manager.
Claire L. Raftery	NSO Head of Education and Public Outreach.
Robert E. Tawa	DKIST Data Center Project Manager.
Mark Warner	DKIST Program Manager.
Carolyn Watkins	NSO Business Operations Manager.

Graduate Students

Elizabeth Butler	University of Colorado	Analysis of solar flare observations from IRIS.
Ryan Hofmann	University of Colorado	Comparison of inversion-derived temperature profiles with ALMA observations.
Momchil Molnar	University of Colorado	Chromospheric dynamics.
Gary Simons	University of Colorado	Radiative-hydrodynamic modeling of the Fe XXI line in solar flares.
Amanda White	University of Colorado	DKIST polarization performance & modeling.

Table 3.1 NSO Scientific Staff Estimated Percent FTE by Activity (FY 2018)								
Name	**Adm/Mgt[1]**	**Research[2]**	**EPO[3]**	**Project Support**	**User Support**	**Internal Comm.**	**External Comm.**	**TOTAL**
Anan, T.		80.0		20.0				100.0
Beck, C.		31.3	3.0	39.2	24.8	1.7		100.0
Bertello, L.		51.0		29.0	20.0			100.0
[b]Burtseva, O.		100.0						100.0
Criscuoli, S.		84.0	2.0	4.0	8.0	2.0		100.0
Davey, A.		2.0		98.0				100.0
Dima, G.		89.0	1.0	10.0				100.0
Fehlmann, A.				100.0				100.0
[b]Giampapa, M.S.								
Gosain, S.		5.0		95.0				100.0
Harrington, D.			4.0	96.0				100.0
[a]Harvey, J.W.								
Hill, F.	80.4	2.0		12.9		3.2	1.5	100.0
Jaeggli, S.		15.0	1.0	83.0	1.0			100.0
**Jain, K.		36.0		63.5		0.5		100.0
*Kholikov, S.S.		90.0		5.0	5.0			100.0
**[c]Komm, R.W.		50.0		50.0				100.0
[a]Leibacher, J.W.								
Marino, J.		10.0		90.0				100.0
Martinez Pillet, V.	98.0						2.0	100.0
Peck, C.		80.0		19.0		1.0		100.0
[b]Penn, M.J.								
**Petrie, G.J.D.		62.0	3.0	32.0	2.0		1.0	100.0
Pevtsov, A.A.		60.0		35.0		1.0	4.0	100.0
**[c]Plowman, J.		50.0		50.0				100.0
Reardon, K.P.		25.0		55.8	19.2			100.0
Rimmele, T.R.	97.0	1.0	1.0				1.0	100.0
Schad, T.A	2.0	53.0	2.0	43.0				100.0
Schmidt, D.		10.0		90.0				100.0
Tripathy, S.C.	2.0	67.0	3.0	27.0		1.0		100.0
Tritschler, A.	41.0	1.0	2.0	56.0				100.0
Uitenbroek, H.		18.7	0.5	36.3	33.2	6.6	4.7	100.0
Woeger, F.	93.0			7.0				100.0

*Fully grant supported.
**Partially grant supported.
[a]Emeritus status in 2018.
[b]Completed employment in 2018.
[c]Fully grant supported in FY 2019.

[1]Administrative and/or Management Tasks.
[2]Research, including participation in scientific conferences.
[3]Educational and Public Outreach.

4 DKIST CONSTRUCTION AND OPERATIONS RAMP UP

4.1 Introduction

The Daniel K. Inouye Solar Telescope is an all-reflecting, 4-meter, off-axis Gregorian telescope housed in a co-rotating dome. DKIST delivers a maximum 300-arcsec-diameter circular field of view. Energy outside of this field is rejected from the system by a heat stop located at prime focus, allowing manageable thermal loading on the optical elements that follow. The telescope also includes a sophisticated wavefront control system, including active optics (aO) for figure control of the primary, active alignment of the critical optical elements, such as primary and secondary mirrors, and an integrated high-order adaptive optics (AO) system designed to provide diffraction-limited images to the focal-plane instruments at the Coudé observing stations.

The basic telescope parameters and design for the DKIST and its subsystems have been described in detail in a number of recent publications to which we refer the reader for design details and performance analysis (see *http://dkist.nso.edu/library/pubs*). Additional information can be found on the DKIST website, *http://dkist.nso.edu*.

In FY 2018, the DKIST project continued efforts toward completion and handover to operations, which is currently scheduled for January 2020. These efforts included the following elements and subsystems:

4.1.1 Telescope

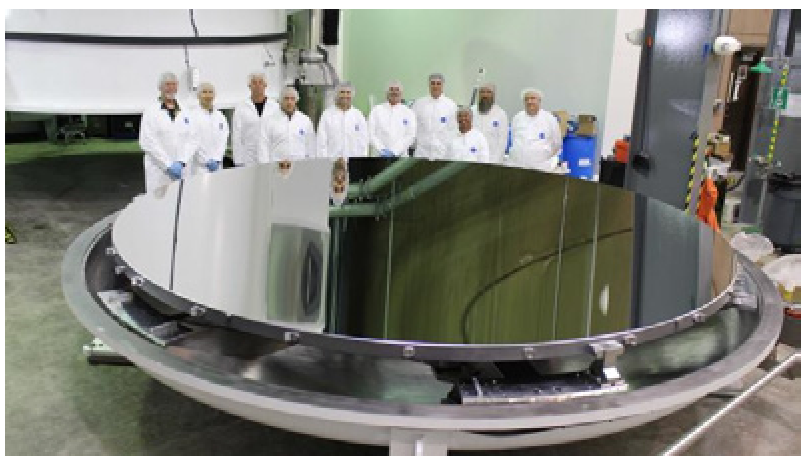


Figure 4.1-1. *The DKIST mirror coating team with the freshly-aluminized primary mirror. Photo by Erik Starman.*

The Telescope Mount Assembly (TMA) successfully passed its Site Acceptance Testing (SAT). An initial servo system tuning and balancing of the structure was accomplished in advance of the Integration, Test & Commissioning (IT&C) efforts. The Primary Mirror (M1) was successfully cleaned and coated at the Air Force facility on Haleakalā, Maui. The M1 was then integrated into the Primary Mirror Cell Assembly (M1CA) and readied for IT&C. The Top End Optical Assembly (TEOA), including the Secondary Mirror (M2), was delivered to Maui and also readied for IT&C. Further, all other mount optic assemblies (M3-M6) have arrived at the site.

4.1.2 Wavefront Correction

The Wavefront Correction (WFC) team completed their Critical Design Review (CDR). They also completed all procurements, fabrication, and assembly of the WFC system in the Boulder NSO lab.

Initial testing has commenced, with an expectation of completing this work in early 2019, followed by packaging and transport to Maui for IT&C.

4.1.3 Instrumentation

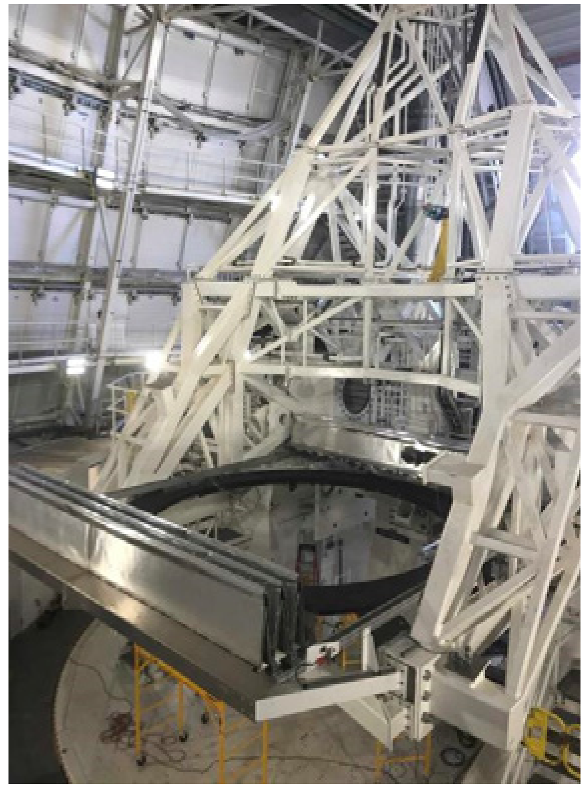


Figure 4.1-2. *The telescope mount with the coated primary mirror (M1) installed and ready for first night-sky pointing tests. Photo by Heather Marshall.*

The Visible Broadband Imager (VBI) procurement, fabrication, assembly, and lab testing was completed in the Boulder NSO labs in 2018; we expect this instrument to be delivered to Maui in January 2019 for IT&C. 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 and started the lab assembly effort; lab acceptance testing will be performed in early 2019, with delivery to the summit for IT&C scheduled in summer of 2019. Similarly, the Diffraction-Limited Near-IR Spectropolarimeter (DL-NIRSP) procurement and fabrication effort continued at the UH/IfA, with some initial lab assembly work completed. The Visible Spectropolarimeter (ViSP) project with the University Corporation for Atmospheric Research (UCAR) High Altitude Observatory (HAO) made good progress this year, with nearly all procurement and fabrication work completed, and some initial assembly and testing work completed; we expect the formal Lab Acceptance Testing (LAT) work to be completed by spring of 2019, with delivery to Maui occurring in early summer. The Visible Tunable Filter (VTF) project with the Kiepenheuer Institute for Solar Physics (KIS) in Freiburg, Germany continued in its procurement and fabrication phase.

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

4.1.4 High-Level Software

The Observatory Control System (OCS) passed its lab acceptance test and is now undergoing initial user acceptance testing. The Data Handling System (DHS) is progressing through its own LAT process. The computer network (IT) infrastructure hardware for the summit was purchased this year and is being configured prior to site installation. The Global Interlock System (GIS) local interlock controllers (LICs) for the telescope mount assembly, enclosure, and a subset of the facility has been verified for use on the summit.

4.1.5 Site Construction

Site construction this year was focused on completion of most of the exterior work, including the installation of the concrete roadway and parking lot. In addition, the concrete apron that surrounds the south and east side of the facility was completed. Underground water collection tanks were also installed, along with all drainage and valving systems. Exterior painting is underway as time and weather allows.

Inside the facility, a number of individual rooms were completed sufficiently for the site construction crews to use as offices. We've also completed the instrument prep lab, which has been fully outfitted and is now in use for 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. The Site Acceptance Testing (SAT) was successfully completed this year.

4.1.6 Facility Thermal Systems (FTS)

Much progress was made on the FTS system this year. Chief among the accomplishments was 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 early in 2019.

Another significant FTS accomplishment was substantial completion of the Coudé Environmental System (CES), including ceiling plenums, supply ducts, and lighting system. We also completed all of the interior wall treatments and interfaces to the plenums. The Air Knife system successfully passed its factory acceptance testing and was delivered to the site and installed in the telescope.

4.1.7 Integration, Test & Commissioning (IT&C)

As stated earlier, the M1 received its science coating of aluminum and was installed into the 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. 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 has allowed the IT&C team to progress onto installation of the next mirror assembly, M2, which in turn is part of the TEOA assembly. We expect to accomplish wave-front measurements of the M1-M2 system by early 2019. The IT&C team also completed the first CO_2 "snow" cleaning of the primary mirror.

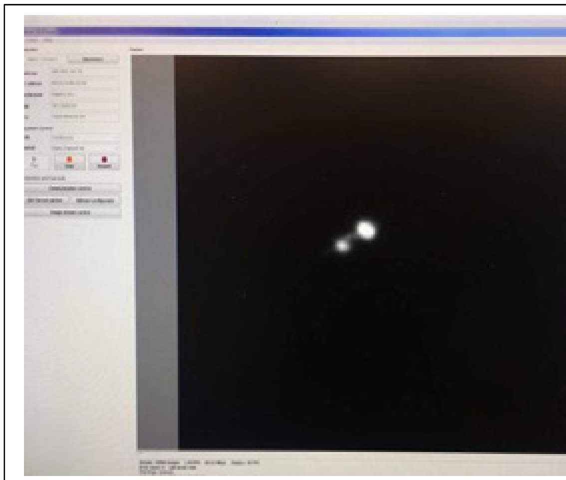


Figure 4.1-3. *One of the first starlight images taken at prime focus with the M1 installed. This image shows the binary star system Castor. Photo by Predrag Sekulic.*

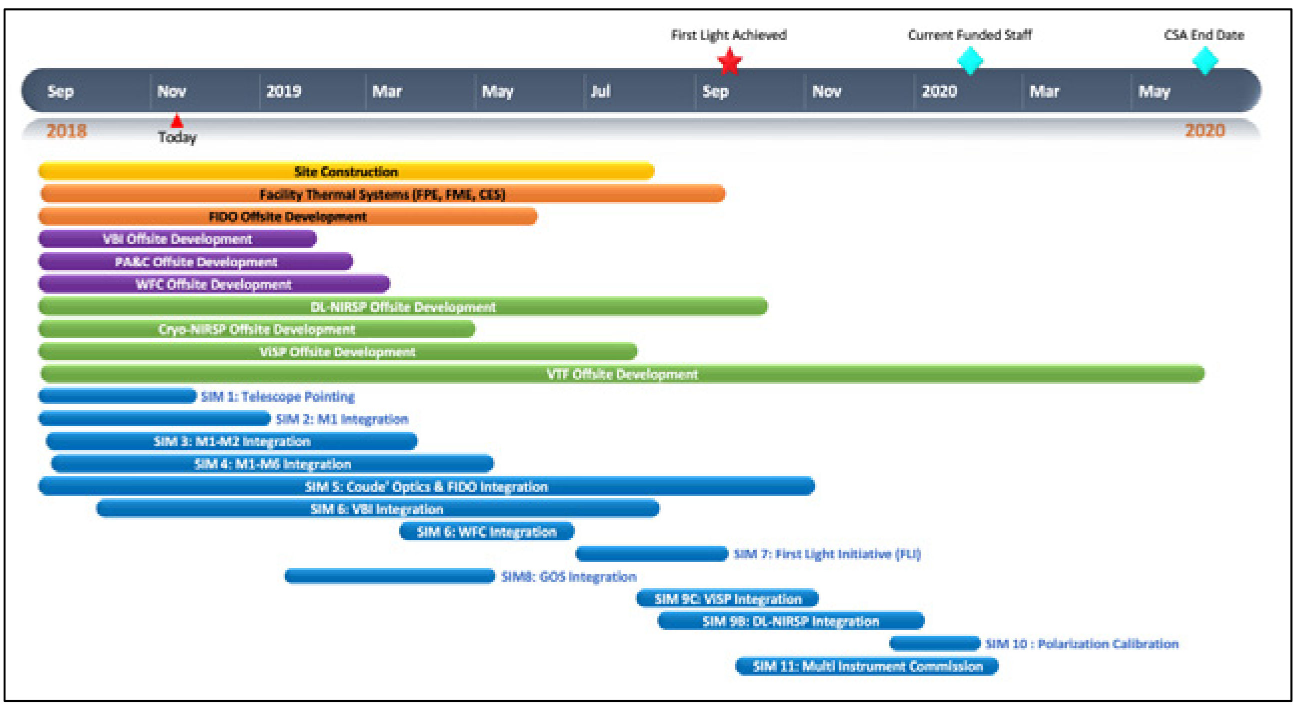
Additional IT&C accomplishments this year included installation of the Coudé rotator mechanical interface (CRIM) plates and the installation and alignment of the VBI and WFC optics tables.

4.1.8 Schedule Status

A subsystem view of intermediate milestone highlights is shown in Table 4.1-1. 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). Training of operations staff will occur during the extended Integration, Testing and Commissioning (IT&C) phase. A science verification period performed by the DKIST teams, supported by the instrument partners, will demonstrate the scientific validity of delivered data products. With the conclusion of instrument science verification, the facility will be handed over to operations.

Table 4.1-1. DKIST Upcoming Major Milestones (2019-2020)

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



4.1.9 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 $178.5M 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.

4.2 DKIST Operations Ramp-Up Phase: Overview

The main deliverables of the ramp-up phase include the DKIST Data Center (DC), which will handle processing, archiving, and distribution to the community of DKIST data products; development of second-generation instrumentation, including MCAO; instrument upgrades and enhancements to be implemented in early operations; software tools supporting operations; and infrastructure, such as the DKIST Science Support Center (DSSC). In addition, an effort to prepare the community for DKIST science by developing a Critical Science Plan (CSP) is organized and supported by NSO.

It should be noted that operations planning and ramp up to operations, including the implementation of a Remote Office Building and a Data Center, are the responsibility of the NSO but are outside the scope of the DKIST construction project. At first light, the 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 and, as funding and available resources allow, during operations.

In FY 2018, operations planning, development of operations processes, support tools and implementation of infrastructure necessary for DKIST operations has accelerated. Emphasis was given to refining cost models for summit operations, further developing the operations model, including detailed definition of daily summit activities and staff shift schedules. Definition and hiring of key operations positions continued in FY18. Training of science operations specialists continued using the Boulder DKIST end-to-end simulator. Furthermore, science operations specialists working closely with science staff serve an important software quality-assurance function. The ramp up of science and technical staff will continue until full operations staffing is reached at the beginning of operations, currently projected for October of 2019.

The Data Center successfully passed its Conceptual Design Review and continues with the preliminary design effort as well as prototyping and benchmarking of key technologies. The Data Center team prepared for its Final Design Review (FDR), which was scheduled for September 2018. However, due to the unexpected departure of the Data Center Project Manager, the FDR had to be postponed. The replacement Data Center PM joined the NSO on October 5, 2018 and is in the process of reviewing the documentation that was prepared for the review. The FDR is now planned for February 19-21, 2019. We note that development and integration work continues as planned while preparation for the delayed review is in progress. Current work is focused on implementation of the infrastructure and services needed to support Data Center functions, such as data transport, data ingestion, storage and search mechanisms. Data processing, i.e., the calibration effort, is a collaborative effort between the instrument partners, construction personnel and Data Center personnel.

Development of the Critical Science Plan (CSP) continued in FY18. The Chair of the Science Working Group (SWG) is leading the effort, supported by NSO staff. A series of CSP workshops was conducted at several US universities over the course of about one year. The goal is to ensure science readiness of the community. The SWG has begun to compile a list of several hundred scientific use cases and experiment descriptions into a comprehensive Critical Science Plan document. The operations team has begun to extract information relevant to operations planning from the CSP use cases. For example, most frequently requested optical configurations of the Coudé lab light distribution system and favored instrument combinations can be derived from the use-case information.

Construction of the ROB, which began in FY17, was completed on-budget in 2018. The building is now occupied by DKIST staff. The building has now been renamed the DKIST Science Support Center (DSSC).

One additional science operations specialist was relocated to Boulder, bringing the total to three. The Chief Science Operations Specialist was hired and is located at the DSSC on Maui. The Science Operations Specialist team is participating in the definition and review of user acceptance test plans and the execution of users' acceptance testing. In FY19, additional focus will be on involving the science operations specialists in the integration and commissioning phase of DKIST systems, in particular operations software, and at DKIST for training purposes. Recruitment of additional operations staff is in progress. The goal is to transition a significant fraction of the construction staff to DKIST operations. Retaining unique expertise of the complex DKIST systems is the key motivation behind the desire to transfer staff from construction to operations. A challenge is the timing of transition. Detailed input from key engineering staff into the technical summit operations planning is currently difficult to obtain as those staff are fully occupied with construction tasks.

In FY18, the staffing plan for the steady-state operations phase has been refined with the caveat that detailed bottom-up estimation of the summit technical operations effort, including maintenance, repairs and upgrades, is still incomplete in some areas. Estimates for non-payroll expenses such as electricity, have also been refined based on more realistic information that is now available.

Steady-state operations will be supported by 81 total staff, nearly equally split between Maui and Boulder Headquarters. The staffing includes 15 scientific FTEs, which at any given time include two postdoctoral fellows. The science staff will provide crucial expertise in DKIST instruments, wavefront correction system, and data handling and calibration. Science staff will also serve as Resident Astronomers (RA). The primary function of scientists in their role as RA is to lead and support the execution of science observations at the DKIST. In addition to the permanent science support staff, science staff and students from partner institutes and international collaborators are expected to spend significant time at the site to support routine observations. A six-FTE staff of telescope operators led by a Chief Observer will be responsible for daily operations of the telescope and instrument systems, using the Observatory Control System as their primary user interface. A 21-FTE engineering and technical staff will maintain the telescope systems and instruments and provide operational and safety support as needed. Data handling, computing, and IT system support will be provided by about four FTEs distributed between Boulder and Maui. Administrative staff support will also be provided in a distributed fashion by approximately four FTEs. Additional HR and purchasing support will come from AURA staff in Hilo. We plan to contract some of the facility support and all janitorial services.

NSO HQ in Boulder houses science staff, the Data Center and its staff, as well as the majority of new instrument development efforts, such as the MCAO development project. However, Boulder-based engineering staff will participate in Maui summit support and maintenance efforts while Maui-based technical staff will contribute to new development and upgrade efforts.

As the operations planning progresses, these staffing plans will be refined. During the next year, we will continue to deploy partial FTEs from construction staff to operations planning tasks, with construction tasks remaining as the priority.

In addition to the detailed planning for steady-state operation, we have begun to plan for a transition phase that will be required to bring the facility from the early operations phase (immediately after handover from construction) into the steady-state operations phase. Experience from similar complex facilities shows that during the first two years of operations, additional technical support staff (above steady-state staffing) will be required to address a mix of subsystem repairs, failures, maintenance and modifications. A first top-down analysis of transition-phase staffing requirements by subsystem has been performed. A total of 10-15 additional engineers and technicians will be required initially. Transition staff will ramp down steeply over a period of approximately two years, after which steady-state operations staffing levels will be achieved.

The budget implications of the revised steady state operations model and the transition phase needs will be discussed in more detail elsewhere. Here we note that according to our current estimates the annual cost of steady state operations has increased by 17%.

4.2.1 Data Center Development

4.2.1.1 Overview

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 and ancillary data, and will produce calibrated data sets while maintaining association to its measurement and engineering context. In addition, the DC will manage the full lifecycle of many petabytes of raw and processed data, enabling advancement through discovery and provenance tools and the publication of open-source implementations of published analysis algorithms.

4.2.1.2 FY 2018 Accomplishments

During FY 2018, following a successful Conceptual Design Review (CoDR), the Data Center definition and development continued. The CoDR panel noted that within an overly-constrained budget and compressed schedule, the presented low-risk design was achievable given continued system development and project planning. Given the compressed schedule, a decision was made to conduct a final design review in the second half of calendar year 2018. Hence, in FY18, significant time was spent by the project manager and his team preparing the relevant documentation, planning scope of the review and assembling a review committee. However, due to the DC project manager resigning his position during this time period, and the need for a new project manager to be ready to lead a review, the FDR was delayed until February 2019.

The design efforts performed in FY18 included risk-mitigation-focused prototyping in support of trade studies done to determine the extent to which design choices are technically feasible, cost-effective, and customizable for Data Center use. This prototyping effort yielded technology choices that the Data Center will move forward with, including:

- The Globus Toolkit for data transfer from the summit to Boulder, and for distribution to end-users.
- Elastic, Saltstack, Docker, and OpenNebula Open-source systems NoSQL DB, orchestration, portability, and provisioning.
- Airflow as the high-performance computing workflow system.

Development activities in FY18 included the elaboration and refinement of user- and science-driven needs into traceable system requirements, definition of engineering scope developed through intensive system analysis, interface specification with the DKIST construction project and NSO teams, iterative rapid prototyping of key technologies to mitigate major risks, and ongoing design activities. System requirements were further elaborated into strategy and process diagrams as final design steps prior to coding. Concurrently, software development efforts related to coding, testing, and integration of the services that make up the Data Center infrastructure began, and continued throughout the year, making considerable progress.

Fruitful collaboration with the DKIST construction project continued on the development of instrument and polarimetric calibration strategies and processing workflow techniques. Programmatically, budget, schedule, and risk analysis refined the estimates for system size and cost, required development labor, and the definition and elaboration of the Data Center operational lifecycle through development, integration with DKIST, and into DKIST operations.

FY 2018 Milestones Summary

- ♦ *Complete DKIST Data Simulator and Validator Toolkit.*

  Completed. A data simulator that creates data in accordance with SPEC-0122 Rev A–*DKIST Data Model*–was completed and tested and has been in use during the development of the DC data-ingest services. In addition, the validator toolkit was also completed and used to validate (or not) simulated data prior to ingest. Both toolkits are expected to undergo some revision as SPEC-0122 is expected to be revised.

- ♦ *Complete Data Center System and Subsystem Requirements*.

  Completed/Ongoing. Version A of the system requirements, which were derived directly from the science requirements, were written and mapped to the science requirements. Subsequently, the system requirements were further decomposed into strategy and process diagrams, which were then used to drive development. In the process, clarifying changes to system and science requirements were proposed and are currently under review through the change-control process.

- ♦ *Complete Data Center Preliminary Design Review*.

  Not Complete. Most of the design work in preparation for a review has been completed; however, due to unforeseen circumstances (project manager resignation), the work to complete documentation for what will be a Final Design Review (FDR)—mostly in the areas of budgeting, scheduling and acceptance and commissioning planning—were left in an incomplete state. It will take a few months for the new project manager to learn enough about the project to complete the preparation, and as the preparation will span the holiday-laden months of November and December, the review is to be held in Q2 (late January to mid February).

4.2.1.3 FY 2019 Plan

- Update Science/System Requirements.
- Update Simulator /Validator.
- Complete the Final Design Review.

During Q1–Q2 FY19, the Data Center staff will complete final design documentation traceable to science and system requirements, as well as finalize planning activities leading to a formal Final Design Review in Q2 FY19. In addition, development activities related to the update of SPEC-022 will be completed, resulting in updated data simulator and validator toolkits. Development activities that were started in FY18 will continue, with efforts focused on completing all of the Shared and Application services defined in the architecture (see Figure 4.2-1)). Together, the Shared and Application services comprise the Data Center software infrastructure, with the notable exception of calibration codes which will be phased in as instruments get delivered, and which, when ready, will utilize portions of this infrastructure to run.

By the end of Q3 FY19, the staff will have completed the Shared and Application Services and will have begun augmenting the current hardware suite horizontally in preparation for putting the Data Center software on an operational footing. This effort aims to exercise the software components at increasing scale to discover and resolve possible bottlenecks, issues, or defects prior to going online as a production Data Center.

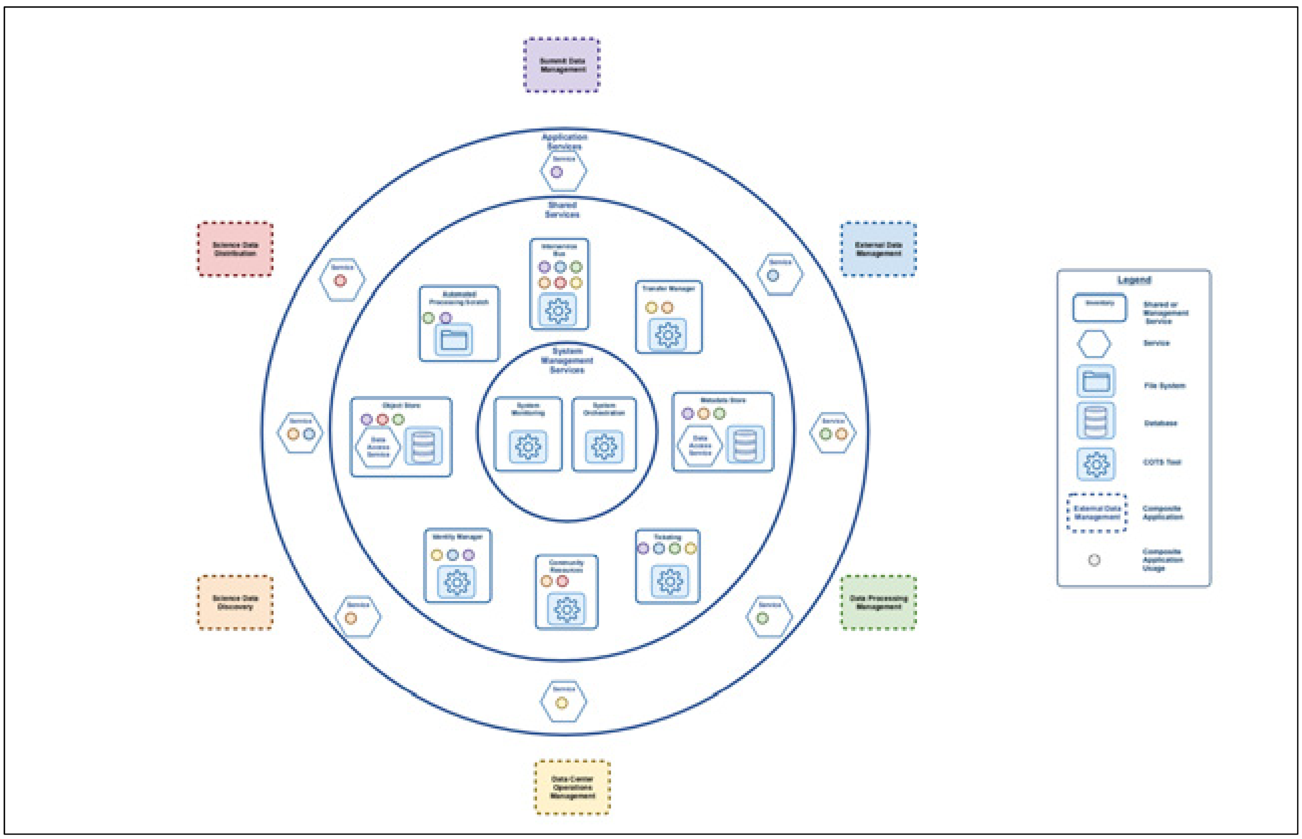


Figure 4.2-1. *High-level Data Center service architecture.*

During FY19, Data Center staff will continue to collaborate with the DKIST construction project on developing calibration strategies for DKIST instrumental data.

FY 2019 Milestones

- Q1- Alpha Release of Summit Data Reception and Ingest Pipeline.
- Q2 - Complete Data Center Final Design Review.
- Q2- Alpha Release of Science Data Processing Infrastructure.
- Q3 -Alpha Release of Data Discovery.
- Q3 - Alpha Release of Data Distribution.
- Q4 - Infrastructure Scaling Performance Analysis: 4th Quarter 2019.

4.2.2 DKIST Operational Tools Development

4.2.2.1 Overview

The Operational Tools will support the submission and management of scientific proposals to use the DKIST, enable their review and approval, create observational programs to be executed by the telescope systems, and aggregate operational information for use by internal DKIST staff. The Operational Tools will work in concert with the DKIST High-Level Software to execute observations and with the Data Center to ensure that data processing can occur, and that adequate metadata can be provided to end-users.

4.2.2.2 FY 2018 Accomplishments

During FY18, the science requirements were completed, and dedicated staff were hired and initiated development of the Operational Tools as specified in the requirements. In FY18, the team focused primarily on three applications: the Proposal Architect (PA), Experiment Architect (EA) and the Operations Planning & Monitoring Tool (OPMT). These are the highest priority as they deliver experiments to the Boulder End-to-End system and the summit.

The preliminary focus of the team's effort was to develop the Experiment Architect, which is a tool that allows DKIST internal scientists to translate proposals to experiments ready to use on the telescope. An alpha version of the Experiment Architect was completed prior to the end of the fiscal year and is currently in use by internal scientists.

In addition, Proposal Architect (PA), which is the front-end proposal tool, was prototyped and implemented. The PA is a public-facing tool that allows scientists to propose experiments for the DKIST. To date, developers have created an application that allows a user to create an empty proposal, add general information (e.g., title, abstract, investigators, etc.) as well as information specific to the proposal. Work on the PA is continuing.

Lastly, the team has worked on the OPMT, which is an internal tool that allows an internal coordinator to move experiments to the telescope, and to monitor for information generated from the experiment execution.

The system development effort involves close and frequent collaboration between engineering staff and the Operations Scientist, and involves frequent communication with other relevant stakeholders who will provide user feedback on functionality, interface design, and performance.

FY 2018 Milestones Summary

- *Q1 FY18: Complete the Science Requirements.*
  Completed.
- *Q4 FY18: Alpha Release, Experiment Architect.*
  Completed.

4.2.2.3 FY 2019 Plan

During FY19, the staff will continue to develop the Operational Tools defined in the science requirements. The primary focus of their effort will be to complete the Proposal Architect, which will allow users to submit experiment proposals for DKIST. The tool will also provide the facilities for submitters and reviewers to enter and complete the proposal review and acceptance process. In addition, the team expects to complete and deliver an alpha version of the Operations Planning and Monitoring Tool. These deliveries are in line with first call for proposals, which are expected in the Q3 timeframe.

4.2.2.4 FY 2019 Milestones

- Q3 – Alpha Release, Proposal Architect.
- Q4 – Alpha Release, Operations Planning and Management Tool.

4.3 DKIST Science Support Center

In FY18, construction of the Remote Office Building (ROB) on Maui was completed within budget. The building was renamed the DKIST Science Support Center (DSSC) and officially inaugurated on October 26, 2018. DKIST staff has moved into the DSSC, abandoning the previously leased commercial office space as well as the temporary office space in the UH Advanced Technology Research Center (ATRC) building. Moving forward, the DSSC will serve as the DKIST local operational and science center. The function of the DSSC will be similar to Gemini's base facility in Hilo, Hawaiʻi, by providing a facility from which the science, operations, and maintenance activities of the Maui-based DKIST staff can be performed. Unlike the other AURA base facilities, however, the DKIST construction budget provided no funding for the acquisition and construction of a DSSC.

Figure 4.3-1. *DKIST Science Support Center at Pukalani, Maui.*

The DKIST 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. In addition to work space, the DSSC will support 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 NSO Data Center in Boulder; and providing a small instrument laboratory for maintenance and future upgrades to DKIST instrumentation.

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. The DSSC currently provides individual and shared office spaces. Limited instrument/optics lab and workshop space is provided. In addition to staff and visitor vehicles, several facility vehicles for DKIST are staged in the DSSC parking lot.

4.4 DKIST Science Working Group

Community participation in and support of the DKIST effort occurs through the DKIST Science Working Group (SWG). The membership of the SWG is listed in Table 4.4-1. The SWG is currently chaired by Mark Rast of the University of Colorado, Boulder, and members include non-project scientists, project co-investigators, and instrument PIs (Table 4.4-1).

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) and through it use expectations that influence operations planning, data handling and processing requirements, data products and data dissemination. Broad community involvement in the CSP is being facilitated via websites which describe the science objectives and instrument capabilities and include links to abstracts of all Science Use Cases currently under development (*https://www.nso.edu/telescopes/dkist/csp/),* and which is a collaborative environment for Science Use Case development (*https://nso-atst.atlassian.net/)*. The latter is password protected. These Science Use Cases will be consolidated and converted to community- member PI-led observing proposals that will be executed as the CSP during the first one to two years of operations.

Current CSP topics and community leaders include but are not limited to:

<u>Magnetohydrodynamics and Dynamo Processes</u>

- Small-Scale Photospheric Magnetic Fields: Formation, Structure, Dynamics
- Turbulent Dynamo: Hanle-Effect Imaging of the Quiet-Sun
- Wave Generation and Propagation
- Magnetoconvective Modulation of Solar Luminosity
- Sunspots: Umbral and Penumbral Structure and Dynamics
- Flux Emergence and Active Region Formation

<u>Flares and Eruptive Activity</u>

- Flare Precursors in the Lower Atmosphere
- Magnetic Field Connectivity Changes in Flares
- Flare Electron Diagnostics in Visible Light
- Flare Footpoints at their Fundamental Scales
- Coronal Mass Ejections

Magnetic Connectivity, Mass and Energy Flows in the Solar Atmosphere

- The Chromosphere-Corona Connection
- Spicule Physics
- Formation, Evolution and Eruption of Non-Potential Configuration
- Multilayer Magnetometry and Atmospheric Heating
- Coronal Waves and Energy Fluxes
- Energy and Magnetic Helicity in Coronal Structures
- Prominence Morphology, Connectivity, and Lifecycles
- Infra-Red Survey of the Solar Atmosphere

Long-Term Studies of the Sun

- Evolution of Surface Magnetism
- Polar Fields in Time
- Small-Scale Field Contributions to Irradiance

Special Topics and Broader Implications

- Magnetic Reconnection in Weakly Ionized Plasmas
- Turbulence in a Radiative Boundary Layer
- Sun-Grazing Comets

Table 4.4-1 DKIST SCIENCE WORKING GROUP

Count	Last Name	First Name	Affiliation	Country	Status	Start of Term
1	Bello-Gonzales	Nazaret	KIS	Germany	Member	2014
2	Cao	Wenda	NJIT	US	Member	2013
3	Cauzzi	Gianna	AO	Italy	Member	2005
4	Cranmer	Steve	U. Colorado	US	Member	2014
5	da Costa	Fatima Rubio	Stanford	US	Member	2017
6	DeLuca	Ed	Harvard	US	Member	2017
7	dePontieu	Bart	Lockheed	US	Member	2015
8	Fletcher	Lyndsay	U. Glasgow	UK	Member	2002
9	Gibson	Sarah	HAO	US	Member	2017
10	Jeffries	Stuart	Georgia St	US	Member	2017
11	Judge	Phil	HAO	US	Member	2003
12	Katsukawa	Yukio	NAOJ	Japan	Member	2014
13	Landi	Enrico	Michigan	US	Member	2017
14	Petrie	Gordon	NSO	US	Member	2017
15	Qiu	Jiong	MSU	US	Member	2011
16	Rast	Mark	U. Colorado	US	Member	2013
17	Rempel	Mattias	HAO	US	Member	2015
18	Rubio	Luis Bellot	IAA	Spain	Member	2002
19	Scullion	Eamon	TCD	Ireland	Member	2014
20	Sun	Xudong	IfA	US	Member	2017
21	Welsch	Brian	Wisconsin	US	Member	2017
22	Goode	Phil	NJIT	US	Co-I	
23	Knoelker	Michael	HAO	US	Co-I	
24	Rosner	Robert	U. Chicago	US	Co-I	
25	Kuhn	Jeff	IFA	US	Co-I & Instrument PI	
26	Rimmele	Thomas	NSO	US	Ex-Officio	
27	Casini	Roberto	HAO	US	Instrument PI	
28	Lin	Haosheng	IFA	US	Instrument PI	
29	Schmidt	Wolfgang	KIS	Germany	Instrument PI	
30	Woeger	Friedrich	NSO	US	Instrument PI	

In FY18, the SWG focused on supporting the CSP development. An SWG meeting was held in March of 2018 at Georgia State University in Atlanta. A large number of Science Use Cases (several hundred) submitted by community members or developed during the ongoing series of CSP workshops was reviewed by the Science Working Group. Science Use Cases form the basis of the DKIST Critical Science Plan. Their completion and conversion to observing proposals will be essential for critical early observations and science. Section 4.6 (and *http://nso.edu/cspw.php)* has the list of CSP workshops, dates of the events, and other relevant workshop information. The goal of the Atlanta SWG meeting and during subsequent telecons was to determine completeness of the information submitted with the use cases; discuss "criticality" of the Science Use Cases; and provide feedback to the PIs or groups developing the use cases. Information and guidance provided by the SWG, as well as by supporting DKIST science staff, will help CSP use-case developers to complete their respective Science Use Cases, and make submission of an observing proposal straightforward. At this point, the SWG has completed a first analysis of existing Science Use Cases, checking for possible redundancies or inconsistencies in the science formulations or overlap between existing Science Use Cases, and making an assessment of each use-case completeness.

The DKIST Science Working Group is currently preparing a Critical Science Plan document. That document aims to reflect the science that the community sees as most critical and will rely heavily on the submitted Science Use Cases in making that assessment. The aim is to have a first draft of the DKIST Critical Science Plan document complete and available by the end of March 2019.

4.5 Instrumentation Development

In FY 2017, the DKIST Multi-conjugate Adaptive Optics (MCAO) project and the SWG recommendation to upgrade the Visible Tunable Filter (VTF) to a dual etalon system were pursued. Design and prototyping for a SWG recommended prominence or limb AO system has also progressed with prototyping efforts shifting to Big Bear Solar Observatory.

The collaboration agreement with the Kiepenheuer Institute for Solar Physics (KIS) for the development of a second etalon for the VTF has been approved and signed by all parties. The development of etalon plates is in progress, following the well-established development plan and procedures derived from the first etalon production. The second etalon production work will continue over a period of two years.

The work to develop a sky brightness monitor that can support daily operations of DKIST on Haleakalā progressed minimally in FY18 due to the departure of the lead scientist, Matt Penn. The search for a replacement of Matt Penn is in progress. The position has been advertised; review of applications and interviews are expected to continue into FY19.

Similarly, the conceptual design for a thermal infrared imager with the science mission to provide high-speed imaging of, for example, flares in a relatively unexplored wavelengths region has to be put on hold since the PI, Matt Penn, left the NSO. Furthermore, given the budget pressures resulting from the much more detailed and realistic cost estimates for operations derived during FY 2018, combined with the many challenges of early operations of DKIST, it is unlikely that the implementation of this second-generation instrument can be pursued within the current Cooperative Agreement.

A strong partnership continues with the New Jersey Institute of Technology (NJIT) and the Kiepenheuer Institute for Solar Physics for development of adaptive optics and multi-conjugate adaptive optics. Solar MCAO will provide diffraction-limited imaging over a large field of view, a capability that NSO is pursuing with high priority for implementation at DKIST as part of second-generation instrument development. In FY18, the 1.6-m New Solar Telescope (renamed the Goode Solar Telescope (GST)) at Big Bear Solar Observatory served as the main pathfinder telescope for the development, implementation and science demonstration of MCAO. NSO, NJIT and KIS AO teams are collaborating closely. Several observing runs were conducted at BBSO to gain experience and to optimize the prototype MCAO system. NSO scientist Dirk Schmidt leads the development effort.

The design effort for the DKIST MCAO upgrade has made significant progress in FY18. Guided by the BBSO experience and a sophisticated simulation tool developed at NSO, several options for integrating two additional deformable mirrors into the DKIST light path have been evaluated. The main challenge is the following. The current light feed, which includes the deformable mirror of the DKIST classical AO system, delivers a corrected beam to a complex arrangement of five instruments. The MCAO upgrade must maintain the characteristics of this light feed, such as pupil locations, beam diameters, and positions of focal planes in order to avoid a costly re-design and re-implementation effort for the entire Coudé instrument layout. The ideal solution is therefore to replace existing and suitable optical elements in the existing light path with deformable mirrors (DMs). The design study, which used the in-house-developed MCAO simulation tool, identified two suitable optics, M4 and M7, located at suitable conjugates to 4-km and 12-km heights in the atmosphere, respectively. Due to physical size and DKIST's field-of-view requirements, both deformable mirrors pose technical challenges and are not off-the-shelf items. As planned for FY18, a contract for design and manufacturing of the DM for the 4-km conjugate was signed with a vendor. The lead time for this device is two years. MCAO performance simulations

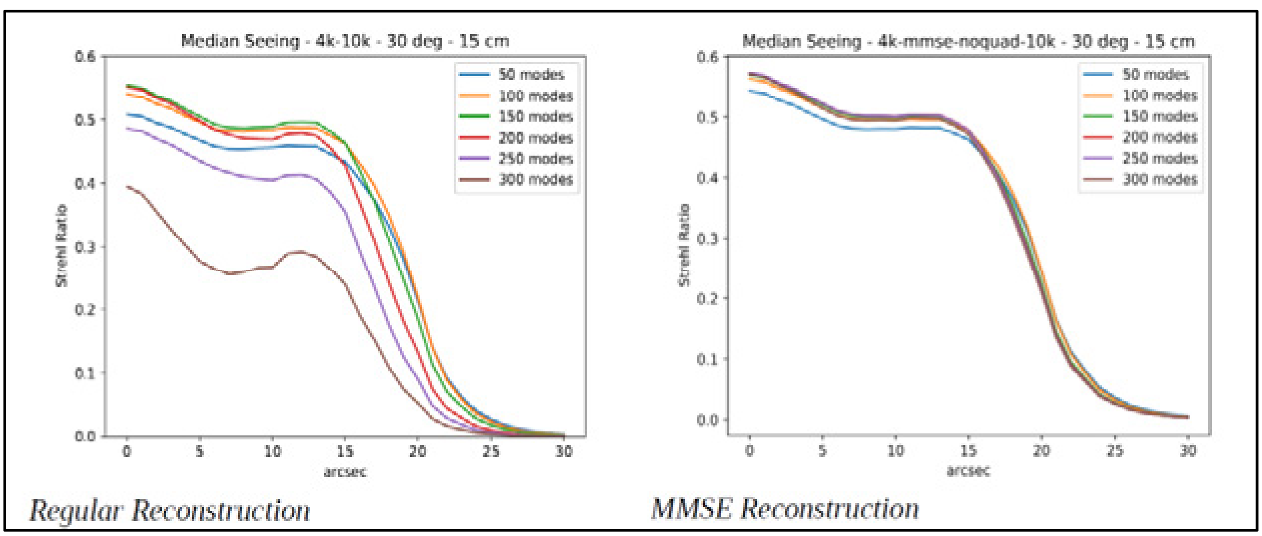


Figure 4.5-1. *Example of MCAO simulation results used to guide design decisions. The DKIST MCAO system was simulated with 1272 sub-apertures and DMs at 4 km and 10 km. The goal of this simulation was to determine the minimal/optimal number of modes of correctability needed for the DM conjugate to the upper atmosphere (10-12 km). Using an effective reconstruction method allows minimization of the number of modes and thus lowers technical risk and cost.*

with the goal of providing detailed requirements for a vendor design study for the M7 DM (12 km) is ongoing. Due to the large size of DM-12km and the fact that only the central area must be deformable, finding a technical solution for this device has been more challenging than anticipated. The contract for DM-12 km, which was anticipated to be led by the end of FY18, has therefore slipped into FY19, pending the results of the design study.

The concept development and initial optical design for the MCAO wavefront sensor upgrade to be implemented on the classical AO bench at DKIST has progressed in FY18. Wavefront sensor prototyping efforts are planned to commence as soon as the DKIST classical AO has been shipped from the Boulder labs to Maui and lab space is available.

The DKIST Science Working Group has requested that adaptive optics capability for off-limb structures, such as solar prominences, be provided. Erupting prominences (or filaments when observed on disk) are at the source of coronal mass ejections. Prominence AO will greatly enhance our ability to measure physical parameters in prominences, such as the magnetic field, with sufficient precision and sensitivity. In FY18, the development of prominence AO continued with the implementation of a prominence AO wavefront sensor into the classical AO system at BBSO. Two on-sky observing runs were conducted.

4.6 Critical Science Plan Development Workshops

As part of the preparation for DKIST operations, the NSO has initiated the so-called DKIST Critical Science Plan (CSP), with the aim of defining the critical science goals for the first years of DKIST operations. The Critical Science Plan is being built from a comprehensive set of PI-led Science Use Cases, which detail the scientific goals and the DKIST instrumental configuration required to achieve them. Envisioning the CSP as a bottom-up effort, NSO has involved the community from the beginning, holding informative sessions during professional gatherings, and providing software tools to simulate instrumental capabilities.

The community effort has gained most momentum in the last year, during a series of Critical Science Plan Development Workshops supported by NSO in collaboration with interested institutions. A total of nine workshops, each focusing on a specific research area, have been held throughout the US and abroad in the November 2017–December 2018 timeframe, with two of the thematic workshops being split in a two-event mini-series (for a total of 11 gatherings). While NSO provided financial and logistical support, the exact research theme and selection of participants for the workshops was left to the local scientific leads (Research Area Team Leaders); this ensured that the community self-organized in selecting both the most relevant topics and the most involved scientists.

A summary of the events is provided in Table 4.6-1. Seven US universities/research labs (plus NSO) have hosted a workshop, ensuring the exposure of US students and young scientists to DKIST topics and science. An additional three workshops were held abroad, in the United Kingdom, Germany (both partners in the DKIST construction effort), and Japan, all using matching funds from the foreign partners. Each workshop lasted typically 2.5 days, and had between 15 and 30 participants, for a total of over 200 scientists and almost 40 students. Three-to-four NSO/DKIST scientists were in attendance at each workshop to support the activities.

A common scheme was adopted for all the workshops. After a series of presentations delivered by the NSO/DKIST scientists to bring the participants up-to-date on the telescope and instruments status, the participants briefly described the science questions that they hoped to address with DKIST observations.

Figure 4.6-1. *Dr. F. Woeger of NSO describing DKIST capabilities during the "waves" CSP workshop in Newcastle, UK.*

This was followed by a room-wide discussion on how to best exploit the first-light instruments of DKIST to satisfy the required observational constraints. This discussion included an overview of the so-called Instrument Performance Calculators, software tools that allow first-order simulation of the instrumental capabilities. Finally, for the rest of the workshop, the participants split into three-to-four thematic groups, to develop their Science Use Cases with the help of one-to-two NSO/DKIST scientists. Periodic re-grouping helped address common questions and doubts.

Well over 200 Science Use Cases were discussed and created during the CSP workshops (the last event will be held in La Cruces, New Mexico, on December 5-7, 2018). The SUCs are collected in a collaborative software environment (JIRA, part of the Atlassian software suite) so that scientists can further discuss, modify and improve upon their cases when new information becomes available. The ensemble of existing SUCs is currently being analyzed by the DKIST Science Working Group in order to organize and formulate the Critical Science Plan itself. At the same time, DKIST scientists are parsing the SUCs to extract important information such as the most requested configurations and instruments, to help refining operational strategies.

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. In order to maintain and build upon this momentum, and in the context of the DKIST Level-2 data effort (see Section 6 NCSP), NSO is now planning several follow-up data workshops, using existing data of the kind that will be produced by DKIST to introduce scientists to the most common data reduction and analysis techniques. Finally, once DKIST is operational and data from (a subset of) the SUCs is obtained by DKIST, Research Area Team Leaders and students will be invited to visit the NSO Boulder Headquarters for in-residence activities.

The workshop held at Johns Hopkins University, Applied Physics Lab (JHU/APL) focused on joint scientific opportunities between DKIST, Parker Solar Probe (PSP), and the ESA/NASA Solar Orbiter mission. The team identified a number of synergistic SUCs using DKIST and one or both space missions. Most of them used specific multi-viewpoint opportunities during the encounters such as quadrature configurations. The discussions at JHU/APL demonstrated that additional efforts are needed to discuss the operational constraints imposed by encounter missions communicating via the Deep Space networks and a ground-based facility in Hawaiʻi. Similarly, the teams concluded that the coordination between the remote sensing observations of DKIST and the in-situ instruments on the spacecrafts needs further consolidation given the distinct nature of the measurements involved. To this end, NSO is considering organizing in FY 2019 additional Workshops with the teams from both missions.

Table 4.6-1. Summary of Critcal Science Plan Development Workshops

Workshop Theme	Dates/location	Hosting Institution (*Research Area Team Leaders*)	# of Participants (US/foreign/students)	# of SUCs Developed
Magnetic Reconnection and Reconfiguration	Nov. 2017, Huntsville (AL)	MSFC/UAH *(D. McKenzie)*	25 / 3 / 6	21
Magnetic Connectivity	Jan. 2018, Washington (DC)	GSFC / Catholic U.. *(D. Schmit, K. Muglach, P. Young)*	14 / 3 / 5	25
Photospheric Magnetic Fields	Jan. 2018, Freiburg (Germany)	KIS *(C. Fischer, N. Bello Gonzalez)*	6 / 19 / 3	25
Magnetic Reconnection and Reconfiguration (#2)	Feb. 2018, Nagoya (Japan)	Nagoya U. *(Y. Katsukawa)*	4 / 23 / 5	30
Joint Science with Solar Orbiter and Parker Solar Probe	Mar. 2018, Laurel (MD)	JHU/APL *(A. Vourlidas, V. Andretta, L. Harra)*	11 / 8 / --	18
Wave Generation and Propagation	Apr. 2018, Newcastle (UK)	Northumbria U..*(E. Scullion)*	17 / 6 / 8	38
Flares and Eruptive Phenomena	May 2018, Houston (TX)	Rice U. *(S. Bradshaw, L. Fletcher)*	14 / 3 / 5	15
Coronal Science Frontiers	Jun. 2018, Maui (HI)	U.Hawaiʻl IfA *(J. Kuhn, T. Schad, M.P. Miralles)*	22 / 5 / 5	20
Broader Implications	Jul. 2018, Bozeman (MT)	MSU *(M. Rast, D. Longcope)*	18 / 4 / --	19
Long-Term Studies	Oct. 2018, Boulder (CO)	NSO/ CU Boulder *(G. Petrie)*	26 / 2 / 1	13
Wave Generation and Propagation (#2)	Dec. 2018, Las Cruces (NM)	NMSU *(J. McAteer)*	8 / 16 / 8	--

5 NSO INTEGRATED SYNOPTIC PROGRAM

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 will 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 extremely 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 report on *Solar and Space Physics: A Science for a Technological Society* strongly supported synoptic solar physics 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 (SWPC) to provide substantial operational support for GONG. Space weather has become increasingly important to national security and planning. The development of improvements in forecasting space weather has been identified by the White House 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. NISP is an active participant in these activities.

Beyond maintaining normal operations, advancing scientific research, and providing support to the community, NISP's activities and goals in FY18 and FY19 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 major 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 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.

5.1 GONG

GONG is a six-site network of automated telescopes circling the world to provide continuous observations of the Sun. Originally established purely to study the internal structure and dynamics of the Sun via helioseismology (i.e., the measurement of resonating acoustic waves that penetrate throughout the solar interior), GONG has since been upgraded to also 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 farside of the Sun, and 20-second cadence 2K×2K Hα intensity images are produced in near-real-time. These data are used by the US Air Force (USAF) 557th Weather Wing and NOAA/SPWC for space weather forecasts, by the Air Force Research Laboratory (AFRL) to drive their

Air Force Data Assimilative Photospheric flux Transport (ADAPT) forecast of the solar magnetic field using data assimilation, by the NASA Community Coordinated Modeling Center (CCMC) to initiate many of its models and by the United Kingdom Meteorological Bureau for its forecasts. 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 are an increasingly popular data product, and have been used to study filaments, flares, and the oscillations of the chromosphere.

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 5.1-1), 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 5.1-1. *Alignment of the turret with the instrument mounting plates (left) and enclosure (middle). Completed GONG engineering site in Boulder (right).*

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, SPRING (see Section 5.6), 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 is underway.
- Improved polarization modulators. Replacement modulators were respec-tively 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 withdrawal of interest on the part of the selected vendor. A subsequent design re-evaluation for greater simplicity and robustness is being carried out.
- 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.

5.2 SOLIS

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 II 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 significant 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, 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.

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 (BBSO; see Figure 5.2-1). BBSO is an excellent site for the type of synoptic observations acquired by SOLIS; the daytime seeing is very good 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.

The last day of SOLIS observations in Tucson was October 22, 2017. During the remainder of the first quarter of FY18, 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 begins December 1. Instrument inspection and preparation will continue in existing BBSO facilities during this period.

Figure 5.2-1. *Delivery of SOLIS (left) to the grounds of the Big Bear Solar Observatory. An aerial view (right) of Big Bear Solar Observatory indicates the final location of SOLIS relative to the existing GONG site.*

5.3 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 5.3-1). Those observations are processed, for both science 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.

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, and time series for spectral parameters as well as global and polar mean magnetic fluxes. These data products are important for understanding the Sun, its activity cycle and related space weather, and even the impact of stellar activity on habitable planets.

Figure 5.3-1. *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).*

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 has been the development, now essentially completed, of the AutoVMBI software package as a replacement for the far more manually-intensive VMBICAL. The automation of this first stage of fully-calibrated GONG data processing was necessitated by the retirement of Greg Ladd, who had previously been dedicated to the operation of VMBICAL.

Significant effort was invested in FY18 towards improving the SOLIS/VSM 630.2 nm 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 simultaneously fit the filling factor, 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 630.2 nm vector observations is now underway. Supporting the protracted migration of GONG's near-real-time space weather data processing to NOAA/SWPC continues to be a major emphasis, as has continued development of the Virtual Solar Observatory (VSO) node hosted at NSO. Further, a comprehensive evaluation of the GONG zero-point correction pipeline has begun.

5.4 NISP Science

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 discussed 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 time-distance technique and GONG data confirm a shallow return flow. Both the Global and local helioseismology continues 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. 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. The observations also indicate that the rotation of the Sun at high latitudes may vary by 1% on the 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.

The influence of magnetic field on the incident acoustic waves is a complex 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 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. This work for several active regions is in progress.

Sunspot activity is often hemispherically asymmetric, and during the Maunder minimum, activity was almost completely limited to one hemisphere. In this work, we use surface flux simulation to study how magnetic activity limited only to the southern hemisphere affects the long-term evolution of the photospheric magnetic field in both hemispheres. The key question is whether sunspot activity in one hemisphere is enough to reverse the polarity of polar fields in both hemispheres. We simulated the evolution of the photospheric magnetic field from 1978 to 2016 using the observed magnetic field of active regions of the southern hemisphere as input. Synoptic maps from the NSO KPVT and SOLIS/VSM were employed in these simulations. We studied the flow of magnetic flux across the equator and its subsequent motion towards the northern pole. We also tested how the simulated magnetic field is changed when the activity of the southern hemisphere is reduced. We find that activity in the southern hemisphere is enough to reverse the polarity of polar fields in both hemispheres by the cross-equatorial transport of magnetic flux. About 1% of the flux emerging in the southern hemisphere is transported across the equator, but only 0.1%–0.2% reaches high latitudes to reverse and regenerate a weak polar field in the northern hemisphere. The polarity reversals in the northern hemisphere are delayed compared to the southern hemisphere, leading to a quadrupole Sun lasting for several years.

The patterns of variation for the Sun and 72 Sun-like stars have been compared by combining total and spectral solar irradiance measurements between 2003 and 2017 from the Solar Radiation and Climate Experiment (SORCE) satellite, Strömgren b, y stellar photometry between 1993 and 2017 from Fairborn Observatory, and solar and stellar chromospheric Ca II H+K emission observations between 1992 and 2016 from Lowell Observatory and NSO data (Sac Peak K-line monitor and SOLIS/Integrated Sunlight Spectrometer). The new data and their analysis strengthen the relationships found previously between chromospheric and brightness variability on the decadal timescale of the solar activity cycle. Both chromospheric H+K and photometric b, y variability among Sun-like stars are related to average chromospheric activity by power laws on this timescale. Young active stars become fainter as their H+K emission increases, and older, less active, more Sun-age stars tend to show a pattern of direct correlation between photometric and chromospheric emission variations. The directly correlated pattern between total solar irradiance and chromospheric Ca II emission variations shown by the Sun appears to extend also to variations in the Strömgren b, y portion of the solar spectrum. Although the Sun does not differ strongly from its stellar age and spectral class mates in the activity and variability characteristics that we have now studied for over three decades, it may be somewhat unusual in two respects: (1) its comparatively smooth, regular activity cycle, and (2) its rather low photometric brightness variation relative to its chromospheric activity level and variation, perhaps indicating that facular emission and sunspot darkening are especially well-balanced on the Sun.

Improving the scientific value of our data products has always been a priority for the SOLIS research and development group. During 2018, 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. This upgrade addresses some of the limitations contained in the old code. Both lines are now included in the inversion code and a 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 together longitudinal (line-of-sight) and full-Stokes photospheric measurements of the solar magnetic field. The basic idea behind this effort is to exploit the best properties of these two types of measurements, by specifically 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-sign magnetograms (for weaker field areas). These maps are now available to the community via the NSO/NISP Data Center at *ftp://nispdata.nso.edu/HMI_composite/*. The other data product is synoptic maps of the pseudo-radial chromospheric field. It is anticipated that these data products will be useful for models used in space weather forecast. The development of these new data products was funded by NASA under Grant #NNX15AN43. The impact of these new products on space weather forecast will be evaluated this year under a NASA/NSF grant to the CU-Boulder Space Weather Technology, Research and Education Center (SWx-TREC) .

Finally, some very preliminary tests are underway with an inversion code, developed at NSO by Dr. Christian Beck, able to process Ca II 854.2 nm chromospheric data from the full-Stokes modulator added to the SOLIS/VSM instrument in late 2015. This is a first attempt to further develop a more sophisticated code designed to provide reliable information of the vector magnetic field in the chromosphere.

In collaboration with international colleagues, NSO/NISP scientists worked on creation of a working group on promoting the use of vector field synoptic maps in 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; 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. US scientists' participation in the third meeting was partially supported by NASA.

The evolution of interplanetary coronal mass ejections (ICMEs) from their origin to their final orientation at Earth is currently not well understood. To examine how ICME orientation is affected by different solar structures, G. Petrie and his REU student, Eden Harris (U. Washington, Seattle) analyzed a sample of 303 magnetic clouds over solar cycles 23 and 24 with dates ranging from August 1996 to May 2018. Solar wind plasma and magnetic field data were obtained from the NASA OMNI database and solar magnetic field information from the NSO Kitt Peak Vacuum Telescope and SOLIS/VSM full-disk photospheric magnetograms, and coronal potential-field source-surface models. Each magnetic cloud was modeled using the Lundquist force-free field solution using the downhill simplex method to determine best-fit parameters: helicity, axial field strength, impact parameter, and orientation angles. They examined how the orientations of magnetic clouds varied over the two solar cycles in relation to the helmet streamer belt distribution, active region flux patterns, and high-latitude interactions between opposite-polarity poleward surges of flux, and concluded that at solar minimum, the global field has the greatest influence on the orientation of a magnetic cloud while during the more active phase of the solar cycle, the magnetic structure and local context of active regions complicate the orientations of magnetic clouds. A minority of magnetic cloud orientations seem to be due to high-latitude filaments. They also found that magnetic cloud field strengths and velocities tended to be lower in solar Cycle 24 than solar Cycle 23 in general, indicating that ICMEs occurring during solar Cycle 24 have generally been weaker than those occurring during solar Cycle 23, consistent with the milder space weather observed during Cycle 24.

Gradient- and curl-type or E- and B-type polarizations have been routinely analyzed to study the physics contributing to the cosmic microwave background polarization and galactic foregrounds. They characterize the parity-even and parity-odd properties of the underlying physical mechanisms, for example, hydromagnetic turbulence in the case of dust polarization. We studied spectral correlation functions characterizing the parity-even and parity-odd parts of linear polarization for homogeneous and inhomogeneous turbulence to show that only the inhomogeneous helical case can give rise to a parity-odd polarization signal. We also analyzed the linear polarization of the Sun as detected by SOLIS/VSM to characterize its helical turbulence without being subjected to the 180-degree ambiguity in the azimuthal angle that vector magnetic field derivation methods have to address.

5.5 Space Weather

NISP has become an important 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 and SOLIS 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 Government shutdown episode. 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 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 using approximately $800K per year to support operation 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. A proposal to NASA's 2014 opportunity for Heliophysics Infrastructure and Data Environment Enhancements (HIDEE) was successfully funded for three years, indicating that NASA also recognizes the importance of NISP data products. In support of one component of that proposal, SOLIS area-scans of active regions observed by NASA's Interface Region Imaging Spectrograph (IRIS) were acquired to provide complementary magnetic field information.

Using helioseismology, NISP produces estimates of the magnetic field on the farside of the Sun that is turned away from the Earth. These 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 STEREO mission ages and the STEREO spacecraft move into positions where it is impossible to acquire the data. NSO is participating, along with NWRA, the Jet Propulsion Lab (JPL), and Stanford, in a NOAA-funded project to improve the reliability and understanding of farside imaging so that the technique can be used operationally. Research at the US Air Force Research Laboratory has shown that the assimilation of farside 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. NISP magnetograms are the primary source of the data that drives the AFRL data assimilation system known as ADAPT, which will be used by NOAA/SWPC for geomagnetic storm prediction.

5.5.1 End-to-End GONG and SOLIS/VSM Calibrations

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. 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 magneto-hydrodynamic (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 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. We will then develop an equivalent model for a SOLIS/VSM photospheric magnetogram observation. 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 VSM. This knowledge will be used to provide, for the first time, absolute Gauss measurements of solar magnetic fields that are uniquely consistent from magnetograph to magnetograph. 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.

5.6 Towards a Multi-Purpose Global Network - Solar Physics Research Integrated Network Group (SPRING)

Synoptic data are vital both for the success of the DKIST and for society in general. Both the aging of GONG and the single-site nature of SOLIS have led the solar physics research community to call for a new, improved synoptic network. Such a network would open new realms of scientific research and provide input data that are vital for space weather operational forecasts. Since the NSF/AST Division Portfolio Review recommended a substantial reduction in NISP support, the funds for developing and operating a new network will need to have major support from the space weather community, including agencies such as USAF, NASA and NOAA.

SPRING has to provide as a 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 prime determinant of the effectiveness of the CME in creating geomagnetic storms. But we lack routine predictions 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 flux ropes that comprise the cores of CMEs. By regularly observing the He I 1083 nm spectral region, SPRING will fill this gap and provide synoptic observations of the vector magnetic field observed in solar filaments, the massive cores 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—the Bz problem. We note that models containing the physics of the propagation of flux ropes in the heliosphere already exist, but their boundary conditions are not based on observed properties of the pre-erupted flux ropes themselves. Currently, the CME field direction can only be determined by observations from DSCOVR, a NOAA satellite located at the L1 Lagrangian point that gives an indication of the field direction only 10-60 minutes before the CME arrival. SPRING will provide greatly improved data-driven boundary conditions for models of the CME magnetic field and eventually increase early warnings from 48 minutes to 48 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. For helioseismology, 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. For magnetic field measurements, it is essential to know the direction and strength of the field above the photosphere for accurate coronal field extrapolations, and to reliably remove the azimuthal ambiguity. 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 (CMEs), 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. 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. In addition, irradiance measurements such as those provided by the Precision Solar Photometric Telescope (PSPT), which are important for climate research, would be improved with additional spectral bands and more continuous coverage.

In addition to the research role of a network, space weather operational forecasts rest on the foundation of synoptic solar observations. Agencies such as the USAF 557th Weather Wing and NOAA/SWPC need reliable and continuous sources of solar data. They are already using NISP facilities as a source of surface magnetic fields, Hα intensity, and helioseismic farside maps. A new network that provides multi-wavelength observations would increase the quality of information available for space weather and is an efficient and cost-effective solution to a multi-agency requirement.

There is considerable international community interest in establishing a new network, as demonstrated by several workshops that have been held in Boulder and in Europe to discuss and gather input on science requirements, capabilities, and instrumentation. About 100 scientists and engineers have attended the meetings or expressed interest, representing space weather agencies, solar physics research institutes, observatories, government agencies, and international organizations.

The instrumentation in a new network should not be a single device providing all observations but should rather 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 different 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.

NSO, with HAO and the Kiepenheuer Institut für Sonnenphysik (KIS) in Germany, is developing the concept of SPRING, the Solar Physics Research Integrated Network Group, and used funding from the European Union SOLARNET program to develop the Scientific Requirements Document. An evaluation of instrumental concepts carried out by Sanjay Gosain (NSO), along with KIS and other partner institutions, will develop into a full proposal for a new network in the next two to four years. In September 2018, the Air Force Research Laboratory (AFRL) at Kirtland AFB in New Mexico, as part of a new agreement between the DOD and NSF, requested a document describing instrumentation and concepts for a new ground-based solar observing system for the US Air Force. A group of NSO and HAO scientists together developed the document, which was submitted to the AFRL and the NSF (both Astronomy and Geosciences) in November 2018. This development, along with changes in the NSF structure of the Major Research Equipment and Facility Construction (MREFC) and new Midscale Research Infrastructure (MRI) funding lines, has opened a window of opportunity for SPRING that could result in combined USAF and NSF support. The compatibility of the USAF and NSF requirements for the development and operation of a SPRING-type facility will ultimately dictate whether there is a need for one or two distinct networks.

An approximate timeline of the network effort is:

- 2019-2020 Work with AFRL, HAO, KIS and other partners to develop concept.
- 2020-2021 Submit instrument development proposal to the USAF and NSF.
- 2021-2022 Develop construction proposal.
- 2022 Submit proposal for network.
- 2022-2025 Construction.
- 2025 Start of operations.

5.7 Space Instrumentation

The Sun is a global and interconnected system, where events happening at one location can create changes at another place separated by more than half of the solar circumference. In addition, 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., SOHO, 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 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), Figure 5.7-1 shows the bread-board instrument, which has already obtained test magnetograms.

NSO is working with two groups interested in including CMAG on space missions. 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 would launch along with IMAP to L1, then continue to L5. MagEx would also include an EUV imager/irradiance spectrometer and a flux-gate magnetometer. The proposal for MagEx was submitted in November 2018. The SWRI mission is a 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.

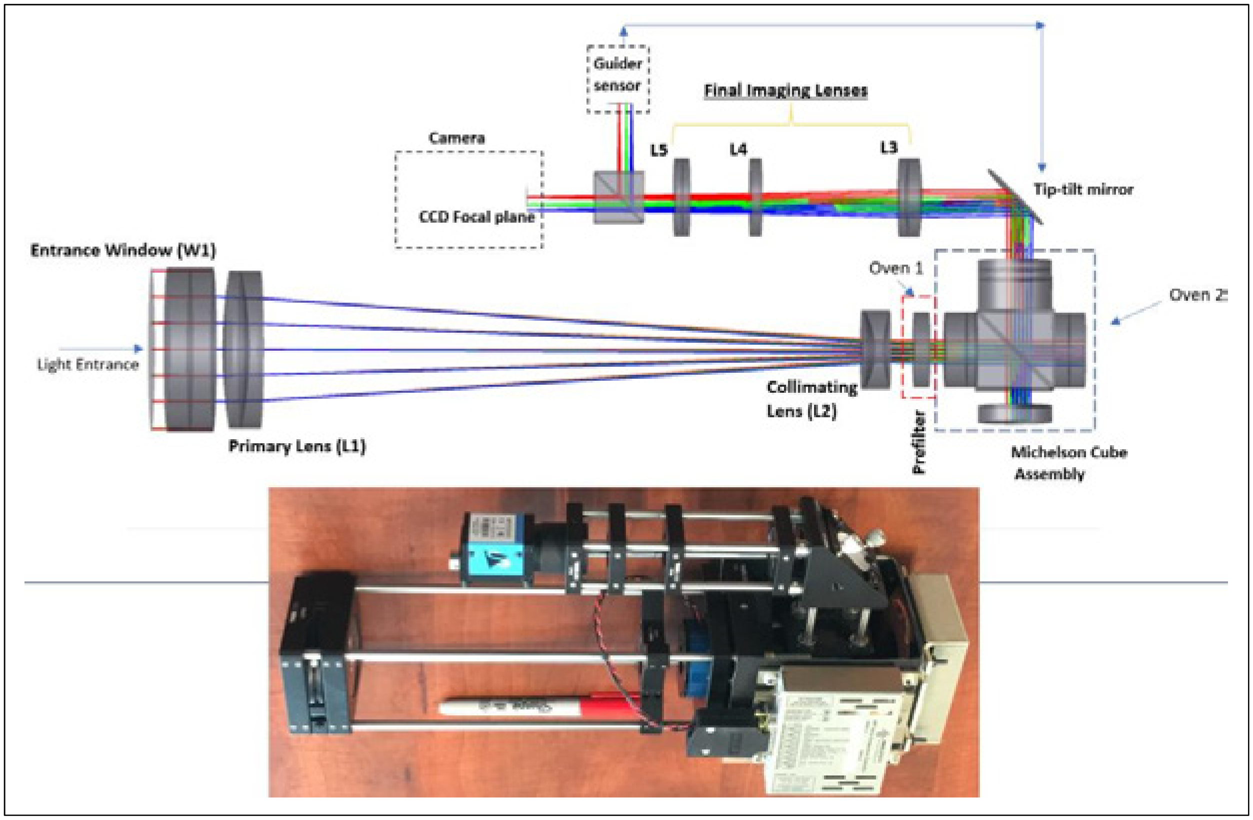


Figure 5.7-1. *The CMAG (Compact Magnetograph) instrument block diagram (Top) and bread board instrument (Bottom).*

5.8 Access to NSO Data

5.8.1 Digital Library

In addition to its dedicated telescopes, the NSO operates a Digital Library that provides synoptic data sets over the Internet 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 (VSO).

5.8.2 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 comprises a collaborative, distributed solar-data archive and analysis system with access through the WWW. 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 SDO 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 NSO COMMUNITY SCIENCE PROGRAM (NCSP)

6.1 Overview and Mandate of NCSP

Traditionally, the DKIST and NISP programs of the NSO focus on operating or constructing distinct facilities for solar observations. The programs have followed different threads within the organization, without much exchange of ideas, services, personnel, and equipment. This separation was reinforced in the past by program locations, with the high spatial resolution and the synoptic scientists located respectively in Sunspot and Tucson. The formation of a third program, the NSO Community Science Program (NCSP) was established in 2018 with the explicit intent of creating synergistic opportunities that, while providing a well-defined service to the community, utilizes the scientific expertise within the two existing program operations. The service provided by NCSP is defined via a strategic initiative (SI) proposed and discussed in conjunction with the community that uses NSO facilities. An SI is organized around a well-defined scientific objective that supports NSO's overall mission and has a clear deliverable and time span. The NCSP promotes scientific solar research within the observatory scientists and the user community, and emphasizes the mentoring of early career scientists. NCSP seeks funding opportunities for research topics with broad community interest and cooperates on science projects that can form a bridge between the synoptic and high-resolution programs.

Start of the NCSP was made possible by an NSF Supplemental Funding Request (SFR) of the NSO Cooperative Agreement through AURA, with a funding line of $3.5M per year for two years to work on (a) the creation of Level-2 data products derived from DKIST Level-1 data; (b) the establishment of Level-2 data production hardware and production pipelines for a set of well-defined standard observations; (c) the organization of solar community workshops to aid the community in under-standing the Level-2 production process; and (d) supporting DKIST related research topics using Level-2 data by providing matching-fund, early-career research funding at US universities.

What follows is a more detailed outline of the Level-2 activities that will be conducted by the NCSP. The NCSP effort in 2019 will be overseen by Han Uitenbroek as its Associate Director (AD).

6.2 Motivation for Production of Level-2 Data

When the NSF's Daniel K. Inouye Solar Telescope starts operations in the spring of 2020, a revolutionizing era will begin in solar physics. Four of the five first-light instruments are complex spectroscopic and polarimetric devices capable of capturing the magnetic and thermal environments of the outer solar atmosphere at unprecedented spatial resolution. These instruments target the solar photosphere, chromosphere and the solar corona in a multiplicity of wavelengths. The data volume, its variety, unique scientific value, velocity of acquisition, and reliability or veracity—that changes depending on the observing conditions—create a "Big Data" challenge of a magnitude unknown to solar astronomy. To cope with this challenge, NSO is designing the DKIST Data Center that will centralize all data management and distribution. The DKIST Data Center, however, is being funded out of the research operational funds and is not a component of the MREFC construction project. The current concept of the Data Center delivers only Level-1 data products (i.e., instrumentally calibrated images and spectro-polarimetric data cubes) to the solar physics community for further analysis. Additional analysis is needed to generate physical parameters on the Sun. This additional analysis involves so-called inversions of the spectro-polarimetric data using computational models that infer, among other quantities, the thermal and magnetic structure of the solar Atmosphere. The NCSP Level-2 effort aims at accelerating the creation of enhanced DKIST Level-2 data products in accordance with the NSF Big Idea: *Harnessing the Data Revolution*.

6.3 A Multipronged Approach to the Production and Utilization of Level-2 DKIST Data

The NCSP Level-2 data effort encompasses a three-tiered approach, with each tier including close collaborations with the US Community, from universities to research centers. They include:

- 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. We will strive to make these tools efficient in dealing with large volumes of data and intuitive enough for a large fraction of the community, but 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 and/or postdoc support program for US universities with existing solar research faculty. This program will combine both the interest of local faculty members and existing DKIST Science Use Cases contained in the Critical Science Plan. This proposal will grow the workforce able to run the inversions in scientifically competitive ways. This initiative will also provide—to the extent possible—hardware capabilities for the inversions required by graduate students' research. The Level-2 data products created through this initiative will be of a highly diversified nature, adapted to the needs of the specific research. NSO does not plan to distribute these data sets. Here the deliverable is a trained workforce familiar with the use of state-of-the-art tools for DKIST data analysis. Training occurs at a series of workshops and summer courses included in the proposal.
- Community Oriented Initiative: Establish a series of visiting programs and data training workshops that help guide the DKIST solar community in the effective use of the spectral inversion tools. This initiative should include understanding 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 Data Products Initiative.

6.4 The Level-2 Work Breakdown Structure (WBS)

This section describes in detail the Work Breakdown Structure of the proposed activity. Work Packages WBS01 and WBS02 are the core components of the Data Products Initiative. WBS03 and WBS04 represent the key activities of the Community Oriented Initiative. WBS05 and WBS06 correspond to the University Focused Initiative. The complete set of activities aim at creating a University-based community pool familiar with operating state-of-art numerical schemes that extract the maximum information from DKIST observations. Similarly, these experts from the community pool will help the adoption of these techniques by new researchers, owing to the training received and the repository of tools that this effort will generate. The WBS is summarized in Table 6.4-1, including deliverables and milestones.

Table 6.4-1. Summary of Work Breakdown Structure, Deliverables and Milestones		
WBS #	**Deliverables**	**Milestones**
WBS01 Science Support		
WBS01.1 **Project Management and Scientific Leadership**	Perform all management, oversight, and scientific leadership tasks.	As needed.
WBS01.2 **Workshops and Networking Activities Management**	Plan eight data training workshops. Plan two schools on spectro-polarimetric inversions.	One workshop each quarter from July 1, 2018 through June 30, 2020. One workshop each year from July 1, 2018 through June 30, 2020.
WBS01.3 **Level-2 Pipeline Development**	Functional (Non-LTE) inversion code with parallelization to convert Level 1 into Level 2 data.	July 1, 2019, in time for first-light testing.
WBS01.4 **First-Light Level-2 Data Generation**	Generate Level 2 data for select observables and handover to DKIST Data Center (DC).	July 1, 2019 – July 1, 2020
WBS01.5 **First-Light Level-2 Hardware**	Purchase and install cluster (or equivalent) in support of generation Level 2 data.	July 1, 2019
WBS02 Data Center Support		
WBS02.1 **Producing Robust Pipelines from Science Code**	Production of reliable Level 1 to Level 2 pipeline software, including ingestion, parallelization and transfer to DKIST DC..	April 1, 2020
WBS02.2 **Integrating Level-2 data in the DKIST Distribution System**	Supply scripts for transfer of Level 2 data to DC and verify reliability; supply proper meta data supplements.	July 1, 2019 –June 30, 2020
WBS02.3 **Data Center Hardware for Level-2 Distributions**	Purchase hardware and assist in installation at DKIST DC for ingestion and distribution of Level-2 data	July 1, 2019
WBS03 **Visitors Program Short-Term**		
WBS03.1 **Training Involving Domestic Partners**	Organize short-term (one to several weeks) visits of domestic partners to NSO or partner facilities.	As needed, starting July 1, 2018.
WBS03.2 **Training Involving International Partners**	Organize short-term (one to several weeks) visits of foreign experts to NSO or partner institutions.	As needed, starting July 1, 2018.
WBS04 **Visitors Program Long-Term**		
WBS04.1 **Visiting Scientist Position**	Organize visits of world-wide experts, with terms varying from several months to one year.	Starting Juyl 1, 2018, when applicable.
WBS05 Graduate Students Program		
WBS05.1 **Graduate Student Support at US Universities**	Fill and support seven graduate student positions at US universities with matching funds, for two years each..	As needed, starting July 1, 2018.
WBS05.2 **Graduate Student Support at CU Boulder**	Fill and support two graduate student positions at CU Boulder, for two years each.	As needed, starting July 1, 2018.
WBS06 Data Training Activities		
WBS06.1 **Data Training Workshops**	Organize eight workshops for data training at different US universities.	Each quarter for two years, from July 1, 2018 through June 30, 2020.
WBS06.2 **Spectro-polarimetric Inversion School**	Organize two courses on spectro-polarimetric inversion.	One course each year, from Juyl 1, 2018 through June 30, 2020.
WBS07 Logistics Support		
WBS07.1 **Administrative Support**	Administrative support for travel, workshop logistics.	When needed.
WBS07.2 **Curriculum Preparation**	Web design and content support.	When needed.
WBS07.3 **Headquarters Expenditures**	Office space, Boulder HQ.	When needed.

6.4.1 Detailed Description of the Level-2 WBS

6.4.1.1 Data Initiative: Science Support

We describe the research-oriented efforts needed to prepare the pipelines that will generate Level-2 data soon after the beginning of DKIST operations (WBS01). The following work packages occur most likely at NSO, but we are discussing with HAO their possible participation, with the intention of ensuring that Level-2 tools are available at the time of early operations of DKIST. We aim at testing these tools at the end of the instruments' commissioning and science verification phases (second half of 2019).

Overall management and scientific leadership of the project will be undertaken by the NCSP Associate Director, who will oversee and direct the hiring of new personnel, serve as the point of contact for remote personnel, oversee the development, testing and delivery of Level 2 pipeline software and its delivery to the Data Center, and lead the mentoring of students at the Boulder location. The NCSP AD will coordinate the planning and organization of data training workshops with workshop lead, Gianna Cauzzi.

Typical observations with DKIST instruments cover a field-of-view of tens of arcsec with spatial sampling of several hundredths of arcsec, yielding data cubes with spectra for each of a million pixels. All these spectra (together with their degrees of polarization) need to be inverted to recover the underlying physical quantities over the field of view. Since all pixels can be inverted independently, it is straightforward to parallelize this process and run it efficiently on massively parallel computers. This parallelization will be implemented with the NSF-supported standard for parallelization message passing interface (MPI) toolkit for our production inversion codes.

This work package also includes scientific planning required to organize a total of eight data-training workshops, over a two-year period, and other networking activities with the highly distributed pool of graduate students and research (including international) partners. Scientific planning and guidance are required to define the existing data sets comparable to the future DKIST data sets. The service-mode data from the Dunn Solar Telescope (Sunspot) represent an excellent repository that can mimic the data that VBI (ROSA instrument at the DST), VTF (IBIS), DL-NIRSP (FIRST), and ViSP (SPINOR) will produce. Future data from the Cyra instrument at the Goode Solar Telescope (BBSO) can help with training on Cryo-NIRSP data management. The data-training workshops will utilize the tools delivered by other work packages and will consider distributing them via a central web-based system for the Level-2 effort.

Level-2 pipeline development is core to the entire effort. The DKIST Level-2 science team will define the data products available at first light, and the deliverable of this work package are the scripts needed to interface DKIST data with the selected inversions codes. An analysis of the existing Science Use Cases in the JIRA Critial Science Plan database indicates that a large fraction of them will benefit if the DKIST Data Center delivers the following Level 2 data products:

1. NLTE inversions, either with the Stockholm Inversion Code (STIC) or DeSIRe, of the Fe I 6301/6302 Å line pair and the Ca II 8498 and 8542 Å triplet lines, observed simultaneously in three separate channels of the ViSP.
2. He 10830 Å full Stokes polarimetry observed with any of the configurations of DL-NIRSP inverted with the publicly available inversion code Hazel.

3. Vector magnetograms and Dopplergrams from the VTF Ca II 8542 Å images based on inversions using the simple weak-field approximation.
4. Basic coronal parameters from single-line full Stokes spectropolarimetry. Spectral-line candidates for this type of analysis are Fe XIII 1074.7 nm, Si X 1430 nm, and Si IX 3925 nm. Except for the Si IX line—observed only by Cryo-NIRSP—all of these lines are accessible by the Cryo- and DL-NIRSP instruments. The proposed analysis consists of:
    a. Gaussian fit to the Stokes I profiles providing peak intensities, doppler broadenings, and LOS velocities.
    b. The azimuth of the magnetic field vector projected on the plane of the sky using $\chi = \frac{1}{2}\tan^{-1}\frac{U}{Q}$.
    c. The B_LOS from the weak-field approximation and/or techniques that can account for the importance of atomic alignment.

This work package includes coordination between the science team producing the pipelines and the Data Center team. NCSP will propose and discuss mechanisms to provide the necessary coordination (regular team meetings, interfacing with the DKIST instrument partners, etc.).

NCSP will work with the CU-Boulder High-Performance Computing facilities to obtain access to one of their large extendable compute clusters to provide the necessary hardware to perform the routine inversions referenced above.

6.4.1.2 Data Initiative: Data Center Support

As part of Cooperative Support Agreement 1400450, NSO is building the DKIST Data Center that's currently scoped to produce only Level-1 data. Level-2 data are outside the scope. The Level-2 effort will detail the steps necessary to integrate into the DC the data and metadata produced by the Level-2 pipeline and its distribution to the broader community.

Science programmers funded by the NCSP will ensure that the set of tools, including the inversion codes, that produce the Level-2 data are adequately documented and have well-defined interfaces for the effective data ingestion into the distribution lines of the DC (Science QA/QC including the metadata). The science programmers also conduct proper testing of the software developed in Section 6.4.1.1 and suggest modifications for its robust operation.

For the robust distribution of Level-2 data products to the community, two primary functions are necessary. First, there is the need to replicate an infrastructure similar to the one used to distribute the Level-1 data and metadata, but now to distribute the Level-2 data products. An NCSP-funded software engineer will be responsible for this replication and the external data ingestion. This person will also create the tools necessary for the proper archiving and search of Level-2 data products.

NCSP will also allocate funds to provide the hardware necessary for the Level-2 data distribution, following the architecture of the DKIST DC, without impacting the Level-1 infrastructure. The hardware will include storage components, servers for distribution, quality control checks, and networking software.

6.4.1.3 Community Initiative: Visitors Program

DKIST Level-2 data products require the use of so-called inversion codes that translate the observed profiles into physical conditions on the Sun. Over the past years, most of the expertise in new code development has occurred overseas. It is thus imperative that, to bring up to speed the US solar physics community in the proper use of these codes, we establish a bi-directional visiting program. This program allows for international experts visiting the US institutions to participate in this effort and for researchers from the US—including graduate students—to stay at our foreign partner institutions as part of their training.

Depending on specific needs, we envision, as part of the Visitors Program, summer contracts at the US participating institutions, or a longer-term hire for one year. The latter may be convenient in the context of developing the research that is still needed to fully develop a coronal inversion code for which only rudimentary examples exists. An example is the efforts pioneered by Judge & Casini (2001) modeling forbidden coronal line emission that can efficiently couple with existing inversion cores. Such combination can enable proper inversions of coronal magnetometry, an area where DKIST will produce revolutionary observations with unprecedented quality.

6.4.1.4 University Initiative: Graduate Students and Postdoctoral Support Program

Through this activity, we will provide financial support for graduate students and/or postdoctoral researchers at US universities during a two-year interval, covering tuition, travel, and overhead. NSO has posted an open call to solar research programs at US universities to select existing or future graduate students and/or postdoctoral researchers with an interest in focusing on DKIST science or adapting their research goals to incorporate DKIST science. This may be manifested in either two years of new funding for upcoming students, or replacement funding for established students, depending on the circumstances. Student research topics should have well-defined links to the DKIST CSP effort and focus on the implementation of creation of Level-2 data products related to specific Science Use Cases. Proposals will be required to identify the specific Science Use Cases in the JIRA database that map to proposed research topics.

After the pool of students has been selected, NSO will search for existing DST and other facilities' data relevant to the selected research topics that can serve as training in preparation for DKIST observations. NSO, including the NSO EPO team as needed, will provide additional mentoring to the students. Our aim is to be as scientifically broad as possible, covering basically all major scientific areas of interest for DKIST. Graduate students and postdocs will produce a multiplicity of Level-2 data as demanded by their own research and that use more instruments, observing modes, and inversion codes than the efforts at NSO. These more diverse data produced by graduate students, however, will not be distributed by the DKIST DC to the broader community.

The pool of graduate students and postdocs will use the Visitors Program for their interactions with experts from around the world and for in-residence periods at NSO, while benefiting from ongoing networking and community-building efforts as developed by the Level-2 project.

We expect this program to provide support to about ten graduate students and/or postdoctoral researchers. In all cases, we will endeavor to select a diverse pool of participants who reflect the available pool of applicants, in particular focusing as much as possible on gender and ethnic equity. Applications will be reviewed by a panel following successful past recruitment practices and a rubric developed by

NCSP leadership and NSO's Head of EPO. The rubric will be well balanced, with review components beyond academic performance, including soft skills (determination, grit) shown to be successful markers of researchers, as well as plans for broadening participation. Additionally, the panel will receive implicit bias training from the NSO Diversity Advocate prior to the review.

In the second year of the Level-2 effort, we will provide the opportunity for participating graduate students and postdocs to visit DKIST in order to familiarize them with the instruments, observational set up and observing conditions. Past experience demonstrates that having a first-hand experience with the instruments and how they operate facilitates the extraction of information using complex algorithms such as inversion codes. This will also provide an opportunity to reinforce collaborations and networking opportunities between students, and content experts.

6.4.1.5 University Initiative: Data Training Activities

During FY 2017 and FY 2018, a series of workshops were devoted to the development of the DKIST Critical Science Plan, i.e., to identify the critical science goals to be addressed during the first two years of DKIST operation. During the workshops, after updates on the telescope and instruments status, participants discussed how particular science topics could be best tackled with DKIST first-light instrumentation. The initiative was well received by the community, with more than 200 scientists and students attending, many of whom were involved with ground-based solar observations for the first time. To build upon this momentum, and to satisfy requests from the community itself, NSO is now planning to conduct several follow-up data workshops over the next two fiscal years. The new workshops will make use of existing data—mostly acquired at the Dunn Solar Telescope and of the same kind that will be produced by DKIST—to introduce scientists to the most common data reduction and analysis techniques. Further, unique peculiarities of ground-based observations will be addressed in some detail; this is particularly relevant for the US solar community, which is mostly accustomed to high-energy, space-based data.

Three to four separate workshops will be run in 2019. The first will be held in Boulder in spring 2019, and aims at providing a first introduction to ground-based data types, issues, reduction and analysis techniques, for a total duration of 3.5–4 days. NCSP scientists, and potentially other NSO personnel, will give most of the lectures. Topics will include:

- Instruments and data types (e.g., slit spectra vs. imaging).
- Level-1 data production; data packaging and retrieval.
- Atmospheric turbulence (seeing) and differential refraction.
- Slit-spectra calibration (fringes, slit curvature, wavelength scale, imaging from raster).
- Image treatment (alignment, de-stretching, reconstruction).
- Polarization issues and calibration (single vs. dual-beam, detection and removal of cross-talk).
- Production of basic Level-2 data (spectral line moments maps, weak field approximation).

This first workshop will be tailored to a relatively large and varied audience (50-60 participants), but US students and young scientists will be especially encouraged to participate. In particular, invitations will be extended to the students funded by the university initiative. Some hands-on activities will be offered, but we envision this workshop as mainly laying the foundations for more focused, successive gatherings. In particular, in 2019, we plan to hold another three smaller workshops devoted to:

1. Image reconstruction techniques (speckle, blind deconvolution, etc.).
2. Spectral inversions.
3. Coronal data analysis.

Actual introduction to software and hands-on exercises will be provided during these meetings. Additional training on inversion codes will be provided. These codes are far too complicated to explain and provide proper training during a two-day workshop. Thus, we plan to replicate the course on inversion techniques that HAO and NSO have organized in September 2018 at Estes Park (*https://www2.hao.ucar.edu/spectropolarimetry*). The second summer can occur at the end of FY 2019 or a year later, depending on the needs of the pool of students.

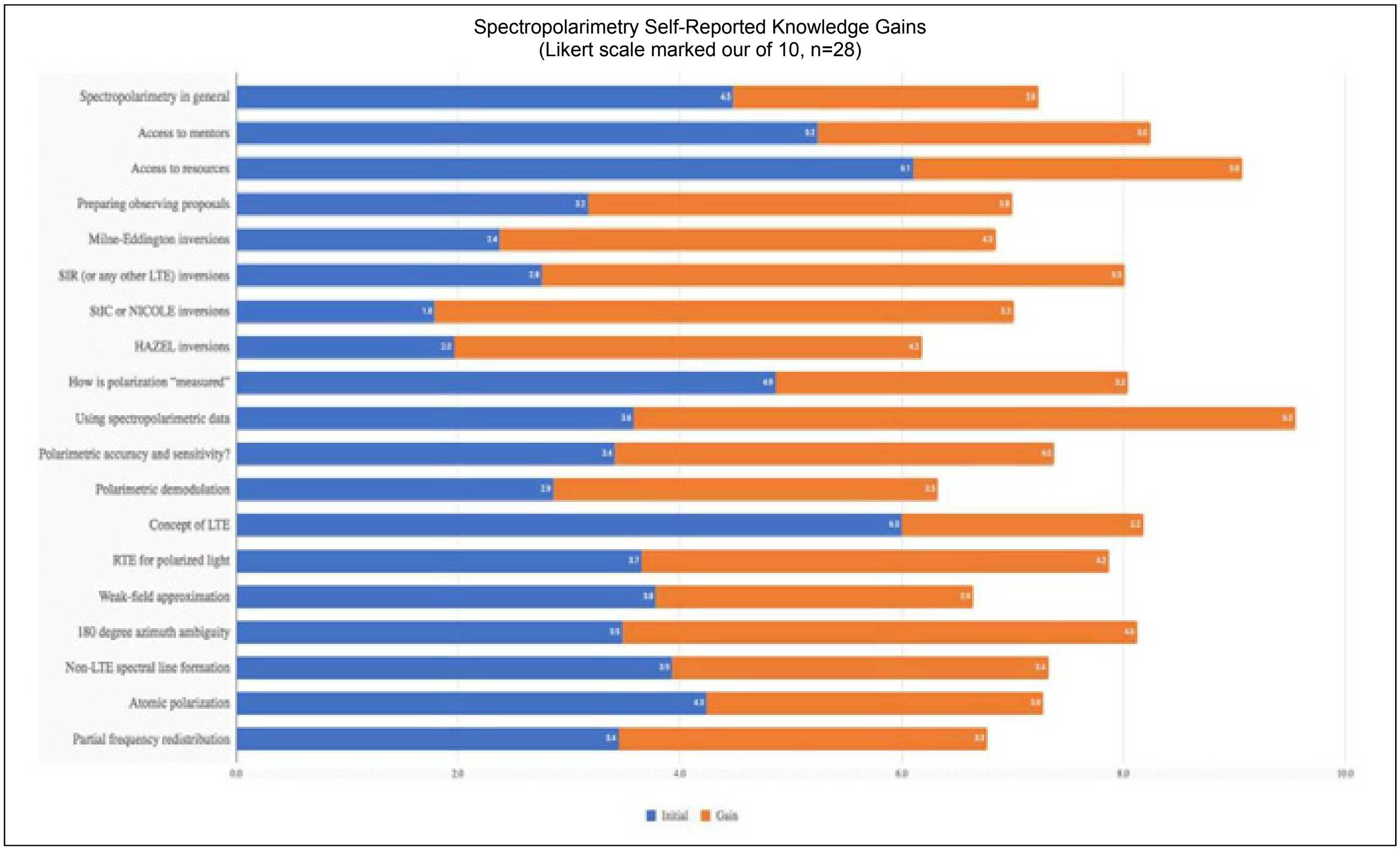


Figure 6.4-1. *Students' Likert evaluation of the 2018 Summer School on Spectropolarimetry organized jointly by HAO/NCAR and NSO. The gains in the area of using inversion codes are highly remarkable.*

7 SACRAMENTO PEAK AND DIVESTITURE OF THE DUNN SOLAR TELESCOPE

As mandated in the NSF solicitation for the renewal of NSO's Cooperative Agreement, the major historical telescope facilities managed by NSO will be closed or divested after 2017. With mid-2020 as the expected date for DKIST first light, we face a two-year gap during which NSO will 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 the 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 the 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 will function under this division of responsibilities. We currently plan to operate the site under this scheme for three years, subject to the availability of funds from the various stakeholders. The feasibility of the model will be evaluated on a yearly basis.

NSF finalized the Environmental Impact Statement (EIS) required by the substantial change in model of operations 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.

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

The National Solar Observatory has 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/*) 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.

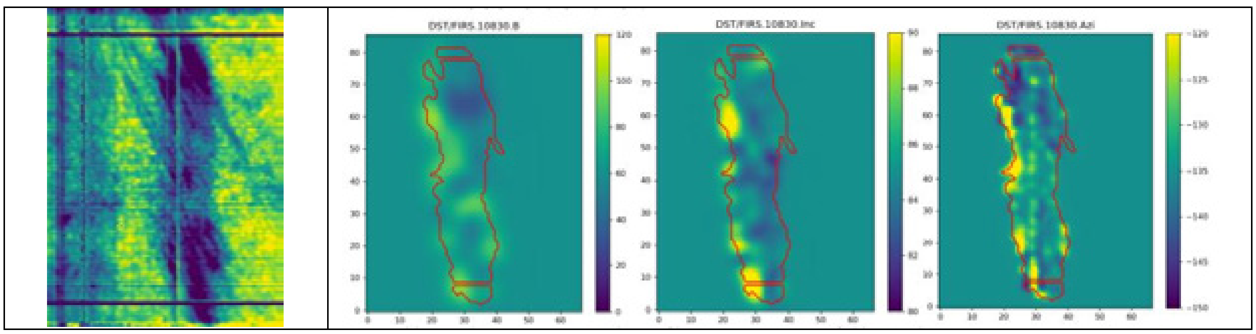


Figure 4.1-1. *Example of Level-2 data obtained as part of the filament vector magnetic field synoptic program. The observations were taken with the FIRS instrument using the He I 1083nm line. The HAZEL (A. Ramos, 2008) inversion code was used to infer the magnetic field parameters.*

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 will start 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 was approved for FY 2018, but the consortium will resubmit a proposal every year to secure a similar level of support. 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 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 under the Chief Observer. The CO will provide oversight and management of all operations at the DST including the 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 Chief Observer. NMSU employees will not be 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 that 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 will maintain regular contact with the SSOC lead scientist to coordinate the activities at the DST including scheduling of telescope time. These planning discussions will include the NSO Director as needed.

NSO will bill NMSU $10K per month to offset the DST operating costs. NSO will also charge 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 plans to undertake 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 on the funding necessary for these activities and repairs as a CA Supplemental Funding Request.

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 has decided to relocate a site manager from the Headquarters in Colorado to Sunspot. The site manager will be responsible for all site activities outside of the DST and the visitor center. Additionally, NSO has contracted a local security firm that will have a regular presence on site. These additional security measures will likely increase the cost of keeping the observatory operational.

7.2 Dunn Solar Telescope

The 76-cm Richard B. Dunn Solar Telescope (DST), 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.

7.2.1 DST Instrumentation

The instrument suite available at the DST is without question what makes the facility one of the most competitive solar telescopes in the world, in spite of being the oldest one among those equipped with modern adaptive optics systems.

7.2.1.1 Facility Infrared Spectropolarimeter (FIRS)

This instrument is a collaborative project between the National Solar Observatory and the University of Hawaiʻi Institute for Astronomy (IfA) to provide a facility-class instrument for infrared spectro-polarimetry at the Dunn Solar Telescope. H. Lin (IfA) is the principal investigator of this NSF/MRI-funded project. FIRS takes advantage of the diffraction-limited resolution provided at infrared wavelengths by the AO system during a large fraction of the observing time. Many of the solar magnetic phenomena occur at spatial scales close to or beyond the diffraction-limited resolution of the telescope. A unique feature of FIRS is the multiple-slit design, which allows high-cadence, large FOV scans (up to four times more efficient than SPINOR and DLSP), a vital feature for studying dynamic solar phenomena such as flares. The high-order Echelle grating allows for simultaneous multi-wavelength observations sensing different layers of the solar atmosphere, and thus enabling 3-D vector polarimetry. The two detectors are a 1K × 1K MgCdTe IR camera and a 2K × 2K camera with Kodak CCD for the visible arm, both synched to their own liquid crystal modulator. FIRS has been fully commissioned as a supported user instrument since 2009. It serves as a prototype for the Diffraction-Limited Near-IR Spectro Polarimeter (DL-NIRSP), a major DKIST first-light instrument.

7.2.1.2 Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)

SPINOR is a joint High Altitude Observatory (HAO)/NSO instrument that replaced the Advanced Stokes Polarimeter (ASP) at the Dunn Solar Telescope with a much more capable system. The ASP has been the premier solar research spectro-polarimeter for previous instrument generations. SPINOR extends the wavelength of the former ASP from 450 nm to 1600 nm with new cameras and polarization optics, provides improved signal-to-noise and field-of-view, and replaces obsolete computer equipment. Software control of SPINOR into the DST camera control and data handling systems has been completed and the instrument is fully commissioned as a user instrument. FIRS, SPINOR and IBIS, are the primary instruments for joint observations with *Hinode*, SDO, and IRIS. They augment capabilities for research at the DST and extend the lifetime of state-of-the-art research spectro-polarimetry at the DST for another decade. SPINOR is also the forerunner of the Visible Spectropolarimeter (ViSP) that is being developed by HAO for the DKIST.

7.2.1.3 Interferometric BIdimensional Spectrometer (IBIS)

IBIS is an imaging spectrometer built by the solar group of the INAF/Arcetri Astrophysical Observatory, with contributions from the University of Florence and University of Tor Vergata in Rome. IBIS delivers high spectral resolution (25 mA in the visible, and 45 mA in the infrared), high throughput, and consequently high cadence. In collaboration with NSO and the High Altitude Observatory, IBIS was upgraded to a vector polarimeter. The wavelength range of IBIS extends from the visible to near-IR and allows spectroscopy and polarimetry of photospheric and chromospheric layers of the atmosphere. NSO has a Memorandum of Understanding with the University of Florence for continued operation and support of IBIS at the DST. NSO and NMSU are discussing the extension of the MOU with the Italian partners. Two new identical Andor 1K × 1K cameras have replaced the slower Princeton narrow-band and Dalsa wide-band cameras for improved data rates. IBIS has been integrated into the DST SAN for faster data storage. IBIS serves as a prototype for the Visible Tunable Filter (VTF) in the DKIST first-light instrument suite and provides experience in reducing the large data sets that instruments in the DKIST era will produce.

7.2.1.4 Rapid Oscillations of the Solar Atmosphere (ROSA)

ROSA is a fast camera system developed and built by Queen's University (QU) in Belfast, Northern Ireland. It consists of up to eight 1K x 1K Andor cameras, including one especially blue sensitive camera, an ultra-fast camera capable of sampling images at up to 60 Hz, and a computer system capable of storing data at these high rates. The computer system has an internal storage capacity of 20 Tb, enough for a few days of observations, even at the extremely high data rates the system is capable of. Typically, the cameras are fed through some of NSO's wide band filters in the blue, while the red light is fed to IBIS. The DST observers have been instructed on operating ROSA and are capable of running the instrument without assistance from QU. ROSA serves as an analogue for the DKIST's Visible Broad-band Imager (VBI).

8 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.

9 EDUCATION AND PUBLIC OUTREACH AND BROADENING PARTICIPATION

9.1 NSO EPO Activities

9.1.1 DKIST First-Light Preparations

With first engineering light for DKIST expected in mid-2019, the EPO team has built and is beginning to implement a first-light plan. This includes the new website, increased exposure through social media and blog posts, and a series of short videos focused on the "fast facts" of DKIST which are designed to integrate into our social media plan. We will continue to work with NSF and AURA on preparations for first light. This will be the dominant focus of our efforts during FY19.

Table 9.1-1 lists the branding objectives and key messages that will be the focus of our first-light efforts.

Table 9.1-1. DKIST Branding Objectives and Key Messages

	Objective. We will…	Key Message
1	Promote DKIST, a new state of the art solar telescope being built in Hawaii, funded by NSF, and operated by NSO.	*Funding to build and operate DKIST comes from the National Science Foundation.*
		The National Solar Observatory has built and will operate DKIST, with partnership from around the world.
2	Communicate that DKIST will revolutionize our understanding of our Sun and its magnetic field.	*Using a suite of advanced, cutting edge instruments and optical systems (including adaptive optics), we will be able to regularly* ***measure*** *the Sun's magnetic field in the corona for the first time.*
		We will use advanced techniques to measure solar magnetic fields in the lower atmosphere.
3	Advertise DKIST's cutting edge technology: Coudé lab rotator, mirror polish, air knife.	*Highlight e.g. the first/highest/best (engineering)* *To including instruments*
4	Explain DKIST's revolutionary science techniques: coronagraph, spectropolarimetry	*Highlight e.g. the first/highest/best (scientific)* *To including instruments*
5	Emphasize that DKIST will feed our understanding of the fundamental processes on the Sun.	*DKIST will provide the most detailed observations of the Sun that we've ever collected (see more, know more).*
		DKIST is a microscope for the Sun.
6	Advertise that DKIST data will be accessible and can be utilized by all, professionals and the public alike.	*DKIST is a research facility operated on behalf of the US people and is funded with US taxpayer money.*
		DKIST supports NSF's Open Skies Policy, which provides equal and free access to the facility for all US and international researchers.
		We live in the atmosphere of a star. We want to understand it.
		DKIST data will be available online free of charge, for use by all, both professionals and public alike.
7	Explain DKIST's role in space weather.	*DKIST will provide cutting edge data that will help improve our understanding of what causes space weather.*
8	Highlight the dedication and expertise of the NSO/DKIST team.	*An incredible group of highly dedicated and skilled people have made DKIST possible.*
9	Highlight that DKIST will be the largest ground based solar physics telescope in the world.	*DKIST will be largest solar telescope in the world, which will provide the highest resolution and quality observations of the Sun ever taken.*

In addition to branding objectives and key messages, we have identified target audiences, including the science community, funding agencies and US government, media, general public, and K-12 educators.

A key strategy for the EPO team is to emphasize the people of DKIST, as well as the science and technology of this cutting-edge facility. Throughout all of our efforts, we will be highlighting the work of the DKIST team. In addition to our ongoing, general EPO efforts, specific strategies around the DKIST first-light plan include four main programs. Each program is described below, and followed by a table indicating the branding objectives that will be addressed, and the audiences reached.

9.1.1.1 Press Preparation

The Daniel K. Inouye Solar Telescope and its instruments are highly complex pieces of technology, around which misconceptions and confusion can arise. We aim to help ensure that the media are sharing correct and accurate information about this project by pursuing the following programs in 2019:

1. We will develop a detailed "Press Kit" in advance of DKIST first light. This kit will be nominally made available online with select printed copies available; number and dissemination TBD. The press kit will include:

- A series of one-page explanatory documents describing the telescope and instruments.
- Key personnel and their contact details.
- Sample stories and/or narratives about the project that can be adapted as necessary.
- Photographs and graphics of the telescope and key science topics.
- Links to additional resources.
- Quotes from NSO, NSF, AURA and Maui community members.
- An overview of the early science goals and what we can expect in the first six months.
- DKIST at a glance overview.
- Sample profiles of DKIST staff.
- Other relevant material that will ease the development of DKIST news articles.

We will host a Media Workshop to review the items in #1 and provide an opportunity to elaborate on them. This workshop will either be in-person (participants travel to Summit/DKIST Science Support Center) or virtual (participants join via telecon). This event will also provide the opportunity for DKIST staff to be interviewed by media attendees.

We will provide external communications training for DKIST staff. We will bring in an experienced facilitator to provide training in how to effectively communicate to the press. DKIST staff members selected by the DKIST Director will be invited to participate.

We will aim to have the press kit available by late spring/early summer 2019, in preparation for the DKIST Engineering First Light celebration. We will provide the communications training in advance of the press event, which is expected to be held in early summer (date TBD dependent on telescope progress).

Table 9.1-2. Branding Objectives and Target Audiences Accessed via Press Preparation Activities

	Branding Objective/Target Audience	Science Community	Funding & Government	Media	General Public	K-12 Educators
1	Promote DKIST, a new state of the art solar telescope being built in Hawaii, funded by NSF, and operated by NSO.			x	x	
2	Communicate that DKIST will revolutionize our understanding of our Sun and its magnetic field.			x	x	
3	Advertise DKIST's cutting edge technology: Coudé lab rotator, mirror polish, air knife.			x	x	
4	Explain DKIST's revolutionary science techniques: coronagraph, spectropolarimetry.			x	x	
5	Emphasize that DKIST will feed our understanding of the fundamental processes on the Sun.			x	x	
6	Advertise that DKIST data will be accessible and can be utilized by all, professionals and the public alike.			x	x	
7	Explain DKIST's role in space weather.			x	x	
8	Highlight the dedication and expertise of the NSO/DKIST team.			x	x	
9	DKIST will be the largest ground based solar physics telescope in the world.			x	x	

9.1.1.2 Graphics and Animations

A key strategy in communicating the complex science and technology at the heart of DKIST will be the use of graphics and animations. We will develop a series of infographics and science graphics that will address our key messages. They will focus on some of the primary techniques used (e.g. spectropolarimetry), and the mechanisms by which the telescope and instruments gather observations. We are also considering contracting a graphic designer to develop an animation sequence of one or two key items. Some initial ideas for infographics include:

- What do the instruments see and where are they looking
- Mirror smoothness
- Energy balance – how much energy falls on M2, how much is removed etc.
- The off-axis mirror alignment – benefits/drawbacks
- Light path – how does the light reach the instruments

These graphics will be developed on an ongoing basis, beginning January 2019 and continuing throughout the year. As they are developed, they will be hosted on the NSO website.

Table 9.1-3. Branding Objectives and Target Audiences Accessed via Graphics and Animations

	Branding Objective/Target Audience	Science Community	Funding Agencies & Government	Media	General Public	K-12 Educators
1	Promote DKIST, a new state of the art solar telescope being built in Hawaii, funded by NSF, and operated by NSO.	x	x	x	x	x
2	Communicate that DKIST will revolutionize our understanding of our Sun and its magnetic field.	x	x	x	x	x
3	Advertise DKIST's cutting edge technology: Coudé lab rotator, mirror polish, air knife	x	x	x	x	x
4	Explain DKIST's revolutionary science techniques: coronagraph, spectropolarimetry	x	x	x	x	x
5	Emphasize that DKIST will feed our understanding of the fundamental processes on the Sun.	x	x	x	x	x
6	Advertise that DKIST data will be accessible and can be utilized by all, professionals and the public alike.	x	x	x	x	x
7	Explain DKIST's role in space weather.	x	x	x	x	x
8	Highlight the dedication and expertise of the NSO/DKIST team.					
9	DKIST will be the largest ground based solar physics telescope in the world	x	x	x	x	x

9.1.1.3 Social Media

We will leverage the social media following we have developed during the 2017 eclipse as a mechanism to communicate and educate about DKIST. We are in the process of developing a series of short videos that address our key messages. Our EPO Officer – Tishanna Ben – is the host of these videos. They are approximately 30 seconds long and address one message per video. They are designed to engage followers quickly and concisely, with redirection to more elaborate information available on our webpage. This, along with the infographics, blog posts, photos and videos will be used to populate our social media pages.

Table 9.1-4. Branding Objectives and Target Audiences Accessed via Social Media

	Branding Objective/Target Audience	Science Community	Funding Agencies & Government	Media	General Public	K-12 Educators
1	Promote DKIST, a new state of the art solar telescope being built in Hawaii, funded by NSF, and operated by NSO.	x	x	x	x	x
2	Communicate that DKIST will revolutionize our understanding of our Sun and its magnetic field.	x	x	x	x	x
3	Advertise DKIST's cutting edge technology: Coudé lab rotator, mirror polish, air knife.	x	x	x	x	x
4	Explain DKIST's revolutionary science techniques: coronagraph, spectropolarimetry.	x	x	x	x	x
5	Emphasize that DKIST will feed our understanding of the fundamental processes on the Sun.	x	x	x	x	x
6	Advertise that DKIST data will be accessible and can be utilized by all, professionals and the public alike.	x	x	x	x	x
7	Explain DKIST's role in space weather.	x	x	x	x	x
8	Highlight the dedication and expertise of the NSO/DKIST team.	x	x	x	x	x
9	DKIST will be the largest ground based solar physics telescope in the world.	x	x	x	x	x

9.1.1.4 Blog Posts

NSO's new website provides an excellent platform for engaging the public in the details of DKIST via the new blogspot. Readers can subscribe to blogs on specific topics, including DKIST. We are planning a series of blog posts that will be posted every 2-4 weeks in advance of First Light. They will address topics including:

- Why DKIST? How will DKIST help our understanding of the Sun?
- What are DKIST science goals?
- How will DKIST work with other Solar Assets e.g. PSP/Solar Orbiter etc
- How does DKIST work?
- What are the instruments and what will they see?
- The people of DKIST.

We will invite the DKIST team to write the blog posts, but we can also interview staff and ghost write posts on their behalf. This effort will take place throughout FY19 and will be ongoing into the future.

Table 9.1-5. Branding Objectives and Target Audiences Accessed via NSO's Blog						
	Branding Objective/Target Audience	Science Community	Funding agencies & Government	Media	General Public	K-12 Educators
1	Promote DKIST, a new state of the art solar telescope being built in Hawaii, funded by NSF, and operated by NSO.					
2	Communicate that DKIST will revolutionize our understanding of our Sun and its magnetic field.	x	x	x	x	x
3	Advertise DKIST's cutting edge technology: Coudé lab rotator, mirror polish, air knife	x	x	x	x	x
4	Explain DKIST's revolutionary science techniques: coronagraph, spectropolarimetry	x	x	x	x	x
5	Emphasize that DKIST will feed our understanding of the fundamental processes on the Sun.	x	x	x	x	x
6	Advertise that DKIST data will be accessible and can be utilized by all, professionals and the public alike.					
7	Explain DKIST's role in space weather.	x	x	x	x	x
8	Highlight the dedication and expertise of the NSO/DKIST team.	x	x	x	x	x
9	DKIST will be the largest ground based solar physics telescope in the world	x	x	x	x	x

9.1.2 New Website

A major undertaking for the NSO EPO team in FY 2018 was to redesign and rebuild the NSO website. With DKIST first light imminent, we anticipate that the world will be focused on NSO and DKIST. 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.

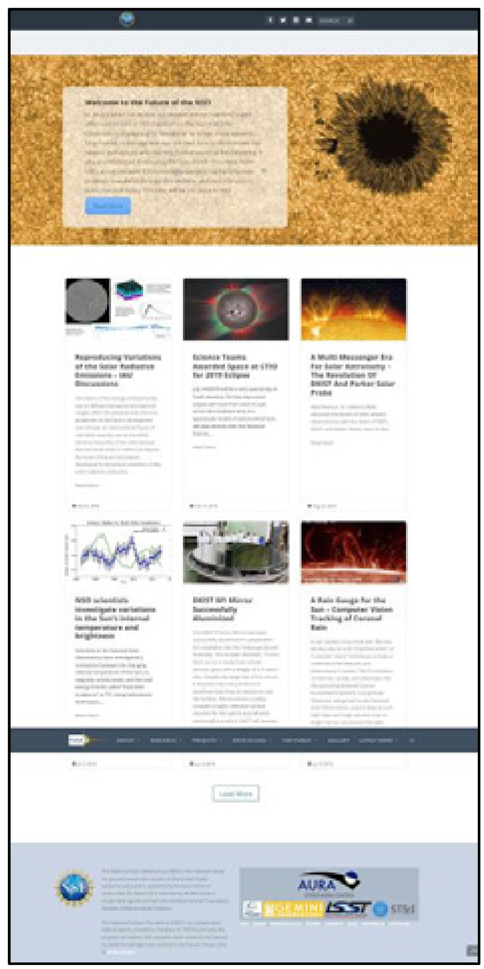


Figure 9.1-1. *Snapshot of NSO's new blog page, https://www.nso.edu/blog/.*

During FY 2019, 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.

9.1.3 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.

Social media will feature heavily during our FY19 efforts, especially around the DKIST first-light campaign. We will continue to engage our followers with updates on NSO science and technology, DKIST efforts, the solar art competition, outreach efforts, and major events in the solar physics and astronomy community.

9.1.4 Graphic Design

A new function of the EPO this year is the creation of effective graphics to support NSO's science and conduction outreach to both the general public and the science community. This will continue to be a key function of our team in supporting NSO's goals.

This effort will continue into FY19 with a focus on DKIST science and technical initiatives. Support for SPRING will feature in this effort during FY19 also.

9.1.5 Lobby Exhibit at Fiske Planetarium

NSO's EPO team is 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 will be focused on the importance of magnetic fields in space, a topic extremely relevant to NSO and DKIST in particular. The project is being undertaken by Fiske Planetarium, NSO, CU Boulder's Laboratory for Atmospheric and Space Physics (LASP) 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).

This effort is expected to take place throughout FY19 and should be completed by the 4th quarter.

9.1.6 Professional Outreach Conference

NSO continues to support AURA and NSF, and its own mission at professional confer-ences through exhibit booths and staff representation. The American Astronomical Society (AAS), AAS-Solar Physics Division (SPD), International Astronomical Union (IAU) and Space Weather Segment (SWE) of the European Space Agency, were the three primary conferences supported in 2018.

This will continue in the same manner in FY19.

Figure 9.1-3. *NSO EPO team member at the NSO booth, 2018 AAS conference.*

9.1.7 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 9.1-4. *Journey to the Sun Teacher Workshop participants (top) and learning to use their telescopes (bottom).*

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 adaption 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 (MEDB) 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, an 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!"*

Since the workshop, NSO EPO staff have continued to interact with, and provide support for, teachers during their implementation. This has been through ongoing school events, field trips, and class visits.

We anticipate continued interaction with the teachers in the coming year. We are also exploring the possibilities for a follow-on workshop and which group of teachers on which that workshop might focus. It may take more than one year to build a relationship with immersion school teachers. However, a workshop with other middle school teachers from Maui County or across the State of Hawaiʻi might be feasible for FY19.

9.1.8 Collaborations with Local Institutes and Organizations

Building connections within the Maui and statewide community is a key priority for NSO's EPO team. Collaborations help us to further support and diversify community engagement in solar science and STEM education. In addition, partnering with organizations that have long-standing and respected reputations aid us in establishing our own reputation and rapport with the community.

9.1.8.1 The University of Hawaiʻi Institute for Astronomy

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 Hawaiʻi Institute for Astronomy (IfA). 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.

Figure 9.1-5. *NSO booth during Astro Day West 2018.*

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.

9.1.8.2 Kamehameha Schools Paukukalo Preschool

NSO, in collaboration with the Kamemeha Schools (KS) kumus (teachers), planned and organized solar science activities for local keiki(children). 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.

Figure 9.1-6. *Kamehameha Preschool students learn about the Sun from their Kumu and NSO Educators. One student looks through a solar telescope. Students faces blurred for privacy.*

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.

9.1.8.3 Hui Noʻeau Visual Arts Center

NSO has participated in the Hui Noʻeau 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.

Figure 9.1-7. *Student work done in collaboration with the Hui Noʻeau Visual Arts Center Summer Youth Program.*

9.1.8.4 Maui Economic Development Board (MEDB)

Women in Technology (WIT) is a Hawaiʻi statewide workforce initiative of the MEDB. NSO is committed to support Women In Technology's Excite Camp in the spring of 2019. Excite Camp is a three-day experience for middle school girls from Maui County, where they participate in hands-on STEM projects and field trips. NSO will be providing two two-hour (four total) STEM sessions. During the sessions, students will explore the natural phenomena associated with engineering challenges faced by DKIST (e.g., heat, turbulence, magnification), while working towards designing a solution for a specific "Engineering Challenge" (i.e., develop a thermal protection system).

Additionally, NSO participates annually in MEDB's Advanced Maui Optical and Space Surveillance Technologies (AMOS) Space Exploration Day event. At the event, MEDB hosts over 100 Maui STEM students and teachers. The students experience space related presentations and activities by exhibitors.

9.1.8.5 Girl Scouts of Hawaiʻi

NSO will participate in the Girls Scouts of Hawaiʻi "STEM Fest" event, to take place in Waimea, Hawaiʻi on November 17, 2018. STEM Fest involves Girl Scout troops of all ages participating in hands-on STEM activities and meeting female professionals from various STEM fields. STEM Fest serves as part of the Girl Scouts' greater effort, the "Girl Scout STEM Pledge – a multiyear initiative to put 2.5 million girls through hands-on STEM programs by 2025." Girl Scouts STEM efforts also include the addition of their space science badges. NSO EPO anticipates future annual participation at the STEM Fest event, both on Maui and the Big Island.

Many of the outreach efforts are on an ad-hoc basis, depending on invitations from external partners. However, we expect this effort will continue on a similar scale through FY19.

9.1.8.6 "My Sun, My Star" 2018 Art Contest by NSO and the Hui No'eau Visual Arts Center

NSO has partnered with Hui Noʻeau Visual Arts Center in presenting an art contest that focuses on the importance of the Sun in our every day life and culture. The Hui Noʻeau Visual Arts Center (Hui) is a community based visual arts education organization that offers access to quality arts instruction by professional artists.

The competition is focused on the role of the Sun in our everyday life, and the role it plays in culture. Participants are encouraged to use themes from their local cultures in expressing their relationship with the Sun and its importance as "our star".

The contest was launched on the Fall Equinox (September 22, 2018) and closes on the Winter Solstice (December 21, 2018). It offers three entry categories (child, young adult, and adult) for both a general competition, and a Maui-only competition. Prizes will be awarded using funds from the "Sting" gift referenced above (not NSF funds).

Figure 9.1-8. *Poster for Sun Art Competition.*

Acceptable media include (but aren't limited to) paint, pencil, ink, music, collage, poetry, videography, crafts, photography, pottery, sculpting, and/or digital creations. A judging panel of Hui artists and NSO staff will select a 1st and 2nd place winner for each competition, as well as an overall grand prize winner. The Hui will display a portion of the winning artwork at their facility.

To promote the art contest, we've done the following:

- Flier handouts at public outreach events and NSO exhibit booths.
- In-person presentations to students at partner schools.
- Strategically placed posters at schools, universities/colleges, art studios and relevant stores.
- Outreach to our network of educators.
- Outreach to Hui's network of artists and art students.
- Disseminate information via Hui's Flash News emails.
- Post contest information weekly on social media (i.e., Twitter, Facebook, Instagram).
- Encourage participant use of #MySunMyStar2018 on posted artwork.
- Feature submitted artwork weekly on social media.

This competition will be completed in FY19. The entries will be reviewed in spring of FY19 and awards distributed soon after. The winning entries will be displayed in the Maui office and possibly at Hui Noʻeau during FY19. The entries will also be featured on our social media pages throughout the year.

9.1.9 Other Education and Career Development Efforts

To fulfill NSO's commitment to education and the Maui community, both EPO and non-EPO staff dedicate time to granting requests for support from the Hawaiʻi Department of Education, and other educational institutions. NSO staff annually serve as judges for the Maui County Regional Science and Engineering Fair and FIRST Lego League Robotics. NSO has also participated in a science project brainstorming and support session that took place at Lānaʻi High and Elementary School on September 14, 2018. Additionally, NSO virtually attended and provided feedback on presentations by students from St. Anthony School, on their "Into Orbit" FIRST Lego League teams project. A requirement was that students present their ideas to professionals in their community. The presentations took place on October 31, 2018.

Figure 9.1-9. *Student using the solar telescope during Lana'i High Career Day.*

Seeking to leverage DKIST's presence on Maui, middle school teachers from the Montessori School of Maui requested a tour of the telescope for their students. We were not able to grant their request of bringing minors to the DKIST site, due to its status as under construction. However, NSO/DKIST was able to provide an educational tour experience for a small group of teachers. Following the tour, teachers proposed integrating NSO/DKIST into their science and technology career pathway program. A teacher sent the following in an email to EPO on June 13, 2018:

"Thank you for helping to arrange this gem of an education outreach. It will definitely be a positive impact on our program and hopefully we can scaffold with more NSO."

The EPO team has been developing a range of career-development materials for use during outreach and school events. Many teachers have expressed an interest in helping their students understand the scope and paths for careers at DKIST. In response to this, we have developed a career booklet, profiling staff from across the observatory who are diverse in both race and ethnicity and in job role. We have also created "Career Trading Cards", similar to the currently popular Pokémon, Yu-gi-oh, or Top Trump cards. Each card describes a job role at NSO, along with the skills needed to succeed. At a recent career fair, a child was overheard exclaiming *"Oh wow, you got an Optical Scientist! They're super rare!"*

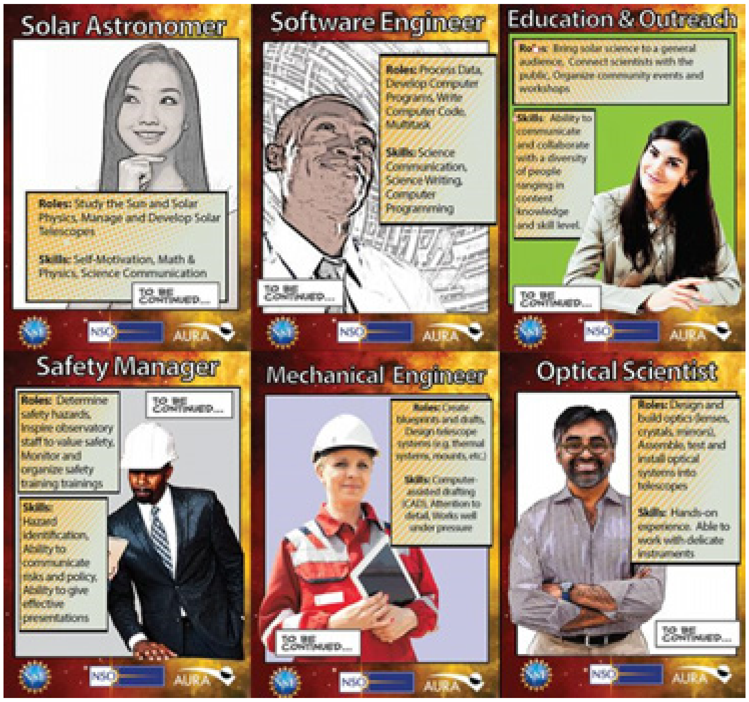


Figure 9.1-10. *Examples of some Career Cards developed by NSO to share the breadth of jobs needed at an observatory.*

It is anticipated that these efforts will continue through FY19 in a similar manner.

9.1.10 Research Experience for Undergraduates

Continuing the partnership with CU's LASP, NSO's EPO team assisted with the planning and implementation of the "Boulder Solar Alliance" Research Experience for Undergraduates (REU), funded by NSF. The number of applications for 2018 increased by 250%, going from an average of 160 to more than 400 in one year! Although definitive conclusions are impossible to draw, the only major change to the program was the provision of three short videos of past participants explaining the program. These videos were the idea of, produced and recorded by, and edited by NSO EPO staff. They focus on the workplace environment, and the insecurity of not knowing anything about the niche subject before applying. Our belief is that this has put the minds of students at ease, recognizing people like themselves already in the program, and finding self-belief as a result.

NSO hosted seven of the 25 undergraduate students from the program, six who identified as female, one as male, and one underrepresented minority. We provided recruitment efforts in Hawaiʻi in order to raise the profile of the program and the opportunity to conduct research at NSO and one of the NSO students was accepted from a Hawaiʻi university. The REU grant will be up for renewal at the end of FY19, so NSO will be working closely with LASP on developing the proposal for this ongoing award during FY19.

Figure 9.1-11. *2019 Boulder Solar Alliance REU cohort.*

9.1.11 Spectropolarimetry Graduate Fall School

NSO EPO staff and scientists partnered with NCAR's Advanced Study Program and the High Altitude Observatory 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 that 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 spectropolarimetric 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.

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, providing 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.

It is unclear whether this program will be repeated in the future. If so, NSO's EPO team will be happy to support it.

Figure 9.1-12. *2018 Spectropolarimetry School participants during an optics lab.*

10 FY 2019 SPENDING PLAN

The NSO spending plan is based on receiving the President's FY 2019 Budget Request of $20.5M for NSO. This amount is reduced by $0.5M from the budget profile in the Cooperative Agreement (CA) to reimburse the $2.5M upfront payment received in FY 2016 for the DKIST Science Support Center (DSSC) in Maui. These repayments occur over a period of five years, ending in FY 2022. The NSO's Program allocations presented here follow the guidelines in Table 10.4-2 of the Cooperative Agreement proposal submitted by AURA in October 2013.

Figure 10.1 describes the organizational structure of the Observatory and includes all of the Cost-Account Managers with financial responsibilities. Red lines in the chart correspond to the DKIST construction project.

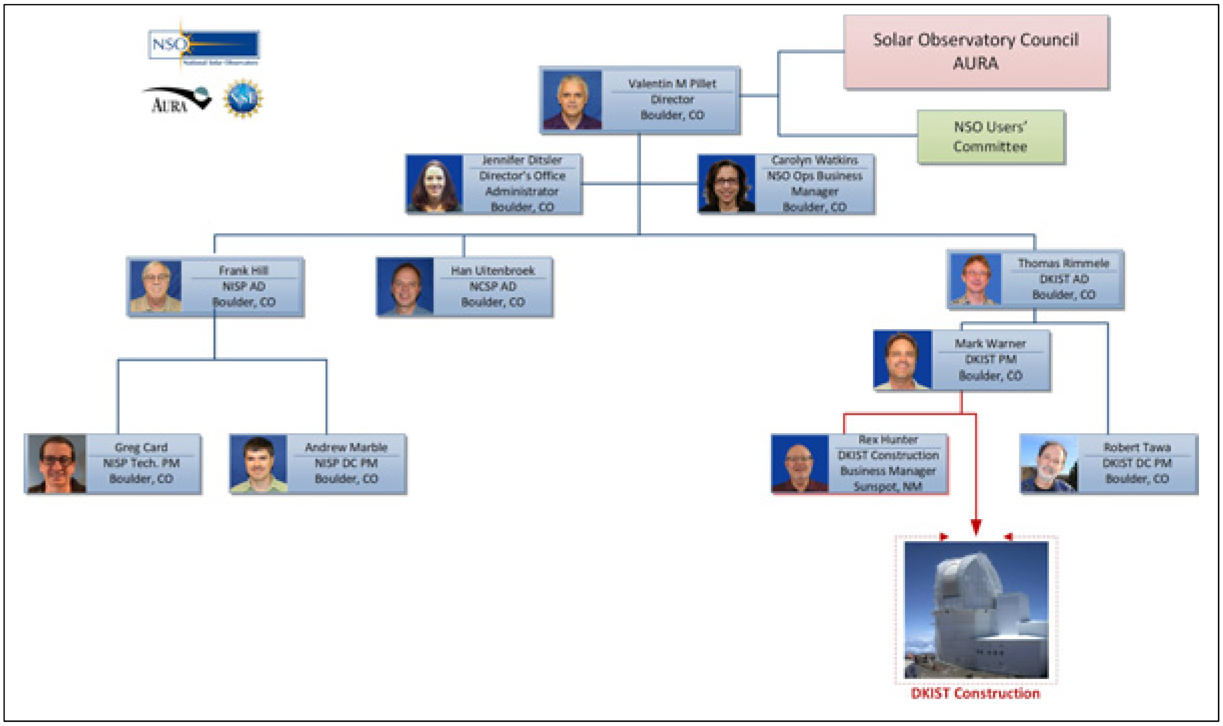


Figure 10.1. *NSO organizational chart of cost-account managers.*

10.1 Total Budget: FY 2019 NSF New Funds, Carry Forward, and Grants

Table 10.1-1 summarizes the funding that NSO expects to receive as new NSF funding, as well as anticipated non-NSF support for operations in FY 2019. The NSO Program in FY 2019 was developed based on receiving $4M of NSF funding for the regular base program (which represents a reduction of $1M with respect to the previous year), and $17M corresponding to this year's funding wedge for ramping up DKIST operations, totaling $21M. As explained earlier, the DKIST funding wedge is reduced by $0.5M to account for the DSSC upfront payment. Additionally, the DKIST Program received in FY 2018 an $8M forward-funding of the FY 2019 DKIST operations wedge to ensure that the availability of funds does not restrict the Data Center development. Thus, the FY 2019 new NSF funds for the DKIST Program amount to $8.5M.

In contrast to past years, no portion of the DKIST operations funding wedge in FY 2019 is utilized to cover the cost of NSO Headquarters relocation to Boulder. All remaining transition costs are covered by carry-forward funds in the Director's budget as detailed below.

Table 10.1-1 NSO FY 2019 Funding	
(Dollars in Thousands)	
NSF Astronomy Division Funding	$20,500
Less FY19 Forward Funding Received in FY18	($8,000)
Subtotal NSF Astronomy Division Funding	$12,500
NISP Grants (VSO, NASA Infrastructure, etc.)	$482
NOAA Support	$800
Total NSO Funding	**$13,782**

NSO receives additional operational support from other sources. In FY 2016, NSO received the first NOAA Space Weather Prediction Center contribution of $800K, intended for support of routine GONG network operations. As reflected in the interagency agreement between NOAA and the NSF, this funding continues through the end of FY 2021 and covers operational costs of the GONG network, including the yearly preventive maintenance trips to the six sites.

NSO also receives support through a variety of grants and contracts, mostly by NISP, with both NSO and non-NSO principal investigators. These funds are used to support research fellows for specific activities, improve the Observatory's infrastructure, and enhance the capabilities of the program. These enhanced capabilities are generally made available to the user community. The FY 2019 budget includes an estimated $482K from grants associated with various activities within NISP, with most of the funds corresponding to several NASA grants, including the participation of NISP in the Virtual Solar Observatory (VSO). The NISP helioseismology group has been particularly successful at obtaining new grants, but overall the NISP grant funding in FY 2019 is smaller than in the previous year by about $150K.

In FY 2018, NSO received a Supplemental Funding Request (SFR) to the operations Cooperative Support Agreement (CSA) of $3.5M for the production of DKIST Level-2 data products. The funding has been allocated to the NSO Community Science Program (NCSP) (see Section 10.2.4), and the funds are budgeted in WEBUD as part of the Program's carry forward. NSO plans to submit in FY 2019 a second similar SFR for the completion of the Level-2 data products efforts. This additional SFR has been discussed with the NSF, and it is contingent upon the availability of funds.

An SFR received in FY 2018 for the operations of Sunspot, and for an amount of $325K, contributes to the carry-forward budget of the Sunspot Program. Additional carry forward exists in this program as a result of ongoing activities (see Section 10.2.5) and recent charges to the Sunspot Solar Observatory Consortium (SSOC). NSO will discuss with the NSF a FY 2019 SFR to complete the budget required for operations of the site.

In FY 2017, NSO received $500K of Phase 1 funds to initiate the demolition of the Kitt Peak Vacuum Tower (KPVT). NSO and AURA have used a small fraction of these funds for the Request for Proposal (RFP) phase of the demolition project. The remaining funds reside in a dedicated account in the Director's carry-forward budget and are intended to cover the initial costs of the activity. The cost of the demolition of the KPVT is expected to be slightly higher than the remnant funding, and NSO will need to submit a request to the NSF for the additional funding.

NSO continues to use the WEBUD budgeting tool that details the expenditures associated with work packages for the corresponding fiscal year. The budgeting tool allows for the inclusion of the Basis of Estimates (BOE) to document the various costs. As in FY 2018, this year's WEBUD allows the selection of one of the three funding sources: new NSF funds corresponding to a specific year (also selectable), carry forward, or grant funding (see Tables 10.1-2, 10.1-3, and 10.1-4). The three funding sources are budgeted separately but with similar references to the various work packages and BOE entries. NSO continues to collaborate with AURA Central Administrative Services (CAS) to further develop WEBUD to include the option of multiyear budgets. As an additional feature, this year WEBUD offers the possibility of preparing trial budgets as needed during proposal preparation, using a sandbox area that is separate from the production budgets.

WEBUD also allows for views that provide a summary for a given year of the combined Observatory funding.

Table 10.1-2 NSO Spending Plan

Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance	Owner
NSO	NSO HQ	NSO Headquarters	Yes	6.2	$1,757,883	$1,759,384	$0	$1,501	Pillet, Valentin J
NSO	DKIST OP	DKIST Operations	Yes	35.5	$8,487,246	$8,474,444	$0	($12,802)	Rimmele, Thomas R
NSO	NSO NISP	NSO NISP	Yes	9.0	$2,197,227	$2,197,160	$0	($67)	Hill, Frank
NSO	NSO SP	NSO SP	Yes	0.0	$0	$0	$0	$0	Hunter, Rex G
NSO	NSO NCSP	NSO Community Science Program	Yes	0.0	$0	$0	$0	$0	Uitenbroek, Han
NSO	NSO MF	NSO Management Fee	Yes	0.0	$69,012	$69,012	$0	$0	
			Total	**50.8**	**$12,511,368**	**$ 12,500,000**	**$0**	**(11,368)**	

Table 10.1-2 shows the six programs, or areas, that can receive new NSF FY 2019 funds: NSO Headquarters, DKIST Operations, NSO NISP, Sunspot Operations (NSO SP), NSO Community Science Program (NCSP), and the NSO Management Fee. The NSO Tucson program does not receive any new funding this year, but we keep the accounts open in case of unexpected expenditures. As in FY 2018, the budgets of the respective programs now include indirect-cost payments. A new component in FY 2019 is the reduction in the allocations for each program by an amount corresponding to their use of the NSO's Management Fee. The fifth column shows the FTEs in each program (supported by base funding). Column 6 details the total spending plan and Column 7 the expenditure targets. Note that the Column 7 total corresponds to the FY 2019 NSF budget of $12.5M (i.e., the $20.5M minus the $8M forward-funding received in FY 2018). NSO SP (Sunspot) has no new funds allocated, and the program uses the carry-forward as discussed below. NSO is discussing with the NSF an FY 2019 SFR for Sunspot to cover the cost of operating the site. The budget for this SFR is currently in the WEBUD sandbox area. Column 9 indicates the variance between the spending plan and the sum of the total revenues.

Table 10-1-3 NSO Distribution of Carry-Forward Funds									
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance	Owner
NSO	NSO HQ	NSO Headquarters	Yes	2.8	$1,658,083	$1,658,547	$0	$464	Pillet, Valentin J
NSO	DKIST OP	DKIST Operations	Yes	6.6	$20,739,711	$20,732,921	$0	($6,790)	Rimmele, Thomas R
NSO	NSO NISP	NSO NISP	Yes	3.5	$1,350,560	$1,350,627	$0	$67	Hill, Frank
NSO	NSO SP	NSO SP	Yes	0.0	$508,252	$507,939	$0	($313)	Hunter, Rex G
NSO	NSO NCSP	NSO Community Science Program	Yes	9.0	$3,494,647	$3,495,032	$0	$385	Uitenbroek, Han
NSO	NSO MF	NSO Management Fee	Yes	0.0	$27,379	$27,379	$0	$0	
			Total	21.8	$27,778,631	$ 27,772,445	$0	$ (6,187)	

Table 10.1-3 provides the distribution of carry-forward funds for each program. The unspent budget originates primarily from delays in implementing various aspects of the transition to DKIST operations. The HQ line also includes the KPVT decommissioning budget; if that amount is subtracted, the total HQ carry forward is smaller than in previous years. The DKIST program carries forward funds that also result from 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 defined and consolidated after this year's scheduled reviews. For NISP, the $1.35M balance results from the SOLIS relocation delays and unused GONG refurbishment funds. Currently, all operational costs in Sunspot are covered from the program's carry-forward funds. The new NSO Community Science Program (NCSP), is entirely budgeted in the carry-forward section as the funds were received in FY 2018. NSO will submit an SFR for the DKIST Level-2 activities later this year. This second SFR will constitute the bulk of the NCSP budget in FY 2020.

Table 10.1-4 NSO External Funds									
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	Variance	Owner
NSO	NSO HQ	NSO Headquarters	Yes	0.0	$0	$0	$0	$0	Pillet, Valentin J
NSO	DKIST OP	DKIST Operations	Yes	0.0	$0	$0	$0	$0	Rimmele, Thomas R
NSO	NSO NISP	NSO NISP	Yes	7.1	$1,265,774	$1,265,774	$0	$0	Hill, Frank
NSO	NSO SP	NSO SP	Yes	0.0	$0	$0	$0	$0	Hunter, Rex G
NSO	NSO NCSP	NSO Community Science Program	Yes	0.0	$0	$0	$0	$0	Uitenbroek, Han
NSO	NSO MF	NSO Management Fee	Yes	0.0	$0	$0	$0	$0	
			Total	7.1	$ 1,265,774	$ 1,265,774	$0	$0	

Table 10.1-4 shows the currently available grant funding, including the NOAA/SWPC FY 2019 contribution and the number of NISP FTEs that are grant supported, including GONG network operations.

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 in FY 2019 for documenting changes to the budget presented in this report.

10.2 Work Package Breakout

The online WEBUD tool allows various modes of visualizing the budget distributions and BOE used in each of NSO's Programs. In this section, we present an overview of the most significant expenses projected for each program. Tables 10.2-1 through 10.2-9 show the spending plan for the major functional areas in more detail, breaking out payroll and non-payroll by work packages. The tables are provided separately for the three different funding sources: NSF FY 2019 funds, carry forward, and grants when applicable.

10.2.1 Director's Office (NSO HQ)

Table 10.2-1 presents the new 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, and two EPO personnel. 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 ($305K, Table 10.2-1, 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. Insurance payments refer to all costs incurred for vehicles and liability at the operational sites.

Table 10.2-1 Director's Office Budget

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO HQ	**6.2**	**$981,521**	**$776,361**	**$1,757,883**	**$0**	**$1,757,883**
Director's Office	1.7	$444,290	$87,617	$531,907		$531,907
AURA Corporate Direct Charges			$37,797	$37,797		$37,797
Post Retirement Benefits			$53,461	$53,461		$53,461
AURA Committees			$104,474	$104,474		$104,474
Business/Administration	1.7	$225,677	$51,290	$276,967		$276,967
Safety			$4,788	$4,788		$4,788
Recruit/Relo - New Positions			$0	$0		$0
Recruit/Relo - Existing Positions			$0	$0		$0
Carry Forward			$0	$0		$0
Insurance			$37,494	$37,494		$37,494
CU Recharge Fees			$3,888	$3,888		$3,888
Science Staff - Research			$0	$0		$0
Research Assistants			$0	$0		$0
NSO Science-Collaborations			$0	$0		$0
NISP Operations Service			$0	$0		$0
DKIST Operations Service			$0	$0		$0
CSP Activities			$0	$0		$0
EPO - Scientists			$0	$0		$0
Joint CU/NSO			$0	$0		$0
Hale Post Doc			$0	$0		$0
HQ Operations			$305,021	$305,021		$305,021
Boulder Computing IT	0.5	$58,527	$37,099	$95,626		$95,626
Vehicles			$4,256	$4,256		$4,256
HQ Development & Relocation			$0	$0		$0
Instrument Development			$0	$0		$0
Education and Public Outreach	2.3	$253,028	$49,178	$302,206		$302,206
CMAG			$0	$0		$0
Total:	**6.2**	**$981,521**	**$776,361**	**$1,757,883**	**$0**	**$1,757,883**
Target:						**$1,759,384**
Variance:						**$1,501**

Table 10.2-2 discloses the Director's Office carry forward from FY 2018 ($1.66M). WEBUD contains the re-budgeting details of these funds, including the BOE. Here we list the most significant items covered by this budget:

1. The last two DKIST Critical Science Plan Workshops and a series of follow up meetings intended to consolidate the multi-messenger science DKIST will carry out in coordination with the Parker Solar Probe (PSP) and Solar Orbiter. Specifically, NSO will organize one workshop that includes the PSP instrument teams and ground-based solar astronomers to discuss ways of establishing connections between remote sensing observations and in-situ measurements. This workshop will occur at a US university. A second workshop will be to plan for coordinated Solar Orbiter and PSP encounters with DKIST operations and will take place at the European Space Agency Science Center in Villafranca (Madrid). A total budget of $73K (Table 10.2-2, CSP Activities) has been allocated to organizing these events.
2. Equipment and personnel moves to Boulder and Maui that have not occurred yet because of delays in the divestiture of the facilities and with the DSSC construction. The carry-forward budget includes $253K (Table 10.2-2, Recruit/Relo–Existing Positions, $106K and HQ Development & Relocation, $147K) for these pending transition activities.
3. An additional FTE for the IT Department totaling about $142K (Table 10.2-2, Boulder Computing IT). These FTEs are for the NSO website redesign and to prepare the NSO cybersecurity plan.
4. Additional science support, not related to the programs, at a similar level as in past years ($237K, Table 10.2-2, Science Staff-Research). The end-to-end GONG magnetograph calibration is part of this budget.
5. The EPO start-up package ($81K, Table 10.2-2, Education and Public Outreach).
6. SOLIS tower (KPVT) demolition ($499K, Table 10.2-2, SOLIS Tower Demolition).
7. $75K in support for the NISP Program (Table 10.2-2, NISP Operations Service).
8. Seed funding for the Compact Magnetograph (CMAG) project. The funds are split into $39K for payroll and $53K for travel and equipment (Table 10.2-2, CMAG). This activity has resulted in NSO leading a CMAG-type instrument as part of a mission proposal to NASA led by LASP/CU that, if selected, can constitute an additional funding revenue for NISP.

The Boulder Computing IT line (both new funds and carry forward) covers a minimal scientific support infrastructure. NSO plans to consolidate all IT efforts into a unified unit that will be a component of the new matrix structure of the Observatory. In this manner, IT efforts will have the flexibility to allocate resources and expertise more efficiently and will avoid existing duplications.

The NSO EPO Program under the Director's Office consists of two FTEs in Colorado and one in Hawaiʻi (NSF new funds). In FY 2019, the EPO team will finalize the NSO website redesign and will implement the plan for communications and outreach of the DKIST first-light initiative. 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 the 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.

The Director's Office carry forward is supporting AURA activities in Chile during the July 2019 total solar eclipse.

Table 10.2-2 Director's Office Carry Forward

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO HQ	**2.8**	**$312,261**	**$1,345,821**	**$1,658,083**	**$0**	**$1,658,083**
Director's Office			$97,795	$97,795		$97,795
AURA Corporate Direct Charges			$0	$0		$0
Solis Tower Demolition			$498,519	$498,519		$498,519
Post Retirement Benefits			$0	$0		$0
AURA Committees			$0	$0		$0
Business/Administration			$8,828	$8,828		$8,828
Recruit/Relo - New Positions			$0	$0		$0
Recruit/Relo - Existing Positions			$106,390	$106,390		$106,390
Carry Forward			$0	$0		$0
Insurance			$0	$0		$0
CU Recharge Fees			$0	$0		$0
Science Staff - Research	1.5	$139,615	$97,507	$237,122		$237,122
Research Assistants			$24,388	$24,388		$24,388
NSO Science-Collaborations			$26,598	$26,598		$26,598
NISP Operations Service			$75,151	$75,151		$75,151
DKIST Operations Service			$0	$0		$0
CSP Activities			$72,859	$72,859		$72,859
EPO - Scientists			$0	$0		$0
Joint CU/NSO			$0	$0		$0
Hale Post Doc			$47,876	$47,876		$47,876
HQ Operations			$0	$0		$0
Boulder Computing IT	1	$133,523	$8,532	$142,055		$142,055
Vehicles			$0	$0		$0
HQ Development & Relocation			$147,350	$147,350		$147,350
Instrument Development			$0	$0		$0
Education and Public Outreach			$80,981	$80,981		$80,981
CMAG	0.3	$39,123	$53,049	$92,172		$92,172
Total:	**2.8**	**$312,261**	**$1,345,821**	**$1,658,083**	**$0**	**$1,658,083**
Target:						**$1,658,547**
Variance:						**$464**

10.2.2 DKIST Operations Program

The DKIST Operations Program is under the direction of Thomas Rimmele as DKIST Associate Director. In FY 2019, the DKIST Operations Program, with 42 FTEs, is the largest operational program at NSO. Table 10.2-3 presents the new NSF funds for FY 2019 divided into work packages. The program's carry forward is shown in Table 10.2-4.

The DKIST scientific staff corresponds to personnel transferred from NSO programs in Sunspot and Tucson, and new hires in Boulder and Maui made over the last three years. Two scientists and several postdocs are based in Maui, where they interact with our instrument partners on the island. For operations, we have hired three observers who trained at the DST in Sunspot and are now Boulder-based. A new DKIST Chief Observer is already in Maui. New hires will occur in FY 2019 in all DKIST work packages. With the availability of the DSSC in Maui, the DKIST Program will ramp up the operations team on the island. New positions that the program will open in Boulder and Maui correspond to additional personnel for the Data Center and operations tools; technical staff for the next generation of instruments, including MCAO; and other scientific support staff, including graduate students and postdocs. The expected total number of positions will vary depending on support from the AURA/HR Department, but we intend to advertise fifteen positions in FY 2019. Some of the new hires for Maui might require training periods at the Boulder Headquarters.

Table 10.2-3 DKIST Operations Program Budget

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
DKIST Operations	**35.5**	**$5,116,103**	**$3,371,143**	**$8,487,246**	**$0**	**$8,487,246**
Operations Management			$0	$0		$0
Directorate	1.3	$285,932	$48,585	$334,518		$334,518
Business/Administration	0.9	$95,284	$22,612	$117,897		$117,897
Quality Control			$42,141	$42,141		$42,141
Carry Forward			$0	$0		$0
DKIST Science			$0	$0		$0
DKIST Science Staff - Research	6.8	$862,457	$484,578	$1,347,035		$1,347,035
Science - Operations Support Staff	2	$304,631	$211,413	$516,044		$516,044
Science - DKIST Maui Operations Service			$0	$0		$0
Science - DKIST Data Center Service			$0	$0		$0
Science- DKIST EPO			$29,827	$29,827		$29,827
Joint CU/NSO			$161,720	$161,720		$161,720
Science - Development (New Programs)			$0	$0		$0
Science- FL Data Center Development	0.8	$134,077	$37,635	$171,712		$171,712
Science - FL Ops Tools Development	0.6	$82,928	$5,299	$88,228		$88,228
Science - MCAO Development	1.5	$170,458	$104,547	$275,005		$275,005
Science - Next Generation Instruments			$0	$0		$0
Science - Data Center Enhancements	0.4	$49,738	$19,431	$69,169		$69,169
Facilities			$0	$0		$0
Facilities Maui			$0	$0		$0
DKIST Facility			$0	$0		$0
DKIST Facility Engineering			$0	$0		$0
DSSC Facility			$0	$0		$0
DSSC Engineering			$0	$0		$0
Facilities Boulder			$0	$0		$0
HQ expenses			$165,944	$165,944		$165,944
HQ Engineering			$0	$0		$0
Boulder Computing - IT	2	$282,208	$206,616	$488,825		$488,825
Data Center Ops			$0	$0		$0
Development (New Programs)			$0	$0		$0
First Light Data Center Development	10.6	$1,619,238	$1,314,224	$2,933,462		$2,933,462
Operations Development	2.7	$461,230	$303,871	$765,101		$765,101
FL Operations Tools Development	2.2	$346,003	$127,162	$473,165		$473,165
Operator Training	3.9	$421,917	$65,893	$487,810		$487,810
MCAO Development			$0	$0		$0
Next Generation Instruments			$0	$0		$0
Data Center Enhancements			$11,597	$11,597		$11,597
Ops Tools Enhancements			$8,048	$8,048		$8,048
DSSC - Development			$0	$0		$0
Total:	**35.5**	**$5,116,103**	**$3,371,143**	**$8,487,246**	**$0**	**$8,487,246**
Target:						**$8,474,444**
Variance:						**($12,802)**

Three work packages that will increase significantly in FY 2019 are Operations Development (NSF base, $765K, Table 10.2-3) and the Instrumentation Program (carry forward, $6.6M, Table 10.2-4, MCAO Development, $3,986K; and Next-Generation Instruments, $2,623K), which include the following activities:

1. *MCAO.* With the successful proof of concept of a fully functional MCAO setup at the Goode Solar Telescope by Schmidt et al., it is imperative that NSO continues the MCAO implementation for DKIST and makes this capability available as soon as practicable after the beginning of operations. The FY 2019 budget includes various full-time and part-time experts for MCAO development and the cost of the MCAO wavefront sensor. In total, we dedicate approximately $4.0M of FY 2019 funds to this critical augmentation of DKIST capabilities.
2. *Prominence AO.* Regular AO cannot work near the limb due to the lack of contrast of the solar structures observed there. Limb observations, however, are crucial to understanding critical magnetic structures such as spicules and prominences. To ensure diffraction-limited performance for limb observations, DKIST needs a specific limb (prominence) AO system for which a prototype was initially tested at the DST. The wavefront sensor for this system is different from those used in ordinary AO as, to increase the contrast, it uses a narrow-band channel typically centered in H-alpha. The budget for this limb wavefront sensor is $0.5M, excluding personnel (included in Table 10.2-4, Next Generation Instruments).
3. *IR instrumentation.* DKIST has five first-light instruments, two of which observe the IR part of the spectrum. Infrared-detector technology needs regular upgrades, and the program is planning to support enhanced capabilities at a level of $1.5M (included in Table 10.2-4, Next Generation Instruments).

As in FY 2018, all aspects of the Data Center are ramped up this year in Boulder. The Data Center continues with personnel hires, and there are plans to recruit additional personnel for Operational Tools development. The Data Center team will concentrate on finalizing the critical design review that will consolidate the scope definition and pave the way for equipment acquisitions expected later in the year ($0.5M, included in Table 10.2-3, First Light Data Center Development). Additional prototyping activities occur in FY 2019 with hardware acquisitions for code development with a cost of $231K (included in Table 10.2-3, First Light Data Center Development). Total Data Center payroll including operational tools development amounts to approximately $2M (Table 10.2-3, First Light Data Center Development, $1619K, and FL Operations Tools Development, $346K).

The CA proposal contained assumptions about the ramp up of personnel for operations in Maui and about Data Center hardware acquisitions that have not occurred. The DSSC construction delays have forced a slower recruitment pace. For the Data Center, the team has re-profiled the hardware expenditures to adjust to a highly dynamic market that forces all capital equipment acquisitions to a date as late as possible. These factors have generated a program carry forward of over $20M. This includes $8M of FY19 forward funding the NSF provided at the end of FY18. The effective carry forward is thus approximately $12M.

DKIST carry forward, thus, 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).

Table 10.2-4 DKIST Operations Program Carry Forward

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
DKIST Operations	**6.6**	**$829,630**	**$19,910,081**	**$20,739,711**	**$0**	**$20,739,711**
Operations Management			$0	$0		$0
Directorate			$26,305	$26,305		$26,305
Post Retirement Benefits			$175,862	$175,862		$175,862
Business/Administration			$0	$0		$0
Quality Control			$0	$0		$0
DKIST Science			$0	$0		$0
DKIST Science Staff - Research	1	$113,483	$7,252	$120,735		$120,735
Science - Operations Support Staff			$0	$0		$0
Science - DKIST Maui Operations Service			$0	$0		$0
Science - DKIST Data Center Service			$0	$0		$0
Science- DKIST EPO			$82,186	$82,186		$82,186
Joint CU/NSO			$0	$0		$0
Science- FL Data Center Development			$0	$0		$0
Science - FL Ops Tools Development			$0	$0		$0
Science - MCAO development			$0	$0		$0
Science - Next Generation Instruments			$0	$0		$0
Science - Data Center enhancements			$0	$0		$0
Facilities			$0	$0		$0
Facilities Maui			$0	$0		$0
DKIST Facility			$6,745,126	$6,745,126		$6,745,126
DKIST Facility Engineering			$6,301,598	$6,301,598		$6,301,598
DSSC Facility			$252,038	$252,038		$252,038
DSSC Engineering			$0	$0		$0
Facilities Boulder			$0	$0		$0
HQ Expenses			$0	$0		$0
HQ Engineering			$0	$0		$0
Boulder Computing - IT			$0	$0		$0
Data Center Ops			$0	$0		$0
Development (New Programs)			$0	$0		$0
First Light Data Center Development			$0	$0		$0
Operations Development			$0	$0		$0
FL Operations Tools Development			$0	$0		$0
Operator Training			$0	$0		$0
MCAO Development	2.5	$292,980	$3,692,825	$3,985,805		$3,985,805
Next Generation Instruments	3.1	$423,167	$2,200,267	$2,623,434		$2,623,434
Data Center Enhancements			$0	$0		$0
Ops Tools Enhancements			$0	$0		$0
Remote Office Building - Development			$426,623	$426,623		$426,623
Total:	6.6	$829,630	$19,910,081	$20,739,711	$0	$20,739,711
Target:						$20,732,921
Variance:						($6,790)

The DKIST project is in conversations with the NSF about reprofiling the significant carry-forward funds for the operational phase in the out years of the CA. In FY 2018, the staffing plan and estimates for non-payroll expenses for the steady-state operations phase was refined with the caveat that detailed bottom-up estimation of the summit technical operations effort, including maintenance, repairs, and upgrades, is still incomplete in some areas. Estimates for non-payroll expenses such as electricity also have been refined based on more realistic system information that is now available. With this information at hand, and after reprofiling the flow of new and carry-forward funds, the project has identified a shortfall of about $300K/year during the out years for DKIST operations. Anticipating this shortfall of operations funds in the out years, DKIST has taken a very conservative approach to the spending of operations ramp-up funds. 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.

Assuming no additional funding will be available, we consider the plan to reprofile the project's carry-forward budget now to cover the cost of the out years as the only viable option to operate DKIST, while staying only slightly above the overall ten-year CA budget. The details of the budget reprofile will be presented in the Long Range Plan the Observatory will prepare and submit for evaluation in FY 2019.

10.2.3 NSO Integrated Synoptic Program

The NISP combines staff from SOLIS and GONG under Frank Hill as Associate Director. Following the recommendation of the NSF/AST Portfolio Review Committee, the NSF base funding for NISP in FY 2019 continues at the $2M level (excluding indirect payments). In FY 2019, the total budget for the program is augmented by the NOAA contribution of $800K 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 the unused funds ($889K) are part of the program's FY 2019 carry-forward budget.

NISP faces considerable challenges in FY 2019. The continued application of merit increases over a three year period 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 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. Facing all these budget constraints, NISP needs to adopt exceptional measures in FY 2019.

The NISP budget breakdown for base funding, carry forward, and grant support is presented in Tables 10.2-5, 10.2-6, and 10.2-7, respectively. Currently, NISP has a total of approximately 20 FTEs. The NSF base funding covers approximately 9 FTEs, with approximately 7 FTEs partially grant supported, while approximately 4 FTEs are allocated to GONG refurbishment and SOLIS relocation activities. The NOAA funds for GONG operations, included in the grants table, support approximately 4 FTEs. The NISP total payroll in FY 2019 is $2.4M, with approximately 30% of these funds coming from grants, including the NOAA contribution. NISP has hired two engineers to cover aspects of the GONG refurbishment project and a fraction of the program attrition that occurred during the transition to Colorado.

NISP comprises an Atmospheric Section and an Interior Section, each led by a program 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 reduced daily by the NISP Data Center and added to the NSO Digital Library for downloading by the solar community. NISP base funding in FY 2019 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 (Table 10.2-5).

NISP carry-forward funds in FY 2019 (Table 10.2-6) total $1.35M, with $0.889M allocated for GONG refurbishment and $0.166M for SOLIS site work at BBSO. SOLIS relocation appeared in the FY 2018 budget, but updated costs are reflected in the FY 2019 budgets for base- and carry-forward funding.

Table 10.2-5 NSO Integrated Synoptic Program Budget

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	**9**	**$1,179,398**	**$1,017,828**	**$2,197,227**	**$0**	**$2,197,227**
NISP Directorate	1	$198,878	$16,155	$215,034		$215,034
NISP Administration	0.7	$60,768	$4,130	$64,898		$64,898
NISP Scientific Staff	3.4	$447,319	$33,755	$481,075		$481,075
NISP Engineering Ops			$1,336	$1,336		$1,336
SOLIS Ops/Supt	0.3	$21,387	$201,118	$222,505		$222,505
Boulder HQ Comp/IT Svcs	0.8	$73,588	$4,702	$78,291		$78,291
NISP Data Center	2.6	$322,048	$187,870	$509,917		$509,917
SOLIS Relocation	0.4	$55,409	$313,406	$368,815		$368,815
Post Retirement Benefits			$50,654	$50,654		$50,654
CU IT Connectivity Fees			$10,005	$10,005		$10,005
Unfunded liabilities			$9,046	$9,046		$9,046
CTIO Site Fee			$26,598	$26,598		$26,598
CU and Machine Shop Lease Fees			$159,053	$159,053		$159,053
Total:	**9.0**	**$1,179,398**	**$1,017,828**	**$2,197,227**	**$0**	**$2,197,227**
Target:						**$2,197,160**
Variance:						**($67)**

The main activities associated with the GONG refurbishment budget are:

- Improved zero-point stability of GONG magnetograms (new liquid crystal modulators).
- Characterization and tests of the MV1-D1024E-CL Photonfocus camera.
- Upgraded H-alpha filters to acquire Doppler shifts.

Table 10.2-6 NISP Carry Forward

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	**3.5**	**$406,921**	**$943,639**	**$1,350,560**	**$0**	**$1,350,560**
NISP Data Center			$295,071	$295,071		$295,071
GONG Refurbishment	2.1	$250,954	$638,601	$889,555		$889,555
SOLIS Relocation	1.4	$155,968	$9,966	$165,934		$165,934
Total:	**3.5**	**$406,921**	**$943,639**	**$1,350,560**	**$0**	**$1,350,560**
Target:						**$1,350,627**
Variance:						**$67**

Some of the new liquid crystal modulators already have been deployed to their respective sites. GONG refurbishment is expected to end in FY 2019 except for the H-alpha upgrades that suffered a delay due to the late acquisition of the tunable filters.

The $800K from NOAA/SWPC (Table 10.2-7, SWPC Packages) covers recurrent operational costs for the GONG network. Payroll includes technical maintenance, scientific validation, and Data Center costs (Table 10.2-7, SWPC Payroll), and totals $441K. The remaining $342K (Table 10.2-7, SWPC Packages, Non Staff Cost) is used to cover facilities costs at the six stations and the preventive maintenance trips to each site.

Table 10.2-7 also shows the various scientific grants obtained by the program.

Table 10.2-7 NISP Budget with External Funds

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	**7.1**	**$815,909**	**$449,865**	**$1,265,774**	**$0**	**$1,265,774**
SWPC Payroll	3.8	$441,399	$55,572	$496,971		$496,971
SWPC Learmonth (LE)			$46,107	$46,107		$46,107
SWPC Udaipur (UD)			$29,633	$29,633		$29,633
SWPC Tenerife (TD)			$31,652	$31,652		$31,652
SWPC CTIO (CT)			$13,349	$13,349		$13,349
SWPC Big Bear (BB)			$75,535	$75,535		$75,535
SWPC Mauna Loa (ML)			$64,474	$64,474		$64,474
SWPC Boulder			$3,795	$3,795		$3,795
SWPC Network			$21,685	$21,685		$21,685
Magnetic Data Driven (Pevtsov)	0.1	$9,075	$1,142	$10,217		$10,217
VSO (Hill)	0.5	$62,741	$7,899	$70,640		$70,640
An Unique Data Set (Kholikov)	0.2	$21,425	$2,697	$24,122		$24,122
Meridional Flow Measurements (Komm)	1.2	$140,456	$78,595	$219,051		$219,051
Subsurface Zonal & Meridional Flow (Komm)	0.2	$18,402	$2,317	$20,719		$20,719
HGIO18_2-0030 (Komm)	1.1	$122,411	$15,412	$137,823		$137,823
Total:	**7.1**	**$815,909**	**$449,865**	**$1,265,774**	**$0**	**$1,265,774**
Target:						**$1,265,774**
Variance:						**$0**

10.2.4 NSO Community Science Program (NCSP)

The NCSP is under the direction of Han Uitenbroek as Associate Director. Table 10.2-8 shows the budget breakdown for the program carry forward in FY 2019 that follows 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 will define 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. Data from the DST service mode (*https://www.nso.edu/telescopes/dunn-solar-telescope/dst-smo-2/*) is a rather unique, readily-available source, with observations of relevant spectral lines taken with instruments that bear similarities with those under construction for DKIST.

Table 10.2-8 NCSP Carry Forward						
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO Community Science Program	**9**	**$1,141,406**	**$2,353,241**	**$3,494,647**	**$0**	**$3,494,647**
Administrative Support	0.5	$50,781	$10,903	$61,684		$61,684
Science Support	3.4	$367,814	$661,623	$1,029,437		$1,029,437
Graduate Students Support			$977,573	$977,573		$977,573
Visitors Program-Short Term			$95,064	$95,064		$95,064
Visitors Program-Long Term	0.6	$80,773	$25,170	$105,944		$105,944
Service Support	2.3	$323,099	$20,646	$343,745		$343,745
Data Center Support	1.8	$268,058	$231,679	$499,737		$499,737
Headquarters Expeditures			$54,094	$54,094		$54,094
Data Training Workshop			$257,175	$257,175		$257,175
Curriculum Preparation	0.5	$50,881	$19,313	$70,194		$70,194
Total:	**9**	**$1,141,406**	**$2,353,241**	**$3,494,647**	**$0**	**$3,494,647**
Target:						**$3,495,032**
Variance:						**$385**

The DKIST Level-2 proposal included three interrelated initiatives: a data products initiative, a community-oriented initiative, and a university-oriented initiative. All three initiatives benefit from logistics and outreach support provided by the NSO.

The Data-Products Initiative represents an effort that occurs with NSO targeting 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 postdoc positions to develop the scientific pipelines for producing Level-2 data. NCSP is considering changes to this model to benefit from the existing expertise at NSO in the Level-2 area. Currently, the program includes a larger number of NSO scientists as part of this effort, and the number of new hires in the form of postdocs is smaller. The payroll service support from NSO scientists to NCSP totals $323K (Table 10.2-8, Service Support), whereas the research time is $368K (Table 10.2-8, Science Support) including two postdocs 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 production of the Level-2 data products. NCSP is performing a tradeoff study to identify a cost-effective model for the computational resources needed to generate Level-2 data products. Preliminary conversations with the CU Boulder Office of Information Technology indicates that the most optimal approach would be the use of their research computing facilities instead of an NSO managed and administered computer cluster. Including the travel for scientists, the cost of this work package is $1,029K. Data Center support for the DKIST Level-2 effort is split into payroll, $268K, and $231K for data-distribution hardware (Table 10.2-8, 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 $95K (Table 10.2-8, Visitors Program-Short Term), and a long-term visiting program (that includes stipends) with a budget of $106K (Table 10.2-8, 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 (Table 10.2-8, Graduate

Students Support) accounts for $977K of the total budget. This initiative includes an additional $257K (Table 10.2-8, Data Training Workshop) for broad community training in the creation of Level-2 data products and that builds on the successful series of DKIST Critical Science Plan Workshops.

NCSP is in conversations with the High Altitude Observatory to define the participation of their scientists in the three initiatives.

10.2.5 Sacramento Peak

In FY 2019, NSO will operate the Sunspot site and collaborate with the SSOC in the operations of the Dunn Solar Telescope. NSO plans to charge the SSOC approximately $150K for costs that include the DST Chief Observer and telescope utilities, following the guidelines in the MOU. It should be noted that the budget associated with this MOU is outside of the budget presented in this document and is not in WEBUD. For the regular site operations and maintenance, including the site manager, NSO will negotiate an SFR with the NSF.

At this point, the funds allocated to the Sunspot accounts correspond to the program's carry forward of $508K as shown in Table 10.2-9. 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 contracts.

Table 10.2-9 NSO Sacramento Peak Carry Forward

Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO SP	**0**	**$0**	**$508,252**	**$508,252**	**$0**	**$508,252**
Administrative Services			$0	$0		$0
Scientific Staff			$0	$0		$0
Telescope Operations			$0	$0		$0
Instrument Development and Telescope Maintenance			$0	$0		$0
Computing Support			$0	$0		$0
Facility Maintenance			$0	$0		$0
Housing			$0	$0		$0
Kitchen			$0	$0		$0
Visitor Center			$0	$0		$0
Sac Peak Carry Forward			$508,252	$508,252		$508,252
Total:	**0**	**$0**	**$508,252**	**$508,252**	**$0**	**$508,252**
Target:						**$507,939**
Variance:						**($313)**

10.2.6 AURA Fees, Fringe Benefit Rate, and Management Fee

Tables 10.2-10 and 10.2-11 show the expenses NSO incurs for AURA Facilities and Administrative (F&A) costs, Central Administrative Services (CAS), and Human Resources (HR) for FY 2019 NSF funds, and for the Observatory carry forward, respectively. Fringe and Indirect Rates were applied in accordance with the FY19 Indirect Cost Proposal submitted to NSF on October 11, 2018.

Table 10.2-10 AURA Fees (FY 2019 NSO Base Funds)	
Indirect Cost Type	Charge
AURA CAS & HR Support	$416,117
AURA Corporate F&A	$298,664
Total	**$714,781**

Table 10.2-11 AURA Fees (FY 2019 NSO Carry Forward)	
Indirect Cost Type	Charge
AURA CAS & HR Support	$548,588
AURA Corporate F&A	$393,745
Total	**$942,333**

A Management Fee of $69K, and the corresponding budget subtracted from the programs that make use of it: HQ, DKIST, and NISP, has been approved by the NSF

APPENDICES

APPENDIX A. NATIONAL SOLAR OBSERVATORY 2020–2025 VISION[1]

NSO will support and lead community research into the nature of the Sun by providing critical ground-based optical capabilities. The Sun is the archetypal astrophysical body, and we can exploit its proximity to explore fundamental processes not directly observable elsewhere in the Universe. Perhaps more importantly, the Sun is the source of the highly variable heliosphere in which the Earth and humanity reside. NSO's unique facilities will include the world's largest solar telescope and a network of full-Sun imaging magnetometers to continuously observe the Sun's structure and evolution. A resident scientific staff will support the development and exploitation of these facilities, support a diverse community of users, and point the way to mid-century frontiers.

The NSO 2020 – 2025 vision provides critical capabilities for solar research that address both fundamental science issues and vital societal imperatives enunciated in several decadal surveys – *New Worlds, New Horizons in Astronomy and Astrophysics*, and *The Sun to the Earth and Beyond* (and its successor *Solar and Space Physics Decadal Survey* to be released in Spring 2012) – as well as the recent NSF sponsored *Workshop on the Future of Ground-based Solar Physics.* The NSO science vision is focused on the basic question[1] of how the Sun creates and evolves its magnetic field: to understand the fundamental physics and its manifestations in other astrophysical settings, and how this violent activity impacts the solar system and Earth while also helping to shield humanity from dangerous galactic cosmic particles. The NSO vision of societal benefits and impacts centers on research leading to a predictive capability for variations of the Sun's radiative and eruptive outputs and planetary effects[2]. The NSO vision is founded upon community-based research objectives and requirements, and enables effective responses to new discoveries, synergistic research with planned and future space missions, and testing the results of advanced numerical models of solar phenomena.

To achieve this vision for the solar research community, NSO is replacing its 50+ year old facilities with major new observational capabilities. The range of observational capabilities that will be available in 2020 – 2025 includes world-leading high-resolution observations of the vector magnetic field, thermal and dynamic structure of the solar surface and atmosphere, and measurements of structure and dynamics of the solar interior, both for short-term and solar-cycle-long time periods. These capabilities will be provided by the high-resolution *Daniel K. Inouye Solar Telescope (DKIST)* (formerly the *Advanced Technology Solar Telescope* (ATST)) and moderate-resolution, nearly continuous ("synoptic") observations of the full solar disk through the *NSO Integrated Synoptic Program* (NISP).

NSO in 2020 and beyond will enable the community to:

1. Clearly resolve fundamental magnetic structure and processes in space and time, and achieve high photon flux for accurate, precise measurements of physical parameters throughout the solar atmosphere[4];

[1]See NSO 2012-2016 Long Range Plan for science goals (*http://www.nso.edu/reports*)
[2]NWNH, p. 64
[3] NWHH, pp. 29, 37,38, 60,61, 115
[4] NWHH, p. 64

2. Study the drivers and manifestations of the long-term, quasi-cyclic, inhomogeneous and intermittent solar magnetic fields and flows;
3. Resolve outstanding uncertainties in the abundance of atomic species;
4. Understand space weather and climate as they affect Earth, the solar system, and space assets today[5], and as a pathfinder for the study of exo-planet habitability;
5. Prepare the next diverse generation of solar researchers; and,
6. Carry out coordinated investigations with solar space-based missions using NSO's robust and adaptable capabilities.

To achieve this, the NSO will in priority order:

1. Operate and enhance the DKIST, currently under development; and
2. Operate and enhance the multi-site NISP.

To continue NSO's engagement in education and outreach NSO will[6]:

1. Conduct a vigorous training program for undergraduate, graduate, thesis students, and postdoctoral fellows;
2. Provide research experience and science training for middle school and high school teachers;
3. Conduct public outreach through its visitor center, tours, classroom talks and displays; and,
4. Increase its efforts to establishing a more diverse NSO staff and bringing underrepresented minorities into science and engineering in general.

Failure to build DKIST or a serious delay in its construction would create a significant gap in US solar astronomy. We would lose the capability to probe the physics of solar magnetic fields on spatial and temporal scales that are critical (according to both theory and observation) for understanding the energy balance of the Sun (and stars) and solar activity that impacts Earth. While space missions provide a complementary part of the required capability, a permanent space-borne 4m class telescope with the necessary functionality and flexibility is not affordable.

[5] NWNH, p. 29: Serving the Nation

[6] NWNH, Chapter 4

APPENDIX B. ORGANIZATIONAL PARTNERSHIPS

B1. Community Partnerships and NSO Leadership Role

Through its operation of the majority of US ground-based solar facilities and its ongoing synoptic programs, NSO is clearly important to the solar community. In turn, NSO must work closely with the solar community and provide leadership to strengthen solar research, renew solar facilities and to develop the next generation of solar instrumentation. Examples of NSO meeting this responsibility include the addition of rapid magnetograms and Hα images to GONG; development of solar adaptive optics and multi-conjugate adaptive optics for both NSO and university telescopes; development of infrared observing capabilities in collaboration with the University of Hawaiʻi, California State University-Northridge, New Jersey Institute of Technology and NASA; leading the development of SPINOR in collaboration with HAO, and participating in IBIS with Arcetri Observatory, and ROSA with Queen's University Belfast. Table C.1 lists ongoing joint projects and development efforts.

NSO will continue to work closely with the DKIST Science Working Group and the community to develop a sound operations plan for exploiting the full potential of the DKIST.

Table B.1. Joint Development Efforts

Telescope/Instrument/Project	Collaborators
Daniel K. Inouye Solar Telescope (DKIST)	HAO, U. Hawaiʻi, U. Chicago, NJIT, Montana State U., Princeton U., Harvard/Smithsonian CfA, UC-San Diego, UCLA, U. Colorado, NASA/GSFC, NASA/MSFC, Caltech, Michigan State U., U. Rochester, Stanford U., Lockheed-Martin, Southwest Research Institute, NorthWest Research Associates, Cal State Northridge
Adaptive Optics, Multi-Conjugate AO	NJIT, Kiepenheuer Institute, AFRL
Diffraction-Limited Spectro-Polarimeter ((DLSP)	HAO
Spectropolarimeter for Infrared and Optical Regions (SPINOR)	HAO
Rapid Oscillations in the Solar Atmosphere (ROSA) Instrument	Queen's University, Belfast
Narrowband Filters and Polarimeters	Arcetri Observatory, Kiepenheuer Institute
Synoptic Solar Measurements	USAF/AFRL, NASA, NorthWest Research Associates
IR Spectrograph and Cameras	U. Hawaiʻi, Cal State Northridge, NJIT
Advanced Image Slicer & Integral Field Unit	Cal State Northridge
Virtual Solar Observatory	NASA, Stanford, Georgia State, Harvard-SAO
H-alpha Imaging System (GONG)	NOAA, Air Force Weather Agency (AFWA)/AFRL

APPENDIX C. PUBLICATIONS

(OCTOBER 2017 THROUGH SEPTEMBER 2018)

Author—NSO Staff **Author**—REU
Author—Grad Student ***Author*** —Undergrad

The following is a list of known refereed papers, conference proceedings and non-refereed papers published during FY 2018 by NSO staff, as well as summer and academic-year graduate and undergraduate students. Papers resulting from the use of NSO facilities are also listed.

Refereed Publications

1. Abdelkawy, A. G. A., Shaltout, A. M. K., Beheary, M. M., "The Chromospheric Magnetic Field in Active Regions Derived from Spectropolarimetry of Ca II 8542", *GJAR*, eprint arXiv:1712.06828, 6 pp., 12/2017.

2. Abdelkawy, A. G. A., Shaltout, A. M. K., Beheary, M. M., **Schad, T. A.**, "Inference of Chromospheric Magnetic Fields in a Sunspot Derived from Spectropolarimetry of Ca II 8542 A", eprint arXiv:1712.06829, 12 pp., 12/2017.

3. Akasofu S.-I., "A New and Quantitative Prediction Scheme for Solar Flares", *JASTP* **174**, 66, 2018.

4. Aliev, A. Kh., Guseva, S. A., Tlatov, A. G., "Results of Spectral Corona Observations in Solar Activity Cycles 17-24", *Ge&Ae* **57**(7), 798-801, 12/2017.

5. Allred J., Daw A., Brosius J., "A 3D Model of AR 11726 Heated by Nanoflares", ArXiv e-prints, arXiv:1807.00763, 2018.

6. Alvarado-Gomez J. D., Drake J. J., Cohen O., Moschou S. P., Garraffo C., "Suppression of Coronal Mass Ejections in Active Stars by an Overlying Large-scale Magnetic Field: A Numerical Study", *ApJ* **862**, 93, 2018.

7. Amenomori M., Bi X. J., Chen D., Chen T. L., Chen W. Y., et al. (75 co-authors) and Tibet AS-gamma Collaboration, "Evaluation of the Interplanetary Magnetic Field Strength Using the Cosmic-Ray Shadow of the Sun", *PhRvL* **120**, 031101, 2018.

8. Amenomori M., Bi X. J., Chen D., Chen T. L., Chen W. Y., et al. (75 co-authors) and Tibet AS-gamma Collaboration, "Influence of Earth directed Coronal Mass Ejections on the Sun's Shadow Observed by the Tibet-III Air Shower Array", *ApJ* **860**, 13, 2018.

9. Amerstorfer T., Mostl C., Hess P., Temmer M., Mays M. L., Reiss M., Lowrance P., Bourdin P.-A., "Ensemble Prediction of a Halo Coronal Mass Ejection Using Heliospheric Imagers", ArXiv e-prints, arXiv:1712.00218, 12/2017.

10. **Anan, T.**, Yoneya, T., Ichimoto, K., Ueno, S., Shiota, D., Nozawa, S., Takasao, S., Kawate, T., "Measurement of Vector Magnetic Field in a Flare Kernel with a Spectropolarimetric Observation in He I 10830 Å", 08/2018, eprint arXiv:1808.06821.

11. **Anan,T.**, Huang, Y-W., Nakatani, Y., Ichimoto, K., UeNo, S., Kimura, G., Ninomiya, S., Okada, S., and Kaneda, N., "Developments of a Multi-wavelength Spectro-polarimeter on the Domeless Solar Telescope at Hida Observatory", *PASJ* Advance Access, 05/2018.

12. Appourchaux, T., Boumier, P., **Leibacher, J.W.**, Corbard, T. "Searching for g Modes. I. A New Calibration of the GOLF Instrument", *A&A* **617**: id.A108, 7 pp., 09/2018.

13. **Beck, C.**, Fabbian, D., Rezaei, R., Puschmann, K. G., "The Polarization Signature of Photospheric Magnetic Fields in 3D MHD Simulations and Observations at Disk Center", *ApJ* **942**(1): id.37, 11 pp., 2017.

14. **Beck, C.,** Rezaei, R., Choudhary, D. P., **Gosain, S., Tritschler, A.**, Louis, R. E., "High-resolution Observations of Hα Spectra with a Subtractive Double Pass", *SoPh* **293**(2): id.36, 24 pp., 02/2018.

15. Berdyugina, S. V., **Harrington, D. M.**, Kuzmychov, O., Kuhn, J. R., Hallinan, G., **Kowalski, A. F.**, Hawley, S. L., "First Detection of a Strong Magnetic Field on a Bursty Brown Dwarf: Puzzle Solved", *ApJ* **847**(1): id. 61, 13 pp., 2017.

16. Bilenko I. A., "Determination of the Coronal and Interplanetary Magnetic Field Strength and Radial Profiles from Large-Scale Photospheric Magnetic Fields.", *SoPh* **293**, 106, 2018.

17. Blanco Rodríguez, J., del Toro Iniesta, J.C., Orozco Suárez,D., **Martínez Pillet, V.**, Bonet, J. A., Feller, A., Hirzberger, J., Lagg, A., Piqueras, J., Gasent Blesa, J. L., "SOPHISM: An End-to-End Software Instrument Simulator", *ApJS* **237**(2): id.35, 17 pp., 08/2018.

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20. **Brandenburg, A.** and **Giampapa, M. S.,** "Enhanced Stellar Activity for Slow Antisolar Differential Rotation?", *ApJ* **855**(2): id.L22, 03/2018.

21. **Brandenburg, A.**, Bracco, A., Kahniashvili, T., Mandal, Sayan, Roper Pol, A., **Petrie, G. J. D.**, Singh, N. K., "E and B Polarizations from Inhomogeneous and Solar Surface Turbulence", *ApJ* eprint arXiv:1807.11457, 10 pp., 07/2018.

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34. **Cliver, E. W.** and D'Huys, E., "Size Distributions of Solar Proton Events and Their Associated Soft X-Ray Flares: Application of the Maximum Likelihood Estimator", *ApJ* **864**(1): id. 48, 11 pp., 09/2018.

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APPENDIX D. MILESTONES FY 2019

This section describes the major project milestones for FY 2019.

E1. Daniel K. Inouye Solar Telescope (DKIST)

- Deliver final Feed Optics to site. Scheduled for November 2018.
- Complete VBI Factory Acceptance Testing (FAT). Scheduled for November 2018.
- Complete all ground-disturbing activities at construction site. Scheduled for December 2018.
- Complete WFC Factory Acceptance Testing. Scheduled for December 2018.
- Deliver VBI to site. Scheduled for January 2019.
- Deliver upper and lower Gregorian Optical System (GOS) to site. Scheduled for February 2019.
- Install VBI on the Coudé Rotator. Scheduled for March 2019.
- Deliver Wavefront Correction System to site. Scheduled for March 2019.
- Install and align M1-M6. Scheduled for April 2019.
- Deliver ViSP to site. Scheduled for May 2019.
- Install WFC on the Coudé Rotator. Scheduled for June 2019.
- Deliver Cryo-NIRSP to site. Scheduled for August 2019.
- Achieve First Light. Scheduled for August 2019.

E2. DKIST Data Center Development

E2.1 Data Center Milestones (see Section 4.2.1.)

- Update Science/System Requirements.
- Update Simulator /Validator.
- Complete the Final Design Review.

- Q1- Alpha Release of Summit Data Reception and Ingest Pipeline.
- Q2 - Complete Data Center Final Design Review.
- Q2- Alpha Release of Science Data Processing Infrastructure.
- Q3 -Alpha Release of Data Discovery.
- Q3 - Alpha Release of Data Distribution.
- Q4 - Infrastructure Scaling Performance Analysis: 4th Quarter 2019.

E2.2 DKIST Instrument and Operations Tools Development (See Section 4.2.2.)

- Q3 – Alpha Release, Proposal Architect.
- Q4 – Alpha Release, Operations Planning and Management Tool.

E3. NISP/SOLIS

- Construct new SOLIS site at Big Bear Solar Observatory (BBSO).
- Recommission SOLIS and resume operations at new BBSO permanent site.
- Install Visible Tunable Filter in FDP.
- Complete removal of VXWorks from remaining SOLIS instruments.

E4. NISP/GONG

- Continue multi-year refurbishment of the GONG network.

E5. NISP Data Center (DC)

- Support the migration/adaptation of GONG's space weather data processing for production operation at NOAA/SWPC.
- Reprocess archival SOLIS/VSM 630.2 nm vector observations to homogeneously reflect data processing improvements.
- Improve SOLIS/VSM 854.2 nm line-of-sight data processing code to address known signal leakage issues near strong active regions.
- Document GONG magnetic zeropoint correction pipeline and evaluate it for potential improvements with respect to future and archival observations.

E6. NISP Compact Magnetoraph (CMAG)

- Develop prototype hardware for MagEX.
- Participate in SWRI SOLARIS mission proposal

E7. NISP Future Network Development

- Work with NSF to pursue new funding opportunities for SPRING.
- Respond to AFRL request for development of new US Air Force ground based solar observing system.

E8. Virtual Solar Observatory (VSO)

- Configure second SDO netDRMS system at NSO.
- Improve web user GUI interface.
- Incorporate new data sets/providers into the VSO.
- Maintain/support existing VSO data providers.

E9. NSO Community Science Program

- Finalize requirement document describing DKIST Level-2 data products produced by NCSP.
- Produce interface document with the Data Center for the retrieval of Level-1 data and the ingestion of Level-2 data products.
- Prototype generation of Level-2 data products using DST data.
- Select the cohort of graduate students and postdocs based in the US university system who will participate in the creation of higher-level data products as part of the DKIST CSP.
- Organize the first series of data-training workshops.
- Develop the web interface for NCSP community interaction as part of the Level-2 project

APPENDIX E. STATUS OF FY 2018 MILESTONES

This section describes the progress of current projects relative to the milestones established in the FY 2018 Program Plan. (FY 2018 milestones appear in italics below.)

F1. Daniel K. Inouye Solar Telescope (DKIST)

♦ Carryover

- *Mount Commissioning Complete (Scheduled for Feb. 2018).*

– Completed March 2018.

- *Coat Science M1 (Scheduled for Jan. 2018 due to resource contention for M1 Cell Assembly SAT).*

– Completed June 2018.

- *PA&C FDR (Scheduled for 1Q FY18; individual mini reviews have taken place to ensure long-lead procurements are in-hand).*

– Completed in various mini-reviews during 2018.

- *VBI Science Camera Integration Testing Complete (Scheduled for Jan. 2018 due to delays in Andor Balor camera delivery).*

– Completed in July 2018.

♦ *2018*

- *M1 Commissioning Blank coating.*

– Completed in February 2018.

- *M1 Cell Assembly Site Acceptance Test.*

– Completed in April 2018.

- *SIM 1: Telescope Pointing Map complete.*

– Expect this to occur in November/December 2018

- *SIM 2: M1 Integration complete.*

– Completed in June 2018.

F2. DKIST Data Center Development

F2.1 Data Center Milestones

♦ *Q1 FY18: Complete DKIST Data Simulator and Validator Toolkit.*

– Completed. A data simulator that creates data in accordance with SPEC-0122 Rev A–*DKIST Data Model*–was completed and tested and has been in use during the development of the DC data-ingest services. In addition, the validator toolkit was also completed and used to validate (or not) simulated data prior to ingest. Both toolkits are expected to undergo some revision as SPEC-0122 is expected to be revised.

- *Q2 FY18: Complete Data Center System and Subsystem Requirements.*

  – Completed/Ongoing. Version A of the system requirements, which were derived directly from the science requirements, were written and mapped to the science requirements.

  Subsequently, the system requirements were further decomposed into strategy and process diagrams, which were then used to drive development. In the process, clarifying changes to system and science requirements were proposed and are currently under review through the change-control process.

- *Q3 FY18: Complete Data Center Preliminary Design Review.*

  – Not Complete. Most of the design work in preparation for a review has been completed; however, due to unforeseen circumstances (project manager resignation), the work to complete documentation for what will be a Final Design Review (FDR)—mostly in the areas of budgeting, scheduling and acceptance and commissioning planning—were left in an incomplete state. It will take a few months for the new project manager to learn enough about the project to complete the preparation, and as the preparation will span the holiday-laden months of November and December, the review is to be held in Q2 (late January to mid February).

F2.2 DKIST Instrument and Operations Tools Development

- Q1 FY18: Complete Science Requirements.

  – Completed.

- *Q4 FY18: Alpha Release, Experiment Architect.*

  – Completed.

F3. NISP/SOLIS

- *Relocate SOLIS to Big Bear Solar Observatory.*

  – In Process. During the first quarter of FY18, SOLIS was taken offline in Tucson and prepared for shipment. Demolition of the Tucson site was completed and, after a brief period of storage, SOLIS arrived at Big Bear Solar Observatory in January 2018. Construction of the new site was bid out, and a company was selected. However, the latitude, environmental conditions, and regulatory considerations of the new location required more extensive design changes to the SOLIS shelter than previously appreciated. As a result, permitting has taken longer than expected and delayed the start of construction to FY19.

- *Recommission SOLIS at new permanent BBSO site.*

  – Deferred. The recommissioning schedule for SOLIS at BBSO was necessarily impacted by delays in site construction and largely deferred until FY19. At the end of FY18, work had begun to establish the computing environment necessary for subsequent instrument recommissioning. Additionally, network upgrades were underway to facilitate the operation of SOLIS at BBSO.

- *Install Visible Tunable Filter in FDP.*

  – Deferred. Installation of the Visible Tunable Filter was not possible in FY18 due to delays in recommissioning SOLIS and the need to establish normal operation of the FDP at BBSO prior to making modifications.

- *Complete removal of VXWorks from remaining SOLIS instruments.*

  – Deferred. Further progress decoupling VXWorks from the ISS was not possible in FY18 due to the prioritization of relocating SOLIS and subsequent delays in recommissioning it.

F4. NISP/GONG

- *Relocate GONG engineering site to Boulder.*

  – Completed. Following weather and construction delays, the foundations and turret piers were poured in December 2017. That same month, the alignment and installation of the instrument mounting hardware was carried out, and the two relocated engineering units were set into place in the final days of the first quarter of FY18. Site construction was completed early in the second quarter.

- *Recommission GONG engineering units in Boulder.*

  – Completed. The GONG engineering site began producing standard magnetic field measurements and H-alpha imagery in the second quarter of FY18. One of the two units was subsequently configured for prototype testing of the CMAG compact solar magnetograph. The engineering site was officially dedicated in a formal ceremony on August 15, 2018.

- *Continue multi-year refurbishment of the GONG network.*

  – In Process. Progress continues on the multi-year GONG refurbishment project, despite the schedule being necessarily impacted by parallel telescope relocations and the corresponding oversubscription of NISP's limited staff. The preventive maintenance kits, spares and additional supplies were deployed to the remote GONG sites. The replacement workstations were acquired and configuration is underway. The network bandwidth upgrade at the Learmonth site went into effect, increasing the bandwidth floor across the network to 4 Mbps. Replacement modulators have additionally been installed at the Big Bear and Learmonth sites. After the vendor for the H-alpha tunable filters fell through, a simpler system for acquiring H-alpha velocities was designed. A 14-bit version of the replacement camera from Photon Focus was acquired, and analysis of its linearity is underway.

F5. NISP Data Center (DC)

- *Repurpose former production hardware for reprocessing/R&D.*

  – Completed. A parallel computing environment for reprocessing, code development, and research purposes was brought online in phased deployment throughout FY18. Six servers and two disk arrays were retired from production operations in Tucson and relocated to Boulder in the first quarter. The servers were reconfigured with common home directories shared with an array of VMs dedicated to less resource intensive development work. The 240 TB (mirrored) of auxiliary data storage was populated over the course of several months with non-critical data that had been temporarily stored in the production environment during the relocation period.

- ♦ Support the migration/adaptation of GONG's space weather data processing for production operation at NOAA/SWPC.
  - In Process. Significant progress was made throughout FY18 in adapting the pipelines for operation at NOAA and developing corresponding builds of the code. However, continued projected delays associated with limited support availability in the original NOAA computing environment resulted in SWPC's decision to restart the effort in an alternate environment during the first quarter of FY19.
- ♦ *Implement upgraded backup tape system and protocols.*
  - Completed. Transcription to LTO6 using dual tape library robots began in FY18, and the writing of all archived raw data was finished by the final quarter. Regular backing up of new data is underway. A secondary off-site tape cabinet was established at NSO's Machine/Electronics Shop in nearby Gunbarrel, and a database with a web query tool was created.
- ♦ *Complete the automation of GONG VMBICAL processing.*
  - Completed. The development of the replacement data processing package, AutoVMBI, was a major initiative in FY18. Following extensive testing of downstream helioseismology results, production AutoVMBI processing began during the final quarter. The backlog of approximately eight months of GONG observations was subsequently processed through the non near-real-time "fully-calibrated" pipelines prior to the end of the fiscal year.
- ♦ *Reprocess archival SOLIS/VSM observations to homogeneously reflect data processing improvements.*
  - In Process. The reprocessing of SOLIS/VSM 630.2 nm vector observations was delayed by the need for further improvement to address newly discovered data processing issues related to the inversion of both spectral lines, the disambiguation of weak field pixels, and the replacement of a camera in the VSM. The corresponding reprocessing campaign commenced near the end of the final quarter of FY18.

F6. Virtual Solar Observatory (VSO)

- *Acquire and implement a second (failover) SDO netDRMS system at NSO.*
  - In Process. A second netDRMS server was specified, initially configured, and installed in the NISP Data Center racks; however, operational use is pending software development currently underway at the SDO Joint Science Operation Center (JSOC).
- ♦ *Incorporate new data sets/providers into the VSO.*
  - *Completed. Involvement of the VSO group at NSO included incorporating data products from the Improved Solar Observing Optical Network (ISOON).*
- ♦ *Maintain/support existing VSO data providers.*
  - *Completed. The VSO group at NSO was involved in facilitating improvements to the provision of data products from the High Altitude Observatory's (HAO) Mauna Loa Solar Observatory (MLSO).*

Additionally, the larger VSO group implemented new tools for monitoring the integrity of access to products from existing data providers.

- *Revamp web user interface.*
  – In Process. Development of improvements to the web interface has been underway within the larger VSO group, with some implementation anticipated in FY19.

F7. Divestment of the McMath-Pierce Solar Telescope Facility

– In March 2017, NSO released a Request for Proposals (RFP) for the McMP, with the intent of finding partners able to use the facility for research and educational purposes after our departure. NSO received one proposal that presented ideas for scientific, educational and outreach use of the McMP, but the proposal failed to identify the financial resources available to ensure that the proposed program could be implemented successfully. NSO therefore declined the proposal and informed the NSF that we have not found a suitable partner for McMP operations.

F8. Establish NSO Headquarters

- *Finalize establishment of the HQ IT program (e-mail servers, web servers, etc.).*
  – Completed. NSO moved most of the IT services under Google (e-mail) and CU Boulder (web services) management, providing robust access to our staff and stakeholders.
- *Continue developing basic infrastructure for scientific support.*
  – Completed. Scientific infrastructure continues to develop as part of the DKIST, NISP, and NCSP Programs.
- *Continue implementing the transition plan.*
  – Completed. NSO has finalized the transition from Tucson and Sunspot to the new HQ at CU Boulder.

APPENDIX F. NSO FY 2019 STAFFING SUMMARY

(In Full-Time Equivalents)

	Director's Office			NCSP	NSO	DKIST				NISP		TOTAL
	Tucson	*Boulder*	*Maui*	*Boulder*	*Sunspot*	*Tucson*	*Sunspot*	*Maui*	*Boulder*	*Tucson*	*Boulder*	
Scientists	-	1.00	-	3.00	-	-	-	6.00	10.00	-	8.00	28.00
Engineering/Science Support Staff	-	2.00	-	1.00	1.00	6.00	-	28.00	30.00	3.00	5.00	76.00
Administrative Staff	0.25	6.00	1.00	-	1.25	0.25	1.00	5.00	1.00	-	1.00	16.75
Technical Staff	-	-	-	-	-	-	-	19.00	3.00	-	3.00	25.00
Maintenance & Service Staff	-	-	-	-	2.00	-	-	10.00	-	-	-	12.00
												0.00
Total Base Program	***0.25***	***9.00***	***1.00***	***4.00***	***4.25***	***6.25***	***1.00***	***68.00***	***44.00***	***3.00***	***17.00***	***157.75***
Other NSF Projects (AO, FTS/CHEM)	-	-	-	-	-	-	-	-	-	-	-	0.00
Graduate Students	-	-	-	-	-	-	-	-	-	-	-	0.00
NASA Supported Science Staff	-	-	-	-	-	-	-	-	-	-	4.00	4.00
NASA Support Engineering Staff	-	-	-	-	-	-	-	-	-	-	-	0.00
NASA Supported Technical Staff	-	-	-	-	-	-	-	-	-	-	-	0.00
Emeritus Science Staff	3.00	1.00	-	-	1.00	-	-	-	1.00	-	-	6.00
Visiting Scientists	-	4.00	-	-	-	-	-	-	-	-	-	4.00
Total Other Support	***3.00***	***5.00***	***0.00***	***0.00***	***1.00***	***0.00***	***0.00***	***0.00***	***1.00***	***0.00***	***4.00***	***14.00***
Total Working at NSO	**3.25**	**14.00**	**1.00**	**4.00**	**5.25**	**6.25**	**1.00**	**68.00**	**45.00**	**3.00**	**21.00**	**171.75**
Scientists	-	-	-	-	-	-	-	1.00	1.00	-	-	2.00
Engineering/Science Support Staff	-	-	-	-	-	-	-	-	2.00	-	-	2.00
Administrative Staff	-	-	-	-	-	-	-	1.00	-	-	-	1.00
Technical Staff	-	-	-	-	-	-	-	1.00	-	-	-	1.00
Maintenance & Service Staff	-	-	-	-	-	-	-	1.00	-	-	-	1.00
Total Open Positions	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***4.00***	***3.00***	***0.00***	***0.00***	***7.00***
Total NSO FTEs	**3.25**	**14.00**	**1.00**	**4.00**	**5.25**	**6.25**	**1.00**	**72.00**	**48.00**	**3.00**	**21.00**	**178.75**
Percentage of Staffing by Program	**10.2%**			**2.2%**	**2.9%**	**71.2%**				**13.4%**		**100%**

APPENDIX G. SCIENTIFIC STAFF RESEARCH AND SERVICE

(*Grant-supported staff)

Tetsu Anan, Postdoctoral Research Associate

Areas of Interest

Solar chromospheric heating; high-energy non-thermal particles; integral-field-unit spectro-polarimetry.

Recent Research Results

T. Anan is developing an integral-field-unit spectro-polarimetry Diffraction-Limited Near-Infrared Spectropolarimeter (DL-NIRSP) as a DKIST facility instrument. He published a paper reporting developments of another multi-wavelength spectro-polarimeter, which allows us to obtain full Stokes spectra in multi-wavelength windows simultaneously (Anan et al. 2018, *PASJ*, tmp, 66A). He also published a paper on measurements of vector magnetic field in a flare kernel with a spectropolarimetric observation in infrared triplet lines of helium (He), and the estimation of lower cut-off energy of high-energy non-thermal electrons accelerated by the flare (Anan et al., 2018, *PASJ*, tmp, 113A).

Dr. Anan developed a method to make flat field of an integral-field-unit spectrometer, which is a prototype of the DL-NIRSP, and he is deriving shock heating rate per unit mass in umbral flashes from spectrometric data in the infrared triplet lines of He. Anan also observed a plage region with another integral field unit spectro-polarimeter of the GREGOR telescope to study Ohmic heating and Alfvénic turbulence heating in the region.

Future Research Plans

Dr. Anan will continue to develop the DL-NIRSP. He will analyze integral-field-unit spectro-polarimetric data to determine mechanisms by which the solar chromosphere is heated and to find laws in the heating process.

Service

Anan is a member of a Japanese space science mission for a solar telescope, in collaboration with the DKIST. He presented a talk about DKIST at a recent Japanese meeting.

Christian Beck, Associate Scientist

Areas of Interest

Post-focus instrumentation; data reduction pipelines; high-resolution spectroscopy and spectro-polarimetry of the photosphere and chromosphere; development of inversion tools for chromospheric spectral lines; polarimetric calibration techniques.

Recent Research Results

Dr. Beck, in collaboration with D. P. Choudhary (California State U.,Northridge (CSUN)) (*ApJ*, **859**, 139, 2018), published a paper on the inverse Evershed effect . The results of an ongoing investigation about polarization calibration of solar telescopes initiated by a 2015 REU project was published as well (*A&A*, **615**, 22, 2018). Collaboration with Queen's University Belfast resulted in two additional publications on umbral dynamics (*ApJ*, **860**, 28, 2018), and on Alfvén waves in the solar chromosphere (*NatPh*, **14**, 480, 2018). The paper on the successful realization of a subtractive double-pass imaging spectrometer at the Dunn Solar Telescope (DST) was also published (*SoPh*, **293**, 36, 2018).

Future Research Plans

With his full-time commitment to the Daniel K. Inouye Solar Telescope (DKIST) project, Dr. Beck's main focus for the near future will be on DKIST instrumentation and polarimetric calibration approaches. The collaboration with CSUN will continue, with studies of the physics of the inverse Evershed effect as the primary topic based on observational data acquired over the past few years at the DST. Work on the inversion code for solar ionized calcium lines will be focused on an application to full-disk spectra from SOLIS. A spectroscopic archive under the assumption of non-local thermodynamic equilibrium was developed during a 2018 REU project and is planned for application to observational data from different sources in the future. Initial results will be presented by the REU student at the Fall 2018 AGU meeting.

Service

C. Beck was a member of the DST time allocation committee through the end of NSO DST operations in October 2017. During the past year, Beck has reviewed publications for *The Astrophysical Journal* and *Astrophysics and Space Science*. C. Beck is a DKIST representative for the DKIST Critical Science Plan (CSP) workshops and specifically a point of contact for the DKIST Visible Spectro-Polarimeter (ViSP).

Luca Bertello, Scientist

Areas of Interest

Solar variability at different temporal, spectral, and spatial scales. Calibration of the observed solar magnetic field data to enhance the database that supports the analysis of conditions in the Sun's corona and heliosphere. Long-term synoptic observations in the resonance line of Ca II K for retrospective analyses of the solar magnetism on multi-decade time scales. Analysis of helioseimological data for better understanding the structure and dynamics of the solar interior.

Recent Research Results

Over the course of 2018, L. Bertello has been involved in several projects related to the improvement of the NISP data catalog. A major task he has undertaken with his collaborators is the revision of 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. By inverting both lines at the same time and including a better treatment for scattered light, determination of the vector magnetic field becomes more reliable, resulting in an improvement of the current Carrington synoptic maps derived from those measurements. Those maps are the main drivers for current coronal and heliospheric models and play a critical role for space weather predictions. Dr. Bertello has also developed an algorithm to merge longitudinal (line-of-sight) and full-Stokes photospheric measurements of the solar magnetic field. The basic idea behind this effort is to exploit the best properties from each of these two types of observations. By merging them into a full Carrington synoptic map, it is possible to create a composite map of the solar radial magnetic field that addresses some of the limitations found in previous approaches. Preliminary results indicate that this approach can indeed improve the diagnostic capability of coronal models.

Another project in which Bertello has been actively involved is the analysis of the Ca II K observations taken at the Kodaikanal Observatory since 1907, and at the Mount Wilson Observatory between 1915 and 1985. These 100,000+ observations (combined) constitute a unique data set for studies of solar activity over a time scale of up to a century. His major contribution to this project is the calibration of those observations into a consistent intensity scale and correcting those images for artifacts. This project is close to conclusion, and the findings will be presented at the February 2019 International Space Science Institute (ISSI) meeting in Bern.

L. Bertello's recent research results have been published in a series of papers and/or presented at various venues. In addition to the main projects described above, he has participated in studies related to the following topics: 1) solar-stellar connection for comparing solar activity to that of Sun-like stars; 2) photospheric activity of the Sun using data from the SOHO/VIRGO and SOHO/GOLF instruments and comparison with standard activity proxies; 3) analysis of the sunspot field strength measurements from the Mount Wilson drawings spanning more than 110 years of solar cycle of activity. From the same database, a first paper has been submitted for publication which describes the tilt's behavior of sunspot dipoles in solar Cycles 15 to 24.

Future Research Plans

The main focus of Dr. Bertello's future research is on improving the quality of current SOLIS/VSM longitudinal and vector magnetic field observations, and to enhance the capabilities of the SOLIS/ISS instrument. He is also involved in the analysis of chromospheric data from the full-Stokes 8542 modulator which was added to the VSM instrument in late 2015. One of his major goals for 2019 is the reconstruction of the solar and heliospheric magnetic field evolution over the past century using the Ca II K observations described above as a proxy for the magnetic field. Bertello maintains strong collaborations with several national and international institutes. This synergy has grown consistently over the years and has opened several new research channels.

Service

As the Data Scientist for SOLIS, L. Bertello's major responsibility is to provide the solar and heliophysics community with high-quality and reliable data. During 2018 he has reviewed several publications for *Solar Physics* and other journals, and served on a NSF proposal review panel.

Serena Criscuoli, Associate Astronomer

Areas of Interest

High-spatial resolution spectroscopy and spectropolarimetry of the photosphere and chromosphere; radiative transfer; numerical simulations; solar irradiance variations.

Recent Research Results

Dr. Criscuoli recently worked on topics in the framework of the 'Areas of Interests' mentioned above. She investigated the different radiative properties of magnetic elements when observed in network and facular regions, and the impact of such differences on estimates of Total Solar Irradiance variations measured during the solar cycle. She also investigated the effects on spatial resolution induced by numerical diffusion when employing numerical radiative transfer codes making use of the short-characteristic technique. If not properly taken into account, such effects may be larger than the spatial resolution that we expect to achieve with the DKIST, and can therefore potentially hinder a correct interpretation of future DKIST observations. She was author and coauthor of of various papers published in peer reviewed journals, including a review about stellar and solar magnetism.

Service

Dr. Criscuoli is a scientific consultant for the DKIST while still partially supporting the use of data acquired with at the Dunn Solar telescope. She was a referee for scientific journals. She also supervised undergraduate students and was member of the committee for the evaluation of a PhD thesis at the University of Colorado, Boulder.

Alisdair Davey, Associate Scientist

Areas of Interest

CMEs and associated phenomena such as EUV waves and Dimming Regions. The acceleration and heliospheric propagation of SEPs during solar flares and CMEs. The use of computer vision/AI in identifying solar features and events. Development of the Virtual Solar Observatory (VSO), and the heliospheric data environment, including integration of data and modeling efforts.

Recent Research Results

Dr. Davey and colleagues presented a framework for the coronal analysis of shocks and waves (CASHeW). It combined analysis of NASA Heliophysics System Observatory data products and relevant data-driven models, into an automated system for the characterization of off-limb coronal waves and shocks and the evaluation of their capability to accelerate solar energetic particles (SEPs). With this framework, Davey and colleagueshope to contribute to the overall understanding of coronal shock waves, their importance for energetic particle acceleration, as well as to the better ability to forecast SEP events fluxes. This work was published in *the Journal of Space Weather and Space Climate*.

Service

Dr. Davey worked on a number of topics for the VSO including bringing new data sets online for the solar physics community. He also maintains the Solar Physics E-print Archive and is the web master for the AAS Solar Physics Division. In 2018, he was a referee for a number of scientific journals. He was an invited speaker at EarthCube RCN: Towards Integration of Heliophysics Data, Modeling, and Analysis Tools.

Gabriel Dima, Postdoctoral Research Associate

Areas of Interest

Coronal magnetic field measurements; polarimetry; infrared emission line diagnostics.

Recent Research Results

G. Dima published polarimetric observations of several coronal infrared lines taken during the 2006 eclipse (Dima et al., *ApJ*, 2018). He also finished analyzing coronal polarimetric observations of the SiX 1430 nm and Fe XIII 1075 nm lines and is preparing the results for publication.

Future Research Plans

Dr. Dima plans to study the feasibility of using simultaneous full Stokes measurements of two bright coronal lines from different ions to determine the coronal magnetic field and estimate sensitivity of the choice of lines on the resulting magnetic field.

Service

G. Dima has participated as a judge in two science fairs on Maui and traveled to the island of Lanaʻi to participate in Career day at the local middle school.

Andre Fehlmann, Assistant Scientist

Areas of Interest

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

Recent Research Results

A. Fehlmann assembled and aligned the Cryogenic Near-Infrared Spectropolarimeter (CryoNIRSP), a DKIST first-generation facility instrument. He implemented and tested a new infrared camera system for CryoNIRSP. Fehlmann is also involved in optimizing the polarization calibration plan for DKIST.

Future Research Plans

Dr. Fehlmann will help refining and implementing the DKIST calibration plan and integrate and commission the facility instruments on the telescope. He is looking into maintaining and improving infrared camera systems for the facility. As a participant of the coronal science working group, he will be involved in developing a critical science plan for early DKIST observations.

Service
Fehlmann is a member of the DKIST science team and infrared instrumentation specialist for DKIST facility instruments. The development of an instrument performance calculator helps the community to plan observations with CryoNIRSP.

Sanjay Gosain, Associate Scientist

Areas of Interest
Astronomical instrumentation: optical design of instruments for polarimetry and spectroscopy. Solar Physics: flares, eruptive filaments and coronal mass ejections; chromospheric magnetic field of solar active regions; solar cycle evolution of magnetic field.

Recent Research Results:
Developing optical design and prototype of a GONG-type Compact MAGnetograph (CMAG): Recently, there has been a lot of interest in making solar velocity and magnetic field measurements from new vantage points, i.e., away from the Sun-Earth line, from space, such as from out of the ecliptic plane and/or from Lagrange L5 orbit. Such missions require a compact instrument design that has low mass and requires low power to operate. The CMAG concept was developed as part of an NSO-LASP collaboration, and the basic idea is to make a compact GONG-type system for observing from space. S. Gosain was heavily involved in developing the concept and optical design of CMAG. Further, using the GONG-site at CU Boulder, he demonstrated that the idea of CMAG was feasible. A NASA proposal was developed together with LASP, to fly CMAG to L5 orbit, among other instruments that complement CMAG. Currently, Gosain is testing a CMAG prototype at the GONG site in Boulder.

3-D thermal structure of solar chromosphere using NLTE archive: In collaboration with C. Beck of NSO and Chantelle Kiessner, an REU student from the Univeristy of Hawaiʻi, S. Gosain worked on spectral inversion of Ca II infrared 854 nm lines to infer 3D thermal structure in quiet solar chromosphere. An archive of synthetic spectral profiles, computed using the non-local thermodynamic equilibrium (NLTE) radiative transfer code NICOLE, was generated and observations were compared with best matching profiles in the archive and a corresponding model atmosphere was selected as the best fit result. Initial results will be presented at an AGU meeting and full results are under preparation for submission to a refereed journal.

Other activities:

- GONG refurbishment activities included a detailed survey of commercial off-the-shelf CCD and CMOS cameras for GONG camera replacement. Some candidate cameras were procured and are being evaluated.
- Designed a tunable H-alpha filter concept using air-gap Fabry-Perot etalon; however, after Lunt Solar Systems denied supplying low-cost pressure-tunable etalons, the project it is no longer financially feasible.
- The idea of tilt-tuning the existing GONG mica etalon was evaluated and was found to be sufficient for detecting large velocities associated with eruptive filaments. This approach is currently being implemented.

Publications: "Design of a Next Generation Synoptic Solar Observing Network: Solar Research Integrated Network Group (SPRING)": **Gosain, S.**, et al., in *Proc*. SPIE, **10702**, id.107024H, 2018.

Future Research Plans & Service
Dr. Gosain plans to: a) complete the upgrade of the GONG H-alpha tunable Doppler imaging system; b) participate in the commissioning of SOLIS instruments at Big Bear, CA; c) complete the CMAG prototype; and d) participate in NCSP activities for DKIST Level-2 data products.

David M. Harrington, Associate Scientist

Areas of Interest

Instrumentation; spectropolarimetry, adaptive optics, novel optical systems, detector systems, applied research, community workforce development.

Recent Research Results

Dr. Harrington has been developing polarization system performance models, optical system models and calibration algorithms for large telescopes. He has also been working on the design and fabrication of a high precision lab spectropolarimeter for full Mueller matrix characterization of optics in the visible and near-IR. Other activities include: daytime sky polarization calibration technique development for large telescopes (AEOS, Keck, Dunn Solar Telescope); and data reduction and analysis pipelines for polarimetric instrumentation (HiVIS & InnoPOL on AEOS, LRISp on Keck, curvature adaptive optics and EMCCD imaging polarimeters).

Future Research Plans

Dr. Harrington is actively developing new techniques to calibrate, model and improve the polarimetric performance of astronomical telescopes and instruments. New lab equipment and methods are in development for characterizing and modeling large polarimetric optics. Software modeling improvements and new mathematical techniques will advance the state-of-the-art for calibration precision and accuracy. Applying new interdisciplinary techniques both from theory and components will keep DKIST on the cutting edge of technology. With DKIST first-light instruments and novel data sets, a wide range of science cases for a diverse community will be impacted by system improvements.

Service

Harrington is an active member of the DKIST Science Group and is the DKIST polarimetry scientist working with the Polarimetry Analysis & Calibration team to integrate and calibrate the first-light instrument suite. The DKIST user community is being engaged and educated in anticipation of the new DKIST polarimetric capabilities. Harrington is an active participant in the Akamai Workforce Initiative, which involves working with industry and academic partners, mentoring Hawai‘i-connected local interns for summer and year-long projects and facilitating connections between industry and various STEM-focused educational programs.

Frank Hill, Senior Scientist

Areas of Interest

Helioseismology; asteroseismology; fluid dynamics of the solar convection zone; the solar activity cycle; virtual observatories; solar magnetic fields; space weather.

Recent Research Results

Dr. Hill continues to perform research in helioseismology. Working with R. Howe and R. Komm, Hill continues to track the progress of the east-west zonal flow and the north-south meridional flow in the solar interior as they evolve over the solar cycle. Recent data through 2017 still indicate that the poleward zonal flow for Cycle 25 is weak and intermittent, but a similarly weak equatorward flow can now be seen, suggesting that Cycle 25 could start as soon as 2019.

Hill has worked with K. Jain, and S. Tripathy, comparing the solar acoustic radius with the total solar irradiance (TSI). They find that the solar irradiance increases with decreasing seismic radius; however, the anti-correlation between them is moderately weak and the TSI variations cannot be fully explained by the temporal changes in seismic radius. Hill is also working with C. Lindsey (NWRA) and others on improvements to the helioseismic far-side maps, with the goal of using them to improve the AFRL ADAPT magnetic field, F10.7 flux, and EUV flux forecasts.

Future Research Plans

In addition to continuing studies of the evolution of large-scale cycle-related flows, Hill plans to work with T. Monsue and D. Pesnell (NASA GSFC) on applying power map movies to GONG and SDO data to study the dynamics of the chromosphere in flaring regions. He will also work on the evaluation of the impact of composite longitudinal/vector magnetic field synoptic maps on space weather forecasts.

Service

Hill is the Associate Director for the NSO Integrated Synoptic Program (NISP), which combines SOLIS and GONG. He continues to participate in the development of the Virtual Solar Observatory. Hill typically supervises several staff, currently eight scientists, one Administrative Assistant, and two managers. He arranged annual operational support for GONG from the NOAA Space Weather Prediction Center (SWPC), was responsible for an NSF supplement to refurbish GONG, and is coordinating the relocation of the SOLIS instrument. Hill participates in about four proposals a year for outside funding. He typically reviews ten proposals annually for the NSF and NASA, as well as five papers for *ApJ*, *Solar Physics*, etc. He serves on the scientific organizing committee for international scientific meetings and is a member of the European HELAS Board. He is currently leading the development of SPRING, a new network to obtain multi-wavelength observations for helioseismology, solar magnetometry, and space weather. He is also participating in the development of CMAG for MagEX and SOLARIS.

Sarah A. Jaeggli, Assistant Astronomer

Areas of Interest

The 3-dimensional structure of sunspot magnetic fields; atomic and molecular physics of the photosphere and chromosphere; radiative transfer modeling and spectral synthesis; instrumentation for spectroscopy and spectropolarimetry, including DKIST facility instrument development; engaging the community to perform multi-facility observations.

Recent Research Results

In 2018, Dr. Jaeggli published results from research conducted with P. Judge (NCAR/HAO) and A. Daw (NASA/GSFC) on the formation of ultraviolet molecular hydrogen emission lines in the Sun's atmosphere. These modeling results lay the groundwork for further analysis of molecular hydrogen lines that have been observed with the Interface Region Imaging Spectrograph (IRIS), both during flares and in quiet regions, and observational results will soon be released in a second publication. Dr. Jaeggli continues to collaborate with the IRIS team and made significant contributions to the instrument calibration paper published this year. She has also been working closely with B. Snow (U. Sheffield) in order to simulate DL-NIRSP observations of the dynamic solar corona, which is now published.

Future Research Plans

Dr. Jaeggli is currently collaborating with A. Kobelski, L. Tarr, and S. Savage on a multi-observatory dataset obtained during a joint campaign with the Dunn Solar Telescope. This massively multi-instrument dataset covers a fairly boring, but typical, region of the Sun and will be used to understand energy transfer from the photosphere to the corona at many wavelengths. A proposal for conducting this research was selected for funding under NASA's Heliophysics Supporting Research program and will provide 1/4 FTE for Dr. Jaeggli. She is also continuing research on delta-type sunspots in a study led by X. Sun, looking at what spectropolarimetric observations from *Hinode* can reveal about the magnetic topology of these complex regions, and how that connectivity of the magnetic field in the delta-sunspot changes as the active region evolves.

Service

Dr. Jaeggli is supporting the DKIST project, acting as instrument scientist on the DL-NIRSP team, and as a member of the polarization calibration team. As a DKIST scientist, she supported three critical science planning workshops conducted during 2018.

Kiran Jain, Associate Scientist

Areas of Interest

Helioseismology – oscillation mode characteristics, multi-wavelength helioseismology, subsurface dynamics, active regions, solar activity, Sun-Earth connection.

Recent Research Results

Jain and collaborators explored the relationship between the solar seismic radius and total solar irradiance (TSI) during the last two solar cycles using the uninterrupted data from space-borne instruments on board SoHO and SDO. The seismic radius is calculated from the fundamental modes of solar oscillations utilizing observations from SoHO/MDI and SDO/HMI, and the TSI measurements are obtained from SoHO/VIRGO. Their study suggests that major contribution to the TSI variation arises from the changes in magnetic field, while the radius variation plays a secondary role. It is found that the solar irradiance increases with decreasing seismic radius; however, the anti-correlation between them is moderately weak. The estimated maximum change in seismic radius during a solar cycle is about 5 km, and is consistent in both solar Cycles 23 and 24. Previous studies suggest a radius change at the surface of the order of 0.06 arcsec to explain the 0.1% variation in the TSI values during the solar cycle; however, their inferred seismic radius change is significantly smaller, hence the TSI variations cannot be fully explained by the temporal changes in seismic radius.

Jain and collaborators also investigated temporal changes occurring beneath the solar surface using simultaneous observations from spare-borne instruments GOLF and VIRGO, and ground-based networks BiSON and GONG. Although the oscillation mode frequencies from all observations are found to vary in phase with the solar activity, the minimum sensed by the modes confined to the convection zone happened around the same time as in the solar activity indicators while the modes that travel to the core sensed minimum about a year earlier. In addition, the analysis based on the modes with lower turning point in the core (low-degree modes) indicates that the magnetic layer of the Sun is changing gradually and has become thinner in the last two solar cycles; however, an analysis with modes in intermediate-degree range do not support these findings. Thus, these results hint toward a complex relationship between different layers in the solar interior and the surface magnetic activity.

In order to investigate the links between subsurface properties with eruptive- and confined-flaring regions, Jain and collaborators also studied the subsurface flows in several active regions in Cycle 24. While the flows in all flaring regions are strongly modified, no further subsurface characteristics are found that may isolate eruptive or non-eruptive nature of the flaring regions.

Future Research Plans

Dr. Jain will study the variability in acoustic mode parameters with the changing level of magnetic activity in order to improve the understanding of their complex relationship. In particular, she plans to explore the quasi-biennial periodicity in oscillation frequencies in different layers of the solar interior and different phases of the solar cycle. This will allow us to understand the physical mechanism responsible for various periodicities observed in oscillation data.

Jain will also continue to work on the Solar Rotation Project. This project brings together helioseismologists from all over world to derive a unique reference solar rotation profile by utilizing un-interrupted observations from various instruments for more than two cycles, and by employing various mode fitting and inversion methods.

Jain will further continue to work on multi-spectral data to obtain a better picture of the excitation and damping mechanisms of solar oscillations and to study the effect of inclined magnetic field on active regions to probe the characteristics of seismic waves propagating in layers above and below the solar surface.

As active regions are the main drivers of space weather, Jain will continue to study the subsurface weather in order to explore precursors of the emergence of such regions and their eruptions.

Service

Dr. Jain continues to serve as a member of the NSO Scientific Personnel Committee. She also served as the internal reviewer for research papers submitted to peer-reviewed journals. She further tested and verified various helioseismology data-reduction pipelines during their migration to NSO's Boulder location, and regularly monitors the quality of the data products. In addition, Jain developed solar interior science and data products webpages for the new NSO website. She also hosts regular meetings for the International Solar Rotation Project.

Maria Kazachenko, Assistant Scientist

Areas of Interest

Inversion techniques to derive the electric fields and Poynting fluxes on the surface of the Sun using magnetic field measurements; data-driven simulations of the solar coronal magnetic fields; statistical properties of solar flares.

Recent Research Results

In 2018, Dr. Kazachenko continued working on the "Areas-of-Interest" topics as detailed below. Dr. Kazachenko has been collaborating with Dr. George Fisher and the members of the Coronal Global Evolutionary Model (CGEM) on the details of the electric-field inversions on the staggered grid and writing a manuscript describing this work. Together with her student Erkka Lumme, Dr. Kazachenko has analyzed the effect of the temporal and spatial resolution on the electric fields inversions—the results of this work have been presented at the Data-driven Workshop in Boulder, CO and the AGU meeting in DC. Together with Dr. Steve Kahler and Dr. Ed Cliver, Dr. Kazachenko has analyzed the relationship between reconnection fluxes in the flares and SEP/gamma-ray events. Together with Dr. Benjamin Lynch, Dr. Kazachenko has worked on analyzing the properties of the superflare and Carrington-scale coronal mass ejection from the Young Sun using MHD simulations. Together with Dr. Bill Abbett and Dr. Dave Bercik Dr. Kazachenko has been working on the techniques to drive the RADMHD simulations of active region 11158 using the electric fields in the photosphere. To present the results of this work Dr. Kazachenko 1) gave five invited and one contributed talks including a plenary talk at the Solar Dynamics Observatory Science Workshop in Ghent, Belgium; 2) submitted five manuscripts as a primary- and a co-author, three of which have been accepted by the Astrophysical Journal. In 2018 Dr. Kazachenko submitted 8 proposals to NASA and NSF (3 as a PI and 5 as a co-I): four proposals have been selected for funding and four proposals are still under review.

Service

In 2018, Dr. Kazachenko was elected and served as a member of the Solar Physics Division Committee. She also joined and served as a member the Daniel K. Inouye Solar Telescope (DKIST) Science Working group. Together with Dr. Matthias Rempel and Dr. Yuhong Fan, Dr. Kazachenko co-organized an international Data-driving Workshop in Boulder, CO and co-organized three science sessions at SHINE workshop, FL and the AGU meeting, LA. In addition, Dr. Kazachenko participated in three workshops to develop two science use cases (SUCs) for the DKIST. In 2018 she continued mentoring a graduate student at the University of Helsinki Erkka Lumme. She also continued to serve as a referee for scientific journals (Astrophysical Journal, Nature Communications) and NASA and NSF funding proposals.

*Shukirjon S. Kholikov, Associate Scientist

Areas of Interest

Helioseismology; data analysis techniques; time-distance methods.

Recent Research Results

Shukur Kholikov works primarily on time-distance applications using GONG++ data. He has developed a time-distance pipeline, which provides travel-time maps of daily GONG-network data and produces reconstructed images with specified filters. At present, the pipeline has been tested to produce several types of specific travel-time measurements to probe the deep layers of the Sun.

The main focus of the pipeline is deep meridional flow measurements. Meridional flow measurements were obtained by using GONG/MDI/HMI spherical harmonic (SH) time series for using travel-time differences from velocity images reconstructed from SH coefficients after applying phase-velocity and low-L-filters. This particular approach is the key tool for extending the local time distance applications to the deep convection zone diagnostic analysis. The depth profile of meridional flow obtained using the above described pipeline shows a distinct and significant change in the nature of the time differences at the bottom of the convection zone. Travel-time measurements are affected by center-to-limb (CTL) variations across the solar disk. Corrections of this artifact on meridional flow measurements revealed an evidence of return flow at ~60 Mm depth of the solar interior. Using several years of GONG data, detailed meridional flow profiles of both poleward and equatorward components were obtained. Initial inversions of measured meridional travel-time differences showed single-cell structure of the meridional flow in both depth and latitude. Recently, new inversions based on spherical Born kernels including lower thresholds for singular value decomposition were applied to the same dataset. In this case, refined results exhibit a multi-cell structure in depth. It should be noted that the magnitude of the meridional flow, circulation profile and its topology strongly depend on CTL—in particular, return component of flow is not possible to measure without an understanding of CTL origin and removing this artifact from measured time differences. Kholikov is working on new ways of obtaining and removing CTL systematics and explaining its nature.

At present, Dr. Kholikov is working on comparative analysis of the deep meridional flow between HMI and GONG projects.

Another important research focus of Kholikov's is a new estimation of solar-core rotation. Based on multi-skip time-distance approach, acoustic time shifts due to internal solar rotation can be measured up to R=0.05, while rotation profile from global helioseismic inversions provide acceptable results only up to R=0.3. This project requires involving low-degree acoustic modes into multi-skip time-distance and using as many portions as possible of the solar disk from all available observations (GONG, MDI, HMI).

Future Research Plans

Dr. Kholikov will continue to improve the time-distance pipeline and provide the scientific community with specific GONG/HMI data for local helioseismology analysis. The main focus will be the deep equatorward return-flow measurements and its temporal variations involving GONG, MDI and HMI data series. He will incorporate HMI time series with extended solar disk usage to produce a new set of measurements of solar-core rotation.

Service
Dr. Kholikov will monitor the quality of available local helioseismic data products provided by NISP. He also provides time-distance measurements and high-degree SH time series of GONG data upon request.

Rudolf W. Komm, Associate Scientist

Areas of Interest
Helioseismology; dynamics of the solar convection zone; solar activity and variability.

Recent Research Results
Dr. Komm continues to perform research in helioseismology. He is deriving solar sub-surface fluid dynamics descriptors from GONG data analyzed with a ring-diagram. Using these descriptors, he was able to derive, for example, the divergence and vorticity of solar sub-surface flows and study their relationship with magnetic activity. Komm is exploring the relationship between the twist of subsurface flows and the flare production of active regions and, in collaboration with S. Gosain, he started exploring the relationship between flare-activity, helicity, and lifetime of long-lived activity complexes. Komm is studying the solar-cycle variation of the zonal and the meridional flow in the near-surface layers of the solar convection zone, in collaboration with F. Hill, and R. Howe. He has focused on the variation of the flows during solar Cycles 23 and 24.

Future Research Plans
Dr. Komm will continue to explore the dynamics of near-surface layers and the interaction between magnetic flux and flows derived from ring-diagram data, and will focus on the relationship between subsurface flow characteristics and flare activity in active regions and long-lived activity complexes. He will continue to explore the long-term variation of subsurface flows, focusing on the differences between regions of high and low magnetic activity and, in collaboration with M. Dikpati (HAO). explore the influence of the meridional flow on dynamo models.

Service
R. Komm has improved a correction for systematic effects present in subsurface flow data and is working on turning the corrected subsurface flows into a data product. He also works on creating a data product from the measured helicity of the corrected subsurface flows. He works on creating daily and synoptic maps of these corrected fluid-dynamics descriptors.

Adam Kowalski, Assistant Astronomer

Areas of Interest
Flare observations and radiative-hydrodynamic modeling; white-light flare radiation and continuum properties; connection between magnetic activity and flares on the Sun and younger M dwarf stars; models of broadening in hydrogen emission lines that will be observed by the DKIST during flares; teaching the physics of stellar atmosphere modeling and observational astronomy and spectroscopic analysis; multi-wavelength observations of solar and M dwarf flares.

Recent Research Results
Adam Kowalski has recently updated the RADYN code to include an accurate prescription for hydrogen line broadening in solar flares, the quiet Sun, and flaring M dwarfs. He led an effort to complete a model grid of M dwarf flares with this model improvement. The initial results were presented in a poster at

Cool Stars 20 (Boston, MA, July / Aug 2018) and are being prepared for an article to be submitted to *ApJ*. Kowalski was first author of two articles published in *ApJ* in 2018.
His major results for 2018 are the following:

- Kowalski, A.F., Allred, J.C. 2018 "Parameterizations of Chromospheric Condensations in dG and dMe Model Flare Atmospheres" *ApJ* **852**, 61 (19 pp).
- Kowalski, A. F. et al. 2018, The Near-Ultraviolet Continuum Radiation in the Impulsive Phase of HF/GF-Type dMe Flares I: Data", *ApJS* (in press, 35 pp
- Kowalski, Mathioudakis, & Hawley 2018, Proc Cool Stars 20 Workshop (in press).
- Kowalski led a large collaborative effort on a seven-day multi-wavelength flare campaign on AU Mic. Observations were obtained over Oct 10 – 17, 2018 with XMM-Newton, Swift, the JVLA, the ATCA, the ARC 3.5m at APO, the SMARTS 0.9m and 1.5m telescopes, and 7 telescopes at LCO Global Telescope Network. New types of measurements are being made at every wavelength that we observed (X-rays, radio, near-UV, and optical). Kowalski is leading the effort to synthesize this unprecedented multi-wavelength data set of M dwarf flares. He will present initial results at the AAS in January 2019 in Seattle, WA.

Future Research Plans

Dr. Kowalski is working on a follow up study on the formation of the red-wing asymmetry in Fe II lines and NUV continuum radiation (Kowalski et al. 2017 ApJ 836 12) using data from IRIS of one of the best observed solar flares. This paper will present new models with accurate hydrogen broadening included in the hydrodynamics; our hydrogen broadening method results in much broader emission lines in model atmospheres and can be used to accurately constrain the electron density in the flare. For DKIST level-2 work, he is producing a grid of hydrogen profiles that will be available to the community for comparison to ViSP data of solar flares. This grid is being calculated with the RADYN code and will include the new broadening physics. Kowalski's grid will be the only predictions with high electron beam fluxes and accurate hydrogen broadening available to the solar community. Kowalski will lead the analysis and modeling of the 7-day multi-wavelength data set obtained in Oct 2018 (he is actively looking for an eager graduate student to use these data for a PhD). Kowalski will publish his grid of dMe flare models in early 2019. He is involved with several white papers for the 2020 Decadal Survey. In Dec 2018, he will submit a first-author paper on IRIS data of the 2014-Oct-25 X1 solar flare. He observed this solar flare with a custom IRIS observing mode and found a very bright continuum increase as well as a new helium I line in solar flares.

Service

Kowalski was a member of the SOC for Cool Stars 20, a member of the SOC for the DKIST Science Workshop on flares, he mentors three graduates students in the CU/APS department (each working on a project with solar flare data from IRIS or from the DST/IBIS; Elizabeth Butler passed her Comps-II project in Oct 2018 and has advanced to PhD candidacy), he mentors an undergraduate at CU, he mentored a visiting undergraduate from Peking University in Summer 2018, he mentors one high school student (in Portland), he has been on several CU/APS graduate student Comps-II committees, he is teaching an over-load astrophysics seminar (ASTR 6000), he is a Co-I on the FOXSI SMEX proposal; as part of this team he is helping plan for the DKIST flare observations if this is accepted. In the CU/APS department, he is on the Social Committee and the Planetarium Oversight Committee. He is Co-I on a successful grant (PI, John Keller, Fiske Planetarium director) to create an exhibit on magnetic fields in the Fiske Planetarium lobby. Kowalski leads the journal club for the Solar Focus Series.

Jose Marino, Assistant Scientist

Areas of Interest

Solar adaptive optics and multi-conjugate adaptive optics; solar adaptive optics modeling and simulation; high-resolution solar observations; atmospheric tomography; point spread function estimation.

Recent Research Results

Jose Marino continues his involvement as a Co-PI on the Clear Project, an NSF-funded joint project between NSO and the Big Bear Solar Observatory to develop a solar multi-conjugate adaptive optics system at the Goode Solar Telescope (GST). Marino continues the development of Blur, a fast and accurate adaptive optics simulation package capable of simulating solar adaptive optics and multi-conjugate adaptive optics systems. Marino is participating in the project to design and build a multi-conjugate adaptive optics system for the DKIST. He provided simulation results to evaluate the system's performance under different design specifications. He also performed a feasibility study of a new deformable mirror technology developed by AOA Xinetics that could potentially be used for one of the deformable mirrors of the multi-conjugate adaptive optics system.

Future Research Plans

Dr. Marino will continue his participation in the project to design and build the multi-conjugate adaptive optics system for the DKIST. He will continue the development of Blur, the solar adaptive optics simulation package, and continue using it to gain insights into the operation of solar multi-conjugate adaptive optics systems. Marino will continue working to revive the seeing monitor instrument used during the DKIST site survey project by reusing existing components into a functioning system.

Service

Marino served as a reviewer of a scientific paper submitted to the *Journal of Applied Remote Sensing* in January 2018. In July 2018, he served on the panel for the critical design review of the DKIST Wavefront Correction System.

Courtney Peck, Postdoctoral Research Associate

Areas of Interest

High spatial resolution spectroscopy of the solar photosphere; solar irradiance; radiative transfer; numerical simulations; speckle image reconstruction.

Recent Research Results

Dr. Peck is researching the radiative output of small-scale magnetic structures in the solar photosphere using 3D MHD simulations. The results of her work are currently in review for the *Astrophysical Journal*. She is also developing a neural network to perform near real-time speckle image reconstructions on VBI image data.

Future Research Plans:

Peck will continue research on small-scale magnetic structures by investigating the role of convective heat transport on their radiative output. She will also explore the effect of numerical diffusion in short-characteristics radiative transfer techniques on the radiative heating derived in numerical simulations. Furthermore, she is continuing her work to develop, train, and test a neural network for speckle image reconstruction.

Service

C. Peck is using supercomputing resources to calculate the library of speckle transfer functions that will be used to calibrate image data from VBI during operations. She is also a member of the Diversity and Inclusion working group at NSO.

Gordon J. D. Petrie, Scientist

Areas of Interest

Solar magnetic fields.

Recent Research Results

Petrie worked with his 2017 REU student Andrew Schwarz (Bethel U.), Alexei Pevtsov (NSO) and Marc DeRosa (Lockheed) to investigate the possible benefits of full-disk magnetogram data observed from viewpoints distant from Earth: the Lagrange points L5, L4 and L3. Petrie ran the Lockheed photospheric flux-transport model to simulate the full-surface flux distribution over a full 11-year solar cycle, and modeled daily full-disk observations from Earth and from L3, L4 and L5. He constructed synoptic maps, modifying the NSO method to allow new data from a given viewpoint to replace older data for the same locations from another viewpoint. We found that adding observations from each Lagrange point significantly reduces the difference between the synoptic map and the flux-transport model, suggesting ways to improve near-real-time modeling of the solar atmosphere and forecasting space weather. This work was published as *Solar Physics*, **293**, 88.

Petrie studied abrupt changes in the photospheric magnetic vector field, Lorentz force and magnetic shear during 15 X-class flares observed by SDO/HMI. Resolving magnetic changes using a reference potential field, more complex magnetic field, Lorentz force and magnetic shear changes could be analyzed than previously. General patterns were found: dominant change in the horizontal field component which strengthened in the central structure, flux rope or unipolar sunspot, accompanied by a downward Lorentz force change and shear increase, with weaker changes of opposite sign in peripheral regions. Unique was the behavior at a bald-patch structure during the September 6 X9.3 flare: the horizontal and vertical field components weakened and the shear relaxed in both horizontal and vertical directions, pointing to a large free magnetic energy source for the flare, and evidence of organized vertical magnetic flux reduction suggested greater magnetic restructuring and energy release at bald patches. A paper is in press with the *Astrophysical Journal Supplements.*

Petrie supervised REU student Eden Harris (U. Washington, Seattle). They examined how Interplanetary Coronal Mass Ejection (ICME) orientations, critical to ICMEs' effects at Earth, depend on their source region orientation and on the global field. We analyzed NASA OMNI data for a sample of 303 magnetic clouds over solar Cycles 23 and 24, and NSO measurements of the solar field. Each magnetic cloud was modeled using the Lundquist force-free field solution, fitting parameters including orientation angles. We concluded that during solar minimum the global field has the greatest influence on the orientation of a magnetic cloud, while during the active phase the magnetic structure and local context of active regions complicate the orientations of magnetic clouds. An article is submitted to the *Astrophysical Journal*.

Petrie worked with Axel Brandenburg on a study of E- and B-polarization of inhomogeneous photospheric turbulence based on SOLIS/VSM magnetograms. An article is under review with the *Astrophysical Journal*.

Service

Dr. Petrie analyzed errors in the GONG magnetograms, which are heavily used by space weather scientists at NASA, NOAA, AFRL and elsewhere. This included developing an end-to-end calibration and developing polar field correction methods. Petrie mentored REU student Eden Harris (U. Washington, Seattle) during summer 2018, studying ICME orientations (see research). Petrie organized and hosted the DKIST Critical Science Plan Workshop on Long-term Studies of the Sun, 9-11 October, 2018, Boulder, CO. Petrie participated in the DKIST Science Working Group, writing the sections on Changes in Magnetic Field associated with Flares and Coronal Mass Ejections and Long-Term Studies

of the Sun. Petrie participated in SOLARIS science team activities, including two meetings and a section of the proposal on the Sun's open flux and coronal holes, and in the MagEx science team.
Petrie has provided NSO data user support on accessing and applying NSO magnetograms for various users including AFRL, NASA/CCMC, NOAA/SWPC, Predictive Science, U. Michigan, as well as users in Europe. Petrie refereed manuscripts for journals including the *ApJ*, *A&A*, *SoPh*, *FrPhy*, *Nature*, *JPP* and the *JGR*.

Alexei A. Pevtsov, Astronomer

Areas of Interest

Solar magnetic fields, corona, sunspots, chromosphere, solar-stellar research, space weather and space climate.

Recent Research Results

A. Pevtsov worked on several projects aimed at (1) representing the solar magnetic activity using historical data; (2) understanding the effect of noise and azimuth disambiguation on derived orientation of solar vector magnetic fields; (3) modeling the effect of observations from additional vantage points (Lagrangian L5, L4, and L3) on solar wind and coronal field models used in space weather forecast, and (4) solar-stellar research.

Pevtsov and his colleagues used the historical data from Mount Wilson Observatory's sunspot drawings to investigate the tilt angle of active regions and its variations over the last 10 solar cycles. The latitudinal distribution of tilt angles averaged over all cycles was found to exhibit maximum in mid-latitudes. Furthermore, it was also found that latitudinal dependence of tilts varies from one solar cycle to another, but larger tilts do not seem to result in stronger solar cycles. Finally, the data showed the presence of a systematic offset in tilt of active regions (non-zero tilts at the equator), with odd cycles exhibiting negative offset and even cycles showing the positive offset.

Pevtsov and his colleagues used the surface flux-transport model to demonstrate that sunspot activity in one (the southern) hemisphere is enough to reverse the polarity of polar fields in both hemispheres by the cross-equatorial transport of magnetic flux. The polarity reversals in the northern hemisphere are delayed compared to the southern hemisphere, leading to a quadrupole Sun lasting for several years. These findings allow reconciling low sunspot activity concentrated mostly in one hemisphere (based on sunspot observations), and the presence of regular magnetic cycles (based on cosmogenic isotope measurements) as observed during Maunder minimum.

Future Research Plans

Dr. Pevtsov will continue his research on properties and evolution of magnetic fields on the Sun. He will also continue with research aimed at better characterization of benefits of an instrument at L5 point for space weather forecasting, and the solar-stellar studies.

Service

A. Pevtsov chaired the NSO's Scientific Personnel Committee. He reviewed proposals for NASA and NSF, served as a reviewer for several professional publications. He continued serving on the Users' Committee for HAO's Mauna Loa Solar Observatory and the Advisory Board for the Historical Archive of Sunspot Observations (HASO) at the University of Extremadura (Spain). He is co-chair for the International Astronomical Union (IAU) Inter-Division B-E Working Group on Coordination of Synoptic Observations of the Sun. He is a member of the Editorial Advisory Board for the *Open Astronomy* journal and the Advisory Group for the Community Coordinated Modeling Center (CCMC). He also leads the ISSI International Team on Reconstructing Solar and Heliospheric Magnetic Field Evolution over the Past Century and the working group on Promoting international collaboration in multi-vantage observations of the Sun, with a special focus on unique scientific advantages of L4+L5 combined observations under auspices of the International Living with a Star Program.

Valentín Martínez Pillet, NSO Director

Areas of Interest

Solar activity; Sun-heliosphere connectivity; magnetic field measurements; spectroscopy; polarimetry; astronomical instrumentation with an emphasis on the Daniel K. Inouye Solar Telescope.

Recent Research Results

Author of 119 refereed papers, 230 NASA/ADS entries, 4044 citations, H-index 36.

Before joining NSO as Director, Dr. Martínez Pillet was leading the Imaging Magnetograph eXperiment (IMaX) for the balloon borne SUNRISE solar telescope (a Germany, Spain and USA collaboration). IMaX/SUNRISE has flown twice from the Arctic circle within the Long-Duration Balloon program of NASA (June 2009 and June 2013). The data obtained during the first flight has produced the most accurate description of the quiet Sun magnetic fields, reaching unprecedented resolution of 100 km at the solar surface and a sensitivity of a few Gauss. These data have produced well over 40 papers in the last few years, describing a large variety of processes including the discovery of small-scale supersonic magnetized flows. These jets have been recently identified in the *Hinode* satellite data that provide full Stokes spectral profiles and allow for a detailed study of the atmospheric context in which they are generated. Using inversion techniques, such a study is being performed in the context of the PhD of C. Quintero (IAC). It is expected that the data from the second flight will produce results of a similar impact.

Dr. Pillet was also leading (as co-Principal Investigator) the design and construction of the Polarimetric and Helioseismic Imager for the Solar Orbiter mission (a Germany, Spain and France collaboration).

Future Research Plans

As Director, Dr. Pillet has overall responsibility for the operation of NSO and the effort to develop the Daniel K. Inouye Solar Telescope, to maintain and rejuvenate the NSO synoptic program, and prepare for observatory operations at the new NSO directorate site in Boulder, Colorado. Dr. Pillet plans to be involved in the analysis of the data from the Sunspot/DST taken as part of the synoptic filament observations program led by NMSU.

Service

Dr. Pillet is Director of the National Solar Observatory. In the past, he has provided services for a variety of international institutions, including: member of the High Altitude Observatory Science Advisory Board; member of the DKIST Science Working Group; member of the European Space Agency Solar System Working Group; former President of the International Astronomical Union Commission 12 on Solar Radiation and Structure; former President of the International Astronomical Union Division II The Sun and the Heliosphere; and member of the Editorial Board of the journal *Solar Physics*. In 2014, Dr. Pillet became a member of the Kiepenheuer Institut für Sonnenphysik (Freiburg, Germany) scientific advisory committee. KIS is a partner on DKIST contributing with a first-light instrument.

Dr. Pillet has been the PhD advisor of three students at the IAC (Tenerife) and supervisor of three postdoctoral scientists from various international institutions.

Kevin Reardon, Associate Scientist

Areas of Interest

Dynamics and structure of the solar chromosphere, transition region, and corona; implementation of modern techniques for data calibration, analysis, and discovery; application of imaging spectroscopy techniques; post-focus instrumentation development; spectropolarimetry of the solar atmosphere; transit studies of inner planets; public outreach and student training; history of solar astronomy.

Recent Research Results

K. Reardon has continued efforts to study the small-scale dynamics of the solar atmosphere. He has been working with community scientists to explore new approaches and tools for analyzing ground-based solar data. He has provided input on the DKIST Data Center development, including models for the data production rates and usage scenarios.

Reardon was awarded time on the Atacama Large Millimeter/submillimeter Array (ALMA) for his proposal "Investigating thermal diagnostics of the solar chromospheric network" in the Cycle 6 observing plan. He helped organize joint observations between ALMA and the DST in April and August 2018. Together with grad student Momchil Molnar, they obtained observations with IBIS, FIRS, and ROSA simultaneously with ALMA at 1 and 3 millimeter wavelengths, as well as with the IRIS and *Hinode* satellites. The analysis of these data has revealed the diagnostic value of several key chromospheric spectral lines in the visible. A second grad student, Ryan Hofmann, has compared the ALMA temperatures with those retrieved through spectral inversions. The process of calibration of the IBIS data were used to refine the techniques for data reduction that will be needed for DKIST.

Reardon also worked with Dr. Juie Shetye of the University of Warwick in analyzing observations from the DST and the 1.6-meter Goode Solar Telescope (GST) at Big Bear. These observations are being used to probe the fine-scale dynamics of the solar chromosphere, as well as explore the data challenges that result from higher-resolution and larger detectors.

Reardon also studied the application of techniques for destretching, atmospheric dispersion correction, image reconstruction and data mosaicking as additional tools needed prior to scientific usage of the DKIST data. He has analyzed the performance of several DKIST instruments.

Future Research Plans

Reardon will continue to work with graduate students Momchil Molnar (CU), Ryan Hofmann (CU) and Yi Chai (of NJIT), as well as Dale Gary, Steve Cranmer, Phil Judge, Juie Shetye, Lucia Kleint, and others to analyze the rich data sets combining ALMA, IBIS, and other instruments in order to better understand the heating and dynamics of the solar chromosphere on the smallest scales.

Service

Reardon will work on the application of new methods for processing the challenging volumes of data to be obtained with the DKIST. This will include techniques for calibrating, compressing, and classifying the contents of those data. These methods will be part of a toolkit solar scientists can use to make the DKIST data better amenable to scientific analysis of the calibrated DKIST data.

Reardon will work in educating and engaging the community through the DKIST Critical Science Plan workshops, helping them understand how to employ the facility capabilities in service of their science goals. He will develop and present content and datasets for the NCSP community workshops.

Reardon will help mentor students and engage them in the field of solar physics.

Reardon will continue to serve as a member of the SunPy board, supporting the development of SunPy and other open source software packages needed by the solar community. He will make processing software available through these projects or separately. He will assist in the development of visualization tools needed to conveniently navigate the large volume of DKIST data.

Reardon continues to provide images and information that is used in NSO's EPO outreach efforts. He serves as a referee to the *Astrophysical Journal*.

Thomas R. Rimmele, Astronomer

Areas of Interest

Sunspots; small-scale magnetic surface fields; active region dynamics; flares; acoustics waves; weak fields; adaptive optics; multi-conjugate adaptive optics; instrumentation.

Recent Research Results

As DKIST Associate Director with responsibility for the construction of the $344M DKIST as well as the ramp up to full operations of DKIST in 2019, Dr. Rimmele's time is fully committed to the extensive management, organizational and service tasks. Rimmele, however, maintains a strong interest in the development of AO technology.

Future Research Plans

T. Rimmele hopes to continue his efforts to perform observations at the highest spatial resolution in order to study the properties and the dynamics of small-scale magnetic elements. He will continue to develop multi-conjugate adaptive optics for implementation at DKIST. He plans to participate in the DKIST first-light observations with the primary objective of verifying the DKIST facility and instrumentation for science use on behalf of the community. He plans to actively engage in the execution of a number of Critical Science Plan experiments during early operations of DKIST. He will continue to improve the understanding of structure and dynamics of sunspots and test existing MHD models.

Service

Rimmele is NSO Associate Director for the DKIST. He mentors students and postdocs, supervises key NSO staff members and works closely with the DKIST Science Working Group and its chair. He guides the NSO multi-conjugate adaptive optics development effort. He continues to serve as referee of a number of papers submitted to astrophysical and technical journals.

Thomas A. Schad, Assistant Astronomer

Areas of Interest

Chromospheric and coronal magnetic field dynamics; precision spectropolarimetry; infrared instrumentation, including DKIST facility instrument development; student engagement and community outreach.

Recent Research Results

Dr. Schad's recent work has laid the foundation for magnetic field measurements of cooled coronal plasmas using the DKIST. Owing to the success of the 17-slit massively multiplexed slit spectrograph experiment at the Dunn Solar Telescope, Dr. Schad has published results quantifying, for the first time, the presence of neutral helium in dynamic coronal rain observed off-limb. The article published in the Astrophysical Journal (V**865**, 31) accomplishes two major goals: (1) to characterize neutral helium formation in coronal rain relative to IRIS and SDO diagnostics, and (2) to establish the diagnostic potential of the neutral helium triplet lines for cool coronal magnetometry at DKIST. The article solidifies the importance of these type of observations for high resolution studies of coronal magnetic fields undergoing thermal instabilities and affirms the value of the DKIST critical science plan (CSP) use case submitted by Dr. Schad on this topic.

Future Research Plans

Among ongoing work and future plans, Dr. Schad continues to collaborate with external scientists on the 17-slit spectrograph measurements of He I spectral dynamics of the on-disk chromosphere. In addition, he collaborates with Tetsu Anan on previously acquirement measurements of chromospheric dynamics using a prototype IFU imaging spectrograph. Dr. Schad supervises and collaborates with

NSO's Gabriel Dima on coronal spectropolarimetric measurements of the Si X 1430 nm lines. He is currently pursing a survey of potentially interesting and new spectral diagnostics at transition region temperatures that will be made available with DKIST coronagraphy, while also researching multi-spectral coronal polarimetric measurement techniques and their applications.

Service

Schad is an active member of the DKIST Science Group, is the scientific lead for the DKIST Instrument Control System, and is the infrared instrumentation specialist for the facility instrument development and polarimetric calibration and analysis teams. In 2018, he served on the review panels for the PA&C CDR as well as other system level testing. Dr. Schad was also a team leader for the CSP workshop focused on the corona, jointly hosted by the Institute for Astronomy in June. He also served as the DKIST science expert for the Nagoya and Huntsville CSP workshops, and participated in the DKIST Science Working Group first preliminary assessment of the CSP. Schad also participates in outreach to the local community, participating in the Maui County science fairs as well as the UH's future focus conference on Hawaii's innovation initiatives.

Dirk Schmidt, Assistant Scientist

Areas of Interest

Adaptive optics, high spatio-temporal resolution observation techniques; development of adaptive optics systems, in particular multi-conjugate adaptive optics (MCAO) systems.

Recent Research Results, Future Research Plans & Service

D. Schmidt collaborates with the New Jersey Institute of Technology Big Bear Solar Observatory (NJIT/BBSO) and leads the development of the Goode Solar Telescope (GST) MCAO system "Clear", which is the experimental pathfinder for a DKIST MCAO system. Clear has provided the first ever clearly visible improvement to image quality with MCAO correction compared to classical adaptive optics correction in summer 2016. This project is ongoing with about 30 days of observations per year.

Schmidt is also working on a prototype wavefront sensor used adaptive optics for the observations solar prominences. This protype has been installed at the GST and the control loop was successfully closed.

Schmidt is developing the concept of the wide-field wavefront sensor system and the real-time controller for the DKIST MCAO upgrade.

Schmidt served as conference chair and editor of the 2018 Adaptive Optics Systems VI conference at the SPIE Astronomical Telescopes + Instrumentation meeting. He also was a reviewer in the DKIST wavefront correction system critical design review.

Sushanta C. Tripathy, Associate Scientist

Areas of Interest

Magnetoseismology of active regions; global and local helioseismology; solar activity cycle; ring-diagram analysis, sub-surface flows, cross-spectral analysis of oscillation time series.

Recent Research Results

S. Tripathy and collaborators have investigated the impact of the duty cycle on the parameters of global solar p-mode oscillations, namely frequency, line width and amplitude, using the data from Global Oscillation Network Group. This was carried out by simulating several new time series from a base set by modifying its window function. In order to minimize the effect of solar activity, the base set was chosen during the solar activity minimum period between solar Cycles 23 and 24. The study found significant changes between the corrected and observed amplitudes and line widths while the change in mode frequencies was found to be insignificant. The study also compared the variation in mode parameters over the Cycles 23 and 24 and compared their correlations with 10.7 cm radio flux which represents a proxy of the solar activity. This work was primarily carried out in collaboration with a REU student.

Tripathy and collaborators have also investigated the effect of data gaps on the measurement of local helioseismic mode parameters using HMI Doppler observations processed through HMI ring-diagram pipeline. Since HMI is a space-borne instrument, the data gaps primarily occur due to the eclipses and calibration issues and the gap distribution can be characterized by a single large gap. The study showed that (i) the number of modes fitted for different gap lengths does not increase monotonically with the increase of the gap length; (ii) the zonal and meridional flow agree when the gap length is smaller than 50% and (iii) the deviation in mode amplitude is significantly higher among all the mode parameters.

Dr. Tripathy in collaboration with Dr. Jain and Dr. Hill have explored the relationship between the total solar irradiance and seismic radius as measured by the fundamental mode of solar oscillations. It was inferred that the changes in irradiance can not be fully explained by the temporal changes in seismic radius.

Dr. Tripathy in collaboration with several other scientists have studied the subsurface properties of several active regions in order to detect any possible signature that may differentiate between flaring and non-flaring active regions.

Dr. Tripathy and collaborators have also studied the temporal changes occurring in the convection and radiative zone by using simultaneous observations from ground based and space-borne helioseismic instruments covering two solar Cycles 23 and 24. The results suggest complex relationship between different layers in the solar interior and surface activity. Dr. Tripathy is also participating in an international collaborative project to derive a better solar rotation profile using the longest and best possible splitting coefficients and inversion technique.

Future Research Plans

Dr. Tripathy will continue to analyze the formation of acoustic halos around several active regions using multi-wavelength data from Solar Dynamics Observatory. It is expected that a statistical analysis of several active regions will help us to comprehend the interaction of waves with the magnetic field as a function of the solar atmospheric height. Dr. Tripathy will use an asymmetric profile to fit the GONG velocity power spectra since the mode peaks are known to be asymmetric and analyze the differences between the fitted modes obtained from the use of symmetric and asymmetric profiles. With the availability of high-degree oscillation frequencies and other mode parameters for nearly two solar cycles, Dr. Tripathy plans to investigate the long-term behavior of these parameters to comprehend the structural and dynamical changes occurring in the solar interior.

Service

S. Tripathy serves as the science lead for the interior group and also organizes the weekly NISP interior science meeting. He participated in the vetting procedure of the GONG helioseismic pipelines and continues to provide support to the data analysis team. This summer, Dr. Tripathy mentored an REU student. Dr. Tripathy has also been a reviewer for scientific journals as well as research proposals from NASA.

Alexandra Tritschler, Scientist

Areas of Interest

Operations of large astronomical facilities; operations tools used by users and operators of such facilities; high-resolution spectroscopy and spectropolarimetry of the photosphere and chromosphere of active regions; solar magnetic fields; fine-structure of sunspots; numerical simulations of magneto-convection in (and around) sunspots and using those as input for spectral synthesis; post-focus instrumentation.

Current and Future Research Plans

Dr. Tritschler's main interests will continue to be focused on the operations of astronomical facilities and the high-resolution aspects of the photospheric and the chromospheric atmospheric layers of solar active regions. She will continue to develop the operational modes and tools for DKIST Science Operations. As time permits, she will further use ground-based high-resolution spectroscopic and spectropolarimetric observations to determine the properties of photospheric and chromospheric layers of active regions and to infer their three-dimensional dynamic and magnetic structure and to compare those results to forward modeling.

Service

Tritschler is the DKIST's Operations Scientist and as such guides the development of DKIST Science Operations. She is responsible for the development and specification of all operations tools to be used to efficiently operate the DKIST. Tritschler is supervising the future DKIST observers, and preparing them for DKIST operations. She has been mentoring numerous summer REU and SRA students over the years. She is actively involved in the organization and support of DKIST Critical Science Plan workshops. Tritschler has served and continues to serve on NSO and DKIST hiring committees, and has been a reviewer of publications for *ApJL*, *ApJ*, *A&A*, *SoPh, and AN.*

Han Uitenbroek, Astronomer

Areas of Interest

Radiative transfer modeling and structure and dynamics of the solar atmosphere; modeling and measurement of polarized light and interpreting observations.

Recent Research Results

H. Uitenbroek continues to work on expanding and improving his multi-dimensional numerical radiative transfer code RH. The RH code has been made available to the community from the start and is widely used by the solar community and, in some cases, even outside that. Most recently the the code is being used by de la Cruz Rodriguez and collaborators as the forward engine in a new Non-LTE spectral line inversion code STIC (arXive: 1810.0844), as well as in the new inversion code DeSIRe, combining it with the well-established LTE inversion code SIR of Ruiz Cobo.

RH was extensively used to model the spectro-polarimetric signature of magnetic fields in the MgI b-lines and KI resonance lines(Quintero Noda, Uitenbroek et al 2018, MNRAS 481 5675Q, and 2017, 470, 1453Q, respectively), to investigate the influence of the choice of atmospheric models on the determination of chromospheric magnetic fields via the Hanle effect in hydrogen Ly alpha (Ishikawa, Uitenbroek et al 2018, Sol Phys. 293, 741), and to help identify sunspot oscillations at higher azimuthal wavenumbers (Jess et al. 2017, ApJ 284, 59J).

Together with REU student Alexis Vizzera Uitenbroek used the RH code to model the formation of the CO fundamental rotation-vibration lines at 4.7 micron in the latest BiFrost simulations that include the effect of ambipolar diffusion. They found that these simulations still do not have enough heating by ambipolar diffusion in the temperature minimum region to account for the radiation temperatures in the cores of the CO lines.

Future Research Plans

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

Service

Uitenbroek is the new Associate Director for the NSO Community Science Program (NCSP) and will lead the effort to implement the level-2 data initiative. He is also a member of the Scientific Personnel Committee (SPC).

Friedrich Wöger, Scientist

Areas of Interest

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

Recent Research Results

F. Wöger has studied the sensitivity of analytical models for optical transfer functions used by speckle interferometry algorithms to input parameters in collboration with a CU graduate student. This work has provided the foundation for the characterization of the photometric precision in images reconstructed by the VBI.

Wöger is continuing to guide and aid the construction and testing of DKIST subsystem components, such as e.g. VBI optical components and development of user acceptance tests.

Future Research Plans

Dr. Wöger began work on improved methods for image reconstruction for data acquired with 2D spectroscopic and spectro-polarimetric instruments, such as DKIST VTF data. These algorithms will be based on speckle interferometry and allow the post-processing of data to achieve diffraction-limited spatial resolution. He continues to work on developing accurate models for atmospheric transfer functions and is interested in investigating expanding current models for use with multi-conjugate adaptive optics systems.

Service

Wöger is the DKIST instrument systems scientist, and as such, is the scientific interface between the DKIST project and the partner institutes that build instruments for DKIST. He is involved in the DKIST VBI instrument effort as its principal investigator, overseeing its construction at NSO Boulder. Furthermore, as the DKIST Data Handling Scientist, he is supervising the DKIST data handling system development, ensuring the proper documentation and implementation of the requirements defined for the system and creating a complete data model for DKIST. As the DKIST Wavefront Correction Scientist, Wöger has guided the DKIST WFC team towards a Critical Design Review by reviewing all WFC documentation that describes derived design requirements and the design itself. He also has a role in the optical design effort for the wavefront sensors.

Woeger is currently supervising a post-doctorate research assistant in the modeling of optical transfer functions of Earth’s turbulent atmosphere. He as given several talks on DKIST instrumentation over the course of 2018 to further community interest in the DKIST project, and attended DKIST Critical Science Plan workshops to support other participants.

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
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)
AISES	American Indian Science and Engineering Society
aka	Also Known As
ALMA	Atacama Large Millimeter Array
AMOS	Advanced Maui Optical and Space Surveillance Technologies (MEDB)
aO	Active Optics
AO	Adaptive Optics
APRPP	Annual Progress Report and Program Plan (NSF)
AR	Active Region
ARRA	American Recovery and Reinvestment Act
ASP	Advanced Stokes Polarimeter
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
AU	Astronomical Unit
AURA	Association of Universities for Research in Astronomy, Inc.
AWI	Akamai Workforce Initiative (Hawai‘i)
BABO	Baboquivari Instrument (NSO McMath-Pierce Solar Telescope)
BLNR	Bureau of Land and Natural Resources
BBSO	Big Bear Solar Observatory
BOE	Basis of Estimate
BSA	Boulder Solar Alliance
CA	Cooperative Agreement
CAS	Central Administrative Services (AURA)
CATE	Citizen Continental America Telescopic Eclipse
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
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
CLEA	Contemporary Laboratory Exercises in Astronomy
CMAG	Compact Magnetograph (NISP)
CMEs	Coronal Mass Ejections
CNC	Computer Numerical Controlled
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
CR	Carrington Rotation
CRIM	Coude Rotator Mechanical Interface
Cryo-NIRSP	Cryogenic Near-IR Spectropolarimeter (DKIST)
CSA	Cooperative Support Agreement
CSF	Common Services Framework
CSIC	Consejo Superior de Investigaciones Cientificas (Spain)
CSP	Critical Science Plan
CTL	Center-to-Limb
CU Boulder	University of Colorado, Boulder
CYRA	Cryogenic Infrared Spectrograph (NJIT, Big Bear Solar Observatory)
DA	Diversity Advocate
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
DEIS	Draft Environmental Impact Statement
DEM	Differential Emission Measure
DHS	Data Handling System
DKIST	Daniel K. Inouye Solar Telescope (formerlyATST)
DL-NIRSP	Diffraction-Limited Near-Infrared Spectropolarimeter (DKIST)
DLSP	Diffraction-Limited Spectropolarimeter
DLT	Digital Linear Tape
DM	Deformable Mirror
DMAC	Data Management and Analysis Center (GONG)
DoD	Department of Defense
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

EA	Environmental Assessment
EAST	European Association for Solar Telescopes
EF	Evershed Flow
EGSO	European Grid of Solar Observations
EGU	European Geosciences Union
EIS	Environmental Impact Statement
EIT	Extreme ultraviolet Imaging Telescope (SOHO)
EPO	Educational and Public Outreach
ESA	European Space Agency
ESF	Evans Solar Facility
EST	European Solar Telescope
ETS	Engineering and Technical Services (NOAO)
EUV	Extreme Ultraviolet
FAT	Factory Acceptance Testing
FDP	Full-Disk Patrol (SOLIS)
FDR	Final Design Review
FEIS	Final Environmental Impact Statement
FIRS	Facility Infrared Spectropolarimeter
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
FY	Fiscal Year
GB	Giga Bytes
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)
GUI	Graphical User Interface
HAO	High Altitude Observatory
HASO	Historical Archive of Sunspot Observations
HIDEE	Heliophysics Infrastructure and Data Environment Enhancements (NASA)
HMI	Helioseismic and Magnetic Imager
HO	Haleakalā Observatory
HOAO	High Order Adaptive Optics
HQ	Headquarters
HR	Human Resources
HSG	Horizontal Spectrograph
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
IMaX	Imaging Magnetograph eXperiment (SUNRISE)
IMF	Interplanetary Mean Field
INAF	Istituto Nazionale di Astrofisica (National Institute for Astrophysics, Italy)
IR	Infrared
IRES	International Research Experience for Students (NSF)
IRIS SMEX	Interface Region Imaging Spectrograph Small Explorer Mission (NASA)
ISOON	Improved Solar Observing Optical Network
ISP	Integrated Synoptic Program (NSO)
ISS	Integrated Sunlight Spectrometer (SOLIS)
IT	Information Technology
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
KPVT	Kitt Peak Vacuum Telescope
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)
LCROSS	Lunar CRater Observation and Sensing Satellite
LESIA	Laboratoire d'études patiales et d'instrumentation en astrophysique (Paris Observatory)
LMSAL	Lockheed Martin Solar and Astrophysics Laboratory
LoHCo	Local Helioseismolgy Comparison Group
LRP	Long Range Plan
LTE	Local Thermodynamic Equilibrium
LWS	Living With a Star
M1CA	Primary Mirror Cell Assembly (DKIST)
MagEX	Magnetic Explorer (LASP 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
MHD	Magnetohydrodynamic
MKIR	Mauna Kea Infrared
MOU	Memorandum of Understanding
MLSO	Mauna Loa Solar Observatory (HAO)
MPI	Message Passing Interface
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
NDSC	Network for the Detection of Stratospheric Change
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
NPFC	Non-Potential Field Calculation
NRC	National Research Council
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
NWNH	New World New Horizons (Astro2010: Astronomy & Astrophysics Decadal Survey)

NWRA/CoRA	NorthWest Research Associates/Colorado Research Associates
O&M	Operations and Maintenance
OCD	Operations Concept Definition Document (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
OPMT	Operations Planning & Monitoring Tool
O-SPAN	Optical Solar Patrol Network (formerly ISOON)
PA	Proposal Architect
PAARE	Partnerships in Astronomy & Astrophysics Research & Education (NSF)
PA&C	Polarization Analysis & Calibration
PAEO	Public Affairs and Educational Outreach (NOAO)
PCA	Principal Component Analysis
PDR	Preliminary Design Review
PFSS	Potential Field Source Surface
PI	Principal Investigator
PM	Project (or Program) Manager (NSO)
PMCS	Project Management Control System
PRD	Partial Frequency Redistribution
ProMag	PROminence Magnetometer (HAO)
PSPT	Precision Solar Photometric Telescope
QA/QC	Quality Assurance/Quality Control
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
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)S

SCOPE	Southwest Consortium of Observatories for Public Education
SDO	Solar Dynamic Observatory
SDR	Solar Differential Rotation
SFC	Space Flight Center (NASA)
SFR	Supplemental Funding Request
SFT	Surface Flux Transport
SH	Spherical Harmonic
SI	Strategic Initiative
SMO	Service-Mode Operations
S&O	Support and Operations (DKIST)
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
SORCE	Solar Radiation and Climate Experiment
SOT	Solar Optical Telescope
SOT/SP	Solar Optical Telescope Spectro-Polarimeter (*Hinode*)
SOW	Statement of Work
SPINOR	Spectro-Polarimeter for Infrared and Optical Regions
SPD	Solar Physics Division (AAS)
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
SUC	Science Use Case
SUMI	Solar Ultraviolet Magnetograph Investigation (NASA, MSFC)
SUP	Special Use Permit
SW	Solar Wind
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)
TLRBSE	Teacher Leaders in Research Based Science Education
TMA	Telescope Mount Assembly
TIMED/SEE	Thermosphere Ionosphere Mesosphere Energetics and Dynamics / Solar EUV Experiment (NASA)
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
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)
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
WIT	Women In Technology (MEDB)
WSA	Wang-Sheeley-Arge (Solar Wind Model)
WSDL	Web Service Description Language
WWW	World Wide Web