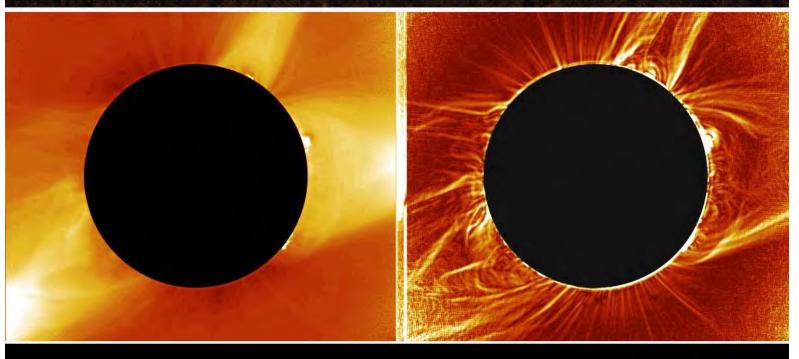


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FY 2017 ANNUAL PROGRESS REPORT &

# **FY 2018** ANNUAL PROGRAM PLAN









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

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

On the cover. Top: Daniel K. Inouye Solar Telescope (DKIST). Bottom: Early analysis of 2017 Citizen Continental America Telescopic Eclipse (CATE) data: the unfiltered, raw image (left) and the highly-processed image designed to enhance scientific detail (right).

# 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.
- 0 *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 helioseismology, synoptic observations of solar variability, and high-resolution studies of the solar atmosphere in the visible and infrared.

Major components of the National Solar Observatory strategic planning include:

- Developing the 4-meter Daniel K. Inouye Solar Telescope (DKIST) on behalf of, and in collaboration with, the solar community.
- 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 (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 new structure has its headquarters (HQ) collocated with the University of Colorado, Boulder (CU-Boulder). The Boulder HQ hosts the DKIST and NISP Data Centers.
- Developing the DKIST operations team and the Remote Office Building (ROB) in Maui.

In parallel with these major components, NSO will continue:

- Expanding interagency collaborations for NISP following the guidance in the National Space Weather Strategy and Action Plan.
- 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), multi-conjugate AO (MCAO), and infrared (IR) technology 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) in FY 2018. NSO will operate the DST in the first quarter of FY 2018.
- Planning for the discontinuation of operations of the McMath-Pierce Solar Telescope (McMP) in a timely fashion to meet the NSF mandate.
- Increasing diversity of the solar workforce.

Some of the programmatic highlights of the NSO Program in FY 2018 include:

- Continuation of DKIST construction on Haleakalā. In FY 2018, the Telescope Mount Assembly (TMA) installation will finalize the site acceptance tests in mid FY 2018.
- Start DKIST systems integration and verification (IT&C phase).

- Finish the construction of the ROB in Pukalani, near the UH/IfA facility.
- Continue forming the core teams for DKIST operations in Boulder and Maui, including the DKIST Data Center (DC).
- Following the guidance in the 2014 Astronomy and Astrophysics Advisory Committee (AAAC) recommendations on Principles for Access to Large Federally Funded Astrophysics Projects and Facilities, define the overarching policy that enables the maximum scientific exploitation of the facility at first light in ways that maximize the participation of the primary stakeholder: the US solar community.
- Relocate SOLIS to the Big Bear Solar Observatory (BBSO) site and resume regular observations.
- Advance the GONG refurbishment project in its main components: acquisition and characterization of new detectors, new polarization modulators, and tunable  $H\alpha$  filters.
- End NSO operations presence in Tucson and Sunspot at the beginning of calendar year 2018.
- Renovate the NSO web site.

A few of the major actions to advance solar physics that NSO will undertake in FY 2018 include:

- Start 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.
- Continue integrating NSO scientists in the CU-led George Ellery Hale fellowship program and promote fluent interaction with graduate students.
- As the operational phase of DKIST nears, continue seeking international participation in the project.
- Building on the success of the activities developed by NSO for the 2017 eclipse, establish an outreach plan to publicize the early science phase of DKIST.
- Advertise and fill the second three-year term CU Boulder faculty position.

In FY 2018, the anticipated observatory funding is \$19M, split into \$14M for the DKIST operations funding wedge and \$5M for base-program actions including HQ operations, NISP non-grant activities and the final stages of NSO operations presence in Sunspot and Tucson. In Sunspot, NSO activities concentrate on training of the NMSU staff that will operate the DST after NSO's departure. This training has already started in FY 2017 and will continue during the first quarter of FY 2018. In order to maximize the training period of the NMSU crew, no open call to the community for DST observing proposals is planned. In Tucson, efforts are concentrated on relocating SOLIS to its new site.

In FY 2018, DKIST construction will complete all major site acceptance milestones, including acceptance of the Telescope Mount Assembly (TMA), while the project enters into the Integration, Testing, and Commissioning (IT&C) phase. The IT&C phase lasts for two years and culminates with the delivery of the facility to the operations crew and the end of the MREFC project. Key milestones included in the DKIST construction project in this year are the TMA pointing verification tests, integration of the primary mirror M1 after aluminum coating, and integration of the top-end optical assembly (TEOA) subsystem containing the secondary mirror. At the end of FY 2018, the plan includes fully integrated primary and secondary mirrors into the telescope, forming an image at the



**Figure 1.** In FY 2018, NSO will start the integration, testing, & commissioning (IT&C) phase of DKIST at the Haleakalā summit, in preparation for the beginning of operations in late 2019.

Gregorian focus. These activities will drive the project's critical path, but many others will occur in parallel, such as laboratory testing of the wavefront correction system in Boulder, or progress with the first- light instruments at the PI institutions. Acquisition of critical optical components for the Facility Instrument Distribution Optics (FIDO) at the coudé platform also occurs in FY 2018.

Preparations for DKIST operations accelerate in FY 2018. The Pukalani-based ROB will be available in the second quarter of the year, allowing a faster build-up of the operations workforce. The delays incurred in the construction of the ROB are responsible for the relatively large amounts of funds the Observatory carries forward. These funds include payments for the building itself, but also an operational crew that is lagging behind the plans described in the Cooperative Agreement. Recovering from these delays is one of the challenges the DKIST project faces in FY 2018 for which a solution is being worked out as part of the transition plan from construction to operations.

After a successful Conceptual Design Review for the DKIST Data Center (DC) in FY 2017, the project is planning for its Preliminary and Final Design Reviews, both taking place in FY 2018. With the DC architecture and design closed and additional activities performed this year—from subsystem prototyping to consolidating interfaces with the construction project—the DC will be in a position to proceed with major hardware acquisitions.

A total of nine Critical Science Plan (CSP) workshops and workshop series have been approved for the next year-and-a-half. The bulk of the activities occurs in FY 2018. Two workshops have a couple of events that occur in series, one in the US and the other overseas. Seven single-event workshops take place in the US, mostly at a University campus. At the end of these workshops, over 160 scientists—65% US-based—will have developed specific science use cases describing unique science enabled by DKIST. These use cases will transform into observing proposals scheduled for the early science phase of the facility. The workshops will also serve as community acquaintance with DKIST's capabilities.

Also in the context of the preparations for the DKIST early science phase, NSO will create a DKIST Science Policy Advisory Committee (DSPAC). Its charge is the definition of detailed guidance on fundamental data rights, data types (commissioning data, guaranteed time data, CSP data, target of opportunity data, etc.) and its publication, and on facility access following the open skies policy as described in the NSF Astronomy and Astrophysics Advisory Committee (AAAC) recommendations. The DSPAC will include the DKIST Co-Is, but other members of the community as well.

NSO and NMSU continue conversations to secure the proper transfer of expertise for operations of the DST by the NMSU-led consortium starting the second quarter of FY 2018. Several NSO employees will continue their presence in Sunspot during the last three months of 2017 to help with the activities in preparation for the divestment to the consortium. The NSO's total effort in FY 2018 corresponds to two FTEs. After this period, some of the NSO employees will transfer to NMSU, ensuring the necessary continuity in the operations of the facility. Conversations with the NSF to define the legal framework in which the transfer of operations occurs will continue during the first three months of FY 2018. With regard to existing discussions in the context of the on-going Environmental Impact Study (EIS), concerns on various safety aspects of the facility have surfaced. These concerns can influence the pace of the divestiture process and the final fate of the facility.

NISP relocation to the Boulder HQ is nearly final. The NISP DC distributes all the data from Boulder and continues negotiating with NOAA on the data transfer for NOAA's Space Weather forecasting pipelines. Site preparations at the CU Boulder campus for the GONG shelters started in early September 2017 and the final relocation occurred in November. By the end of the 2017 calendar year, all scientists who continue long-term in the program will be Boulder-based. In FY 2018, NISP will make critical progress on the two top priorities of the program: the refurbishment of the GONG network and the relocation of SOLIS. Specific milestones in FY 2018 for GONG refurbishment are the testing of the new detectors and the acquisition, calibration, and deployment of new polarization modulators. Validation of the H $\alpha$  tunable filters concept has suffered significant delays due to the high demand of similar filters for the 2017 eclipse; we expect to acquire the tunable filters this year. Preparations for the relocation of the SOLIS facility continue, but delays with the construction permit at Big Bear Solar Observatory have postponed the actual move of the facility. SOLIS will relocate in the first quarter of the fiscal year and, if necessary, mothballed onsite at BBSO until site preparations are complete.

The future of NISP relies on a 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 proposal that meets these needs and has broad international and national support. In FY 2018, NSO will submit a proposal to the NSF to seek funds for the definition phase of the SPRING network.

After the first quarter of FY 2018, NSO presence in Tucson and Sunspot as funded through the Cooperative Support Agreement CSA AST-1400450 will end. NSO will retain only remote-working employees whose status has been previously negotiated in accordance with the relevant AURA policy. No office space will remain at the historical sites in Tucson and Sunspot under CSA AST-1400450 operations.

NSO will continue furthering relations with the CU Boulder departments and laboratories. Three departments participated in the original proposal to host NSO at the University of Colorado: Astrophysics and Planetary Sciences (APS), Aerospace, and Physics. Most of the activities have occurred through iterations with the APS Department. This year, we plan to expand our reach and approach the other two departments to interact with their graduate student programs and explore the possibility of rostering faculty appointments.

In FY 2016, NSO embarked on reinvigorating our education and public outreach program by hiring a Boulder-based Head of Education and Public Outreach (EPO) and an assistant in Maui. Our EPO team played a key role during the 2017 eclipse when the presence of NSO was visible to the general public, the solar community, and the funding agencies. This visibility has resulted in a joint hearing by the Joint Subcommittee on Research and Technology and Subcommittee on Space Hearing to analyze the tremendous impact the eclipse has had in our society. 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.

NSO	2018	Program
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◦ Continue construction on Haleakalā. Begin the IT&C phase.

- End construction of the Remote Office Building in Pukalani.
- Consolidate the scope of the DKIST Data Center. Conduct PDR & FDR.
- $\circ~$  Further recruitment of national and international collaborations.
- Continue development of first-light instrumentation in collaboration with partner institutions.
- $\circ~$  Organize the first series of Critical Science Plan workshops.
- NSO Integrated Synoptic Program (NISP)
  - Operate GONG.
  - Relocate SOLIS to BBSO. Resume operations. Refurbish the GONG network hardware.
  - Submit the SPRING white paper to the NSF.
  - $\circ~$  Continue to seek outside funding for operations.
- Dunn Solar Telescope
  - Operate the facility in a reduced service support model.
  - Train NMSU personnel in the operations of the facility.
  - o Divest the facility.
- McMath-Pierce Solar Telescope
  - Divest the facility.
- New NSO Directorate Site and Staff Consolidation
  - $\circ~$  Announce the second three-year term faculty position.
  - Expand the integration of NSO in campus including other Departments.
  - o End NSO Operations presence in Sunspot and Tucson.
- Education and Outreach and Broadening Participation
  - Design an outreach program that promotes the early science phase of DKIST.
  - Renovate NSO's web site.
  - Train the next generation of solar astronomers (REU's, SRA's, thesis students, postdocs).

Figure 2. Planned and ongoing programs and projects at NSO.

# 2 FY 2017 SCIENTIFIC RESEARCH & DEVELOPMENT HIGHLIGHTS

# 2.1 A Study of Solar Photospheric Temperature Gradient Variation Using Limb Darkening Measurements

Temporal variation in the limb darkening might provide changes in total and spectral solar irradiance (Petro, Foukal & Kurucz 1985; Petro et al. 1984). On the other hand, **s**everal sets of measurements since 1974 have shown that the limb darkening is surprisingly constant over a wide range of solar activity (Pierce & Slaughter 1977; Petro et al. 1984; Neckel & Labs 1994; Livingston & Wallace 2003; Elste & Gilliam 2007; Livingston & Milkey 2009). Several error sources might be responsible for a spurious limb darkening variation (Petro et al 1984; Neckel & Labs 1994; Foukal 1989) but a null result is harder to dismiss, especially since it is found by independent observers using different apparatus and procedures over three sunspot cycles.

Recently, Harder et al. (2009) reported a dimming of solar irradiance with increased activity at wavelengths formed deep in the photosphere, together with a brightening at those originating at higher levels. Harder et al. attributed this decrease of irradiance to variations of the photospheric temperature gradient caused by the increase in facular area filling factor with increasing activity. This explanation has since been explored by Fontenla et al. (2011), Criscuoli & Uitenbroek (2014a) and by Fontenla et al. (2015), but results remain controversial.

Using one- and two-component radiative-convective models, Petro, Foukal & Kurucz (1985) found that a 10 K change in temperature gradient around  $\tau_{0.5} = 1$  would produce a 0.7% change in limb darkening at 445.1 nm. This is an order of magnitude larger than the precision of the limb darkening measurements described above, and should be easily detectable. But 3-D MHD modeling has since shown (Uitenbroek & Criscuoli 2011) that the dependence is complicated by granule geometry and cannot be calculated reliably from such semi-empirical models.

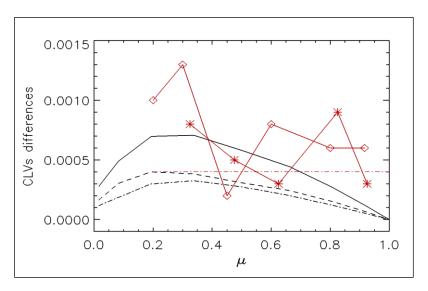
In the present study, S. Criscuoli & P. Foukal (*ApJ* 835, 1, 2017) use snapshots obtained with the Stagger 3-D MHD code (Galsgaard & Nordlund 1996) to investigate the differences in limb darkening produced by changes in flux tube filling factor consistent with the measurements described above. They considered a set of 10 hydrodynamic (HD, thereafter) snapshots and two sets of 10 MHD snapshots initialized with vertical unipolar magnetic intensity values of about 50 and 100 G, respectively. The snapshots simulated a 6 x 6 Mm<sup>2</sup> portion of the photosphere. They then employed the RH code (Uitenbroek 2001) to synthesize the emergent continuum intensity radiation at 445.125 nm for 10 different lines of sight in each of the snapshots. As discussed in Criscuoli & Uitenbroek (2014a) and Criscuoli (2013), the average temperature gradients in the simulations decreased with the increase of the average magnetic flux.

To reproduce the small measured CLV differences, Criscuoli and Foukal employed the MHD snapshots to represent the network and internetwork components, weighted according to their observed filling factors at activity minimum and maximum. The flux values that best represent the network and internetwork are still uncertain (Martínez Pillet, 2013), so they calculated the limb darkening separately using three separate assumptions: a) network: 100 G, internetwork: HD; b) network: 100 G, internetwork: 50 G; c) network: 50 G, internetwork: HD. The models are summarized in Table 2.1-1.

Table 2.1-1. Description of Models					
Maximum: 20% Network + 80% Internetwork Minimum: 15% Network + 85% Internetwork					
Model 1	Internetwork: HD Network: 100 G				
Model 2	Internetwork: 50 G Network: 100 G				
Model 3	Internetwork: HD Network: 50 G				

These modeled CLV differences were calculated using a filling factor increase from 15% to 20% as measured over the full activity range in cycle 21 by Foukal, Harvey & Hill (1991). But the appropriate activity (and filling factor) range for the Elste & Gilliam and Petro et al. measurements is only about half of that. So the calculated CLV variation lies even farther below the measured variation than inferred from Figure 2.1-1. The variation calcu-lated for Model 1 lies above the upper limit set by Neckel &

Labs in their measurements that spanned the full range of activity in cycle 22. This suggests that Models 2 and 3, are to be preferred over Model 1. The dependences of limb darkening upon the network area for the various models are shown Figure 2.1-1, comparison in for with measurements. The plot shows the absolute variation of the intensity CLV (normalized to the disk center intensity) between the maximum and the minimum. The differences peak at  $\mu \approx$ 0.3, at values below 0.0007. Comparison with the measurements indicates that all the modelled CLV differences lie within the values observed by Elste & Gilliam and Petro et al.



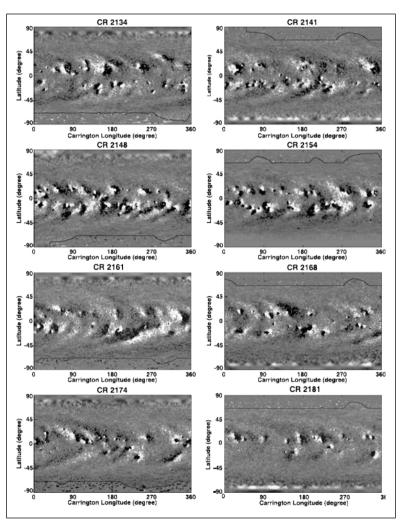
**Figure 2.1-1.** Calculated limb darkening differences plotted versus  $\mu$  for the three network models reported in Table 1. Continuous: Model 1. Dashed: Model 2. Dot-dashed: Model 3. For comparison, results from measurements performed at 445.125 nm are shown in red symbols and lines: Petro et al. 1984 (stars), Elste & Gilliam 2007 (diamonds) and Neckel & Labs 1994 (dot-dashed line).

The models of Criscuoli and Foukal show that, in agreement with observations, a change of network filling factor over the activity cycle produces variation of the photospheric limb darkening below the sensitivity of current instrumentation.

#### 2.2 High-Resolution Vector Magnetograms of the Sun's Poles

At the Sun's poles, the photospheric magnetic flux generally has a unipolar distribution, except during polarity reversal (Petrie, 2015). The average polar magnetic flux density is of order 5 G, but the polar field is highly structured with facular magnetic field concentrations of size 5-10 arcsec and field strengths of order a kilogauss (kG). The Sun's polar flux amounts to less than that of a typical active region, but it is unipolar and spread over a large spatial scale. Thus, most polar flux does not connect back to the Sun, but is open to the heliosphere, supplying most of the interplanetary field and channeling most of the fast solar wind.

Reliable polar field observations are therefore necessary to address many central questions in solar physics. Unfortunately, the polar fields are difficult to measure because of their intrinsic weakness compared to activeregion fields, and the large projection angle (>80° at the pole itself) as observed from Earth, even during March/September when the south/north pole points Earthward. Moreover, synoptic full-disk vector-field observations currently lack sufficient sensitivity or spatial resolution to resolve the small-scale structures that dominate the polar fields. Coronal field models essential for space weather research are usually based on photospheric synoptic magnetograms for the radial flux density, routinely available since the 1970s, and derived from line-of-sight measurements by assuming that the photospheric field is approximately radial. However, high-resolution scans of polar latitudes from the *Hinode* Solar Optical Telescope Spectro-Polarimeter (SOT/SP), first presented by Tsuneta et al. (2008), combined high spectropolarimetric precision and spectral resolution with a multi-arcminute field of view covering the polar cap. Such high-resolution vector-field measurements for the poles could therefore be especially helpful in resolving the intense magnetic concentrations that dominate the polar fields, giving accurate information for the strength and inclination of the fields.



**Figure 2.2-1.** For selected Carrington rotations when the South Pole (left plots) or the North Pole (right plots) was tilted toward the Earth, a composite synoptic magnetogram is plotted, combining radial flux density data derived from Hinode vector magnetograms for the pole facing the Earth, and from SOLIS/VSM or GONG line-of-sight magnetograms for the remaining solar surface. In each plot, the boundary between the Hinode and SOLIS/VSM data is represented by a thin black line. The measurements were taken during March (left plots) and September (right plots) of 2013 (top row), 2014 (second row), 2015 (third row) and 2016 (bottom row). The flux density is represented by a grayscale saturated at  $\pm 30$  G, with light/dark gray representing positive/negative flux.

G. Petrie (*SoPh* **292**, 1, 2017) incorporates radial flux data from SOT/SP vector-field measurements (Kosugi et al., 2007); Tsuneta et al., 2008b) into standard SOLIS/VSM and GONG synoptic magnetograms, including the geometrical effects of finite Sun-Earth distance. Since 2006, *Hinode* has provided continuous high-quality vector magnetogram coverage of the polar fields, including the recent polar field reversal, with high sensitivity and good spatial resolution free of seeing effects. The SP obtains line profiles of two magnetically sensitive Fe lines at 630.15 and 630.25 nm and nearby continuum, using a 0."16×164" slit. For this study, Petrie used Level 2 *Hinode* vector magnetograms processed at the High Altitude Observatory using the algorithms of Lites and Ichimoto (2013), together

with standard synoptic magnetograms from the National Solar Observatory's Synoptic Optical Longterm Investigations of the Sun (SOLIS) Vector Spectro-Magnetograph (VSM) (Keller et al., 2003), and the Global Oscilla-tions Network Group (GONG).

Figure 2.2-1 shows hybrid synoptic maps representing March and September of 2013-16. The *Hinode* data are clearly more structured, being dominated by small, intense flux concentrations. The SOLIS data have lower spatial resolution and are affected by atmospheric seeing; they are therefore less structured. The SOLIS polar data have been filled where necessary by surface interpolation between more reliable high-latitude observations—these can be seen in each map at the pole facing away from Earth. Throughout 2013–2016, when the south polar field reversed from positive to negative polarity, the SOLIS/GONG and *Hinode* flux distributions remained compatible. The *Hinode* flux densities tend to be weaker within about 10° of the poles than at neighboring latitudes because only the largest concentrations are resolved there, perhaps because Stokes Q and U measurements have high intrinsic noise.

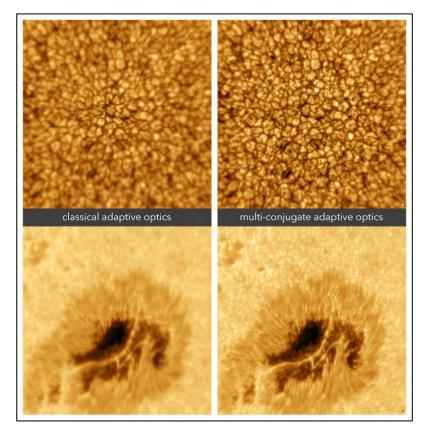
When the full-Stokes measurements can resolve the facular magnetic flux concentrations that dominate the polar fields, then they clearly provide much important information that is lacking from the line-ofsight measurements, also including a true field strength, the correct inclination angle, and a true radial flux distribution. On the other hand, whereas the Stokes measurements and inversions for the vector fields become less sensitive at the highest latitudes because of their dependence on the Stokes Q and U parameters, the line-of-sight measurements have a lower noise level and can pick up smaller flux biases than the vector measurements. These results suggest that vector field measurements of even higher spatial resolution and sensitivity are required, such as those anticipated from the Visible Spectro-Polarimeter (ViSP), Visible Tunable Filter (VTF), and Diffraction Limited Near Infrared Spectropolarimeter (DL-NIRSP) instruments of the Daniel K. Inouye Solar Telescope (DKIST). This telescope with its 4-meter mirror and higher-resolution spatial sampling may be capable of resolving all of the significant magnetic concentrations all the way to the pole.

# 2.3 A Wider View of Areas on the Sun with Multi-Conjugate Adaptive Optics

Multi-conjugate adaptive optics (MCAO) is the next generation of adaptive optics for observations of the Sun that enlarges the field of view corrected for atmospheric turbulence when compared to today's "classical" adaptive optics systems. With MCAO, more details of fast processes in wider areas on the Sun can be revealed.

A decade after pioneering MCAO experiments at the Dunn Solar Telescope, the Daniel K. Inouye Solar Telescope's MCAO pathfinder, Clear, on the Goode Solar Telescope (GST) at the Big Bear Solar Observatory (BBSO) recently provided the first clearly and visibly widened corrected field of view, outperforming quasi-simultaneous classical adaptive optics correction over an area more than nine times as big (Schmidt et al., *A&A* **597**, L8, 2017).

To achieve the wide-field image correction, Clear incorporates three deformable mirrors (conjugate to the ground, 3 km and 8 km distance on the optical axis) and a high-order correlating Shack-Hartmann wavefront sensor that samples optical aberrations in the telescope aperture every 8.8 cm and in nine different viewing directions toward the Sun. This results in 1,872 two-dimensional wavefront slope vectors -6 times more than in any other operational solar wavefront sensor—that are used to compute the proper control signals for the deformable mirrors. Clear is the first MCAO system to successfully



**Figure 2.3-1.** The Sun observed in a field of view of  $53 \times 53$  arcsecsonds with multi-conjugate and classical adaptive optics correction with Clear on the Goode Solar Telescope through a TiO filter (705.7 ± 0.5 nm). In this example, classical correction provided a clear area of about 7,000 × 7,000 km on the Sun's surface. While MCAO correction improved the image over its full size, the image detail that is on par with classical correction is found in about 22,000 × 2,000 km.

use three deformable mirrors for three-dimensional wavefront correction for observations of astronomical objects, while classical adaptive optics systems such as AO76 on the Dunn Solar Telescope, or the first-generation adaptive optics in DKIST include only one deformable mirror for the wavefront correction and one viewing direction for the wavefront sensing.

Clear was built as part of a collaboration between the NSO and New Jersey Institute of Technology (NJIT), supported by the NSF, in order to develop MCAO for DKIST. The German Kiepenheuer Institute for Solar Physics is an international partner on the project. The recent success in solar MCAO is the result of continuous and persistent development of avant-garde adaptive optics techniques with NSO in a key role to provide solar sciences with everimproving observational instruments.

The experiences gained from Clear lay the foundation of the future MCAO implementation on DKIST, enabling highly-resolved—in both the spatial and temporal domains—observational data of rapidly progressing solar activity in a wide area on the Sun. While Clear has been and will continue to be an indispensable experimental pathfinder platform for solar wide-field adaptive optics development (including both multi-conjugate and ground-layer adaptive optics), it has come to a stage this year that enables the very first scientific observations of the Sun that benefit from MCAO.

**Figure 2.3-2.** The Clear instrument in the laboratory at the Goode Solar Telescope at Big Bear Solar Observatory.

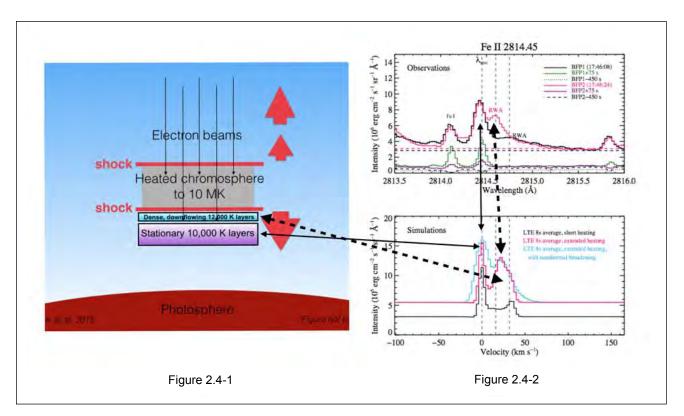


## 2.4 The Atmospheric Response to High Nonthermal Electron Beam Fluxes in Solar Flares. I. Modeling the Brightest NUV Footpoints in the X1 Solar Flare of 29 Mar 2014

The Interface Region Imaging Spectrograph (IRIS; De Pontieu et al. 2014) has observed many solar flares in Solar Cycle 24 with high spatial, spectral, and temporal resolution. The near-ultraviolet (NUV) spectra (around Mg II h and k) and the far-ultraviolet (FUV) spectra (around C II and Si IV) provide critical tests of radiative-hydrodynamic simulations of electron beam heating during flares. The NUV continuum intensity from IRIS is a proxy of the white-light emission, which constitutes the majority of the radiative energy release in solar and stellar flares. However, the origin of the white-light emission as either chromospheric or photospheric (or a combination of both) has been largely unconstrained since its discovery in 1859. IRIS data of solar flares provide long-sought information on the relationship between the origin of the continuum emission and the atmospheric dynamics produced by electron beam heating.

A. Kowalski et al. (*ApJ* **836**, 1, 2017) presented a detailed analysis and modeling of the 29 Mar 2014 large X-class flare, which is often described as the "best observed flare ever." Kowalski and colleagues used the hard X-ray constraints from NASA's RHESSI spacecraft to derive properties of electron beams in the impulsive phase, and they completed 1D radiative-hydrodynamic flare simulations with these beam parameters using the RADYN code. For the lower estimates of the beam fluxes in this flare, they found that the predicted far-ultraviolet and near-ultraviolet continuum intensity values are significantly below the observed values. Instead, a model with a very high electron beam flux (F=5x10<sup>11</sup> erg cm<sup>-2</sup> s<sup>-1</sup>; "5F11") better reproduces the NUV continuum and Fe II emission line properties in the 29 Mar 2014 X-class flare.

With this ground-breaking 5F11 model, the NUV continuum intensity in the March 29th flare can be explained by hydrogen recombination radiation emitted over low optical depth ( $\tau_{NUV} < 0.2$ ) in two flare layers at chromospheric heights: a cooling, dense, downflowing compression of ~25 km depth and heated non-moving flaring layers extending ~150 km below the compression (Figure 2.4-1). The atmospheric density at T~10,000 K in the compression is not high enough to produce blackbody-like radiation, and thus the origin of the continuum intensity is primarily chromospheric in this flare. The electron beam heating in these two flaring layers also explains the complex Fe II line profiles that exhibit a bright, redshifted emission component (Figure 2.4-2), which has previously also been observed in H-alpha and Mg II (Ichimoto & Kurokawa 1984, Canfield et al. 1990, Graham & Cauzzi 2015). For the first time, Kowalski and colleagues reproduced the shape of this profile and the strength of the asymmetry in the red wing using electron beam heating. Modeling with high electron beam fluxes provides a new modeling approach for data of the optical emission lines, such as H-alpha which was also observed by L. Kleint with the IBIS instrument at the Dunn Solar Telescope during this flare. Kowalski and colleagues are working on new predictions of the hydrogen line profiles that will be observed with the DKIST to further test the model predictions of heating over two flaring chromospheric layers in the Sun.



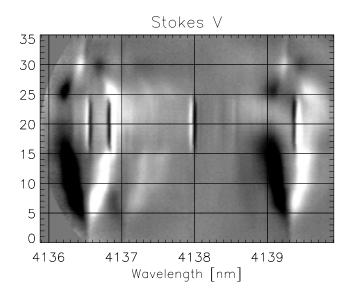
**Figure 2.4-1.** A cartoon illustrating the two flaring layers produced by high-flux electron beam models of solar flares: a dense, downflowing chromospheric compression (light blue) and stationary flare layers just below (purple) which are heated by the highest energy electrons in the beam.

**Figure 2.4-2.** Top panel shows IRIS spectra of the Fe II 2814.45 line during the March 29th 2014 X-class solar flare (pink, black). The model line profile from the scenario in Figure 2.4-1 reproduces the asymmetric profile shape (bottom panel, pink or light blue spectra) and bright NUV continuum radiation. Arrows connect similar spectral features between the model and observations and trace back their origin in the cartoon.

## 2.5 Spectropolarimetry of Atomic and Molecular Lines near 4135 nm

Measurements of solar magnetic fields are essential to solar physics research, and new telescopes (GST and DKIST) and their instruments (CYRA and Cryo-NIRSP) have new infrared magnetic observations at mid-infrared wavelengths in their core science programs. Historically, measurements of magnetic fields at infrared wavelengths have enabled advances and these instruments intend to capitalize on such observations. It is well known that for solar spectral lines with identical magnetic splitting, the relative sensitivity of lines to solar magnetic fields increases with increasing wavelength. The magnetic sensitivity is determined by the ratio of the magnetic Zeeman splitting  $\lambda^2 g_{eff}$  and the Doppler line broadening  $\lambda$  and thus varies as  $\lambda^2 g_{eff}$ . Currently, the most sensitive probes of the solar magnetic field include the Fe I 1564.8 nm spectral line for photospheric fields, the Ti I 2233 nm line for fields in cold sunspot umbrae, and the Mg I 12381 nm line for penumbral and plage magnetic fields. Reports of other very sensitive spectral lines near 4135 nm have been made but no measurements have been published.

New spatially scanned spectropolarimetry sunspot observations are made of photospheric atomic and molecular absorption lines near 4135 nm. The identifications of these infrared solar spectral lines with particular transitions in Fe I and Si I is difficult, but the latest observations from the NSO McMath-Pierce Solar Telescope (McMP) using the NSO Array Camera (NAC) confirms several identifications



**Figure 2.5-1.** Stokes V spectral frame from sunspot observations near 4135nm. The sunspot in NOAA 11846 was observed on 25 Sep 2013 at  $\mu = 0.76$ . The penumbra covers spectral slit positions from 5-15 arcsec and 25-30 arcsec, the umbra is visible from 15-25 arcsec, and the rest of the slit covers the quiet Sun.

made by Kurucz, 2011. The relative splittings among several atomic lines are measured and shown to agree with values calculated with configuration interaction and intermediate coupling.

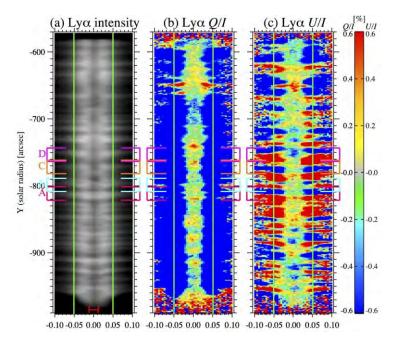
Relative to the Fe I line at 4139 nm, the Zeeman splitting of the 4136 nm line is  $1.28 \pm 0.17$ , consistent with the prediction from the intermediate coupling model. The Zeeman splitting of the Fe I line at 4137 nm shows two components, with an intensity averaged splitting about two times the 4139 nm line splitting; this is roughly consistent with the value predicted from the intermediate coupling. The magnetic sensitivity of this line is therefore very high, with a  $\lambda^2 g_{eff} = 11600$ . While these lines may be useful for sunspot penumbra observations, their main advantage will be realized with future observations with lower backgrounds where they will be a critically useful diagnostic of quiet Sun magnetic fields.

Four of the molecular lines seen in this spectral region show strong Stokes-V profiles. These are the lines at: 4136.48 (OH or SiO), 4136.85 (SiO), 4137.98 (OH) and 4139.40 nm (OH). The lines at 4136.48 nm and 4137.98nm show a Stokes-V profiles which has the opposite sense of the atomic and the other molecular lines: these transitions have a negative  $\lambda^2 g_{eff}$ .

# 2.6 Indication of the Hanle Effect by Comparing the Scattering Polarization Observed by CLASP in the Ly $\alpha$ and Si III 120.65 nm Lines

In situ measurement of magnetic fields in the solar atmosphere, specifically the photosphere and chromosphere is practically impossible. Nevertheless, knowledge of the strength, orientation and evolution of the field is essential to our understanding of the dyanmics and energetics of these layers of the Sun. Fortunately, we have various techniques of spectro-polarimetry at our disposal to determine the structure and evolution of the magnetic field remotely. Of these techniques, magnetometry through the Zeeman effect has been very successful in the denser layers of the photosphere, as well as in the chromosphere over active regions, in both cases because the magnetic field is relatively strong, so it gives rise to measurable polarization signals. Because chromospheric spectral lines form at higher temperatures, and consequently have large Doppler widths, in addition to the weakness of the magnetic fields outside active regions the polarization effects produced by the Zeeman effect are too small.

Recent developments in the theory and numerical modeling of polarization in spectral lines have suggested that the solar disk radiation of some ultraviolet (UV) lines that originate in the upper chromosphere and transition region should, however, show measurable polarization signals caused by scattering processes and that, via the Hanle effect, the line-core polarization signals are sensitive to the presence of magnetic fields in such outer atmospheric regions. The hydrogen Lyman  $\alpha$  line at 121.57 nm is in this case of particular interest because its core, as it originates at the base of the transition region, is sensitive to the presence of magnetic fields with strength between approximately 10 G and 100 G. Theo-



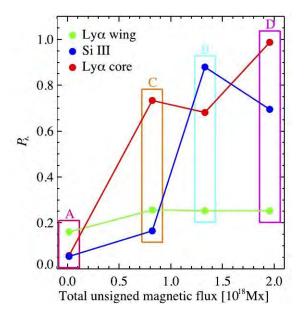
**Figure 2.6-1.** Ly $\alpha$  spectra and linear polarization Q/I and U/I obtained by CLASP. The horizontal and vertical axes show the wavelength and solar radius, respectively.

retical line formation calculations of this line motivated the development of the sounding rocket experiment Chromospheric Lyman-Alpha Spectro-Polarimeter (CLASP).

The CLASP instrument was launched on 2015 September 3 from White Sands Missile Range, and it successfully carried out observations during the 320 s of its suborbital flight. The CLASP observations, for the first time, demonstrated that there is indeed scattering polarization in the hydrogen Ly $\alpha$  line of the quiet solar disk radiation and that the measured Q/I and U/I core and wing signals have conspicuous spatial variations with scales of 10"–20". The Ly $\alpha$  wings, which are insensitive to the Hanle effect, showed scattering polarization perpendicular to the solar limb with a clear center-to-limb variation (CLV) and amplitudes as large as 6% near the limb, in agreement with the theoretical predictions.

Figure 2.6-1 shows the Ly $\alpha$  spectra and linear polarization Q/I and U/I obtained by CLASP. The horizontal and vertical axes show the wavelength and solar radius, respectively.

The polarization oobserved by CLASP in the Ly $\alpha$  core and wing as well as that in the Si III line core shows clear signature of scattering polarization that results both from vertical anisotropy of the radiation field, as evidenced by the center-to-limb variation of Q/I in the Ly $\alpha$  wing and the Si III line, as well as from spatial inhomogeneities, resulting in local variations of both Q/I and U/I with spatial scales of about 10"–20". Concentrating on U/I because it only can be non-zero from spatial inhomogeneities or from the operation of the Hanle effect in the presence of the magnetic field evidence for magnetic fields in the upper chromosphere and transition region can be found by comparing the behavior of U/I in the three wavelength regions of the Ly $\alpha$  core, wing and Si III line.



**Figure 2.6-2.** Values of the polarization imbalance  $P(\lambda)$ , the region-integrated value of signed U/I divided by the region integral if unsigned U/I, versus the total magnetic flux for the regions A, C, B, and D. In case the linear polarization is solely determined by scattering polarization induced by spatial inhomogeneities, the imbalance over the region around the inhomogeneity is close to zero, as the U/I signal averages out over the region.

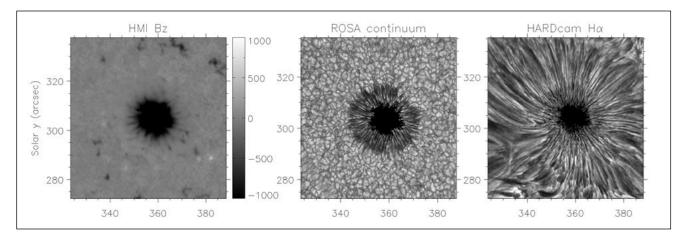
Since the Hanle effect does not operate in the Ly $\alpha$  wing and saturates at about 53 G in the Ly $\alpha$  core, and at 295 G in the Si III line, looking for behavior of U/I that deviates from that expected from resulting from spatial inhomogeneities alone as differentiated in the three wavelength regimes allows an estimate of the magnetic field. This is exemplified in Figure 2.6-2, where an estimate  $P(\lambda)$  of the integrated signed signal in U/I over the unsigned signal over a spatial region (i.e.,  $P(\lambda)$  is close to zero when the sign changes in the region, as expected for scattering polarization due to an inhomogeneity) is compared to the regions total magnetic flux as estimated from HMI. In region A, all three wavelength regimes indicate an U/I that results from pure scattering, while with increasing field first the Ly $\alpha$  core starts to deviate (in C), then the Si III line (in B), while in D only the Ly $\alpha$  wing retains its scattering character, suggesting fields around 50 G in C, below 295 G in B and above 295 in D.

# 2.7 The Dunn Solar Telescope's High Sensitivity Providing an Inside Look at Sunspot Oscillations

The solar atmosphere is a dynamic cauldron of churning plasma intermixed with powerful magnetic field concentrations. Within the relatively cool confines of a sunspot (Figure 2.7-1), the plasma becomes dominated by the tension embedded within the strong magnetic fields. As a result, magneto-hydrodynamic (MHD) wave motion, which is generated beneath the solar surface, is allowed to propagate upwards along the magnetic field lines. These oscillations are dominated by compressive acoustic-type modes, but little was previously known regarding the small-scale morphologies of the observed signatures.

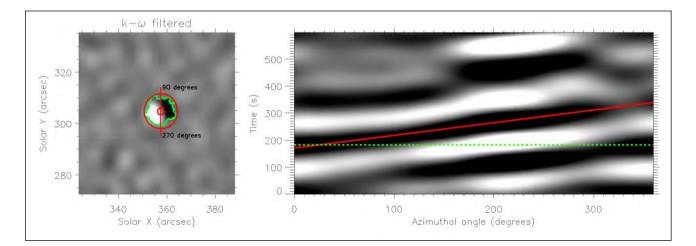
The Dunn Solar Telescope (DST) allowed high-resolution observations, with a resolution of approximately 130 km, to be obtained in the chromospheric H $\alpha$  line core at 656.3 nm (right panel of Figure 2.7-1). The sunspot, which was captured simultaneously by the Solar Dynamics Observatory (SDO) spacecraft and the DST, demonstrated an almost circularly symmetric shape. It was this ideal geometry that allowed Jess and colleagues from universities in the USA (California State University Northridge, University of Colorado), UK (Queen's University Belfast, University of Sheffield) and Belgium (K.U. Leuven) to test modern MHD theory against the high-resolution image sequences captured by the DST.

Following the creation of k- $\omega$  diagram, which maps the spatial and temporal characteristics of the embedded wave motion, it became apparent that there was evidence for considerably elevated



**Figure 2.7-1.** A sunspot simultaneously captured by the SDO/HMI spacecraft (left) and the DST's ROSA (photosphere; middle) and HARDcam (chromosphere; right) instruments, where the axes represent the heliocentric position of the sunspot under investigation. The SDO/HMI panel depicts the magnetic field strength, with umbral values exceeding 1000 Gauss. The approximately circular nature of the sunspot provided an ideal opportunity to test modern MHD theory with high-resolution ground-based observations.

oscillatory power that demonstrated a narrow temporal periodicity (~170 s), yet remained coherent across the full diameter of the sunspot umbra. This type of behavior had not been identified previously. In order to extract the subtle dynamics associated with the newly-identified sunspot umbral wave modes, the high spatial and temporal resolutions of the DST's HARDcam instrument needed to be utilized. The H $\alpha$  time series was Fourier filtered to extract wave signatures with periodicities and spatial dimensions on the order of 170 s and 5000–9000 km, respectively, to allow the origins of the unidentified wave motion to be further studied.



**Figure 2.7-2.** A snapshot from the Fourier-filtered H $\alpha$  time series captured by the DST's HARDcam instrument (left), where only intensity fluctuations displaying periodicities of ~170 and spatial sizes of 5000–9000 km are displayed. The green contour outlines the location of the underlying sunspot umbra, while the red annuli display the azimuthal degrees used in the creation of the azimuth–time diagram (right). Here, the diagonal white and black lines show the rotational motion of the filtered wave signatures, with the solid red and dashed green lines mapping the angular frequency and instantaneous wavelength of the newly-identified wave

Jess and colleagues examined the morphology of the Fourier-extracted wave motion, and found it to rotate about the center of the underlying sunspot umbra. By plotting an azimuth–time diagram (Figure 2.7-2), it was possible to extract the perceived azimuthal motion of the oscillations, which could be compared with expectations from MHD theory.

Theoretical dispersion relations were computed and solved numerically, with the resulting eigenfunctions of these waves determined for a cylindrical configuration best resembling the circular symmetry of the sunspot under investigation. Comparing the modeled wave signatures for an m=+1 slow kink mode to those observed in the Fourier-filtered observations revealed a remarkable level of consistency. Traditionally, for example, in the case of coronal loop oscillations, kink waves are observed to oscillate in a plane. For this to occur, both the m=-1 and m=+1 modes are required to couple together. However, for the sunspot oscillations captured by the DST, no such coupling could be found. This suggests that even though the sunspot umbra is close to being circularly symmetric, any small-scale irregularities may result in the m=-1 mode becoming fractionally weaker than its m=+1 counterpart, hence producing the observed azimuthal (rather than planar) motion.

The high-resolution observations provided by the DST allowed Jess and colleagues to identify, for the first time, evidence for a slow m=+1 magneto-acoustic kink wave manifesting in the chromospheric umbra of a sunspot. These results have since been published (Jess et al., *ApJ*, **854**, 59, 2017). Subsequent observing campaigns have recently been run with additional instrumentation at the DST to search for evidence of how such chromospheric umbral oscillations grow, evolve, and ultimately dissipate.

# **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	DST visitor and instrument support; solar magnetic fields and convection; DKIST operations development.				
Luca Bertello	NISP/SOLIS Data Scientist; solar vector magnetic fields; helioseismology.				
Serena Criscuoli	DST visitor and instrument support; solar magnetic fields and convection; DKIST operations development.				
Alisdair Davey	DKIST Data Center Scientist; solar and heliospheric physics; coronal mass ejections; EUV waves and coronal dimming regions; large-scale solar data management.				
Andre Fehlmann	Infrared instrumentation; precision spectropolarimetry; coronal magnetic fields; student engagement and community outreach.				
Mark S. Giampapa	NSO/Tucson Site Lead; stellar dynamos and magnetic activity; asteroseis-mology; astrobiology.				
Sanjay Gosain	Spectropolarimetry; solar magnetic fields; instrumentation.				
David M. Harrington	Instrumentation; spectropolarimetry, adaptive optics, novel optical systems, detector systems, applied research, community workforce development.				
John W. Harvey	NISP; solar magnetic and velocity fields; helioseismology; instrumentation.				
Frank Hill	NSO Associate Director for NISP; solar oscillations; data management.				
Sarah A. Jaeggli	Sunspot evolution; instrument development; astronomical polarimetry.				
Kiran Jain	Helioseismology; solar cycle variations; ring-diagram analysis; subsurface flows.				
Rudolf W. Komm	Helioseismology; dynamics of the convection zone.				
Adam 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.				

# Scientific Staff (cont.)

John W. Leibacher	NISP; helioseismology; atmospheric dynamics.
Jose Marino	DKIST wavefront correction; image restoration.
Valentín Martínez Pillet	NSO Director; solar activity; magnetic field measurements; spectroscopy; polarimetry; astronomical instrumentation.
Matthew J. Penn	Solar atmosphere; solar oscillations; polarimetry; near-IR instrumentation; DKIST near-IR; McMath-Pierce Telescope Scientist.
Gordon J. D. Petrie	NISP; solar magnetism; helioseismology.
Alexei A. Pevtsov	NISP/SOLIS Atmosphere Program Scientist; solar activity; Ch., Scientific Personnel Committee; coronal mass ejections; solar magnetic helicity, Sun- as-a-star.
Kevin P. Reardon	Data Center Scientist; high-resolution solar data acquisition and analysis; DKIST data handling, storage and processing.
Thomas R. Rimmele	NSO Associate Director for DKIST; DKIST PI and Project Director; solar fine structure and fields; adaptive optics; instrumentation.
Thomas Schad	Infrared solar spectroscopy, precision spectropolarimetry, high-resolution spectral imaging, chromospheric dynamics, coronal structure, non- equilibrium polarization physics, active region dynamics, solar activity cycles, student engagement and community outreach.
Dirk Schmidt	DKIST adaptive optics, high spatio-temporal resolution observation techniques; MCAO systems development.
Sushanta C. Tripathy	NISP Interior Program Scientist; helioseismology; solar activity.
Alexandra Tritschler	DKIST operations development; solar fine structure; magnetism; Stokes polarimetry.
Han Uitenbroek	DST Program Scientist; atmospheric structure and dynamics; radiative transfer modeling of the solar atmosphere; DKIST Visible Broadband Imager.
Friedrich Wöger	DKIST Data Handling Scientist; DKIST Visible Broadband Imager PI; high- resolution convection; solar fine structure; magnetic fields.

## **Grant-Supported Scientific Staff**

Olga Burtseva	Time-distance analysis; global helioseismology; leakage matrix.
Shukur Kholikov	Helioseismology; data analysis techniques; time-distance methods.

#### Key Management Staff

Steven Berukoff	DKIST Data Center Project Manager.			
Scott Bulau	NISP Engineering & Technical Manager (2017).			
Greg Card	NISP Engineering & Technical Manager (2018).			
Jennifer Ditsler	NSO Director's Office Administrator.			
Rex G. Hunter	DKIST business support; Support Facilities and Business Manager.			
Andrew R. Marble	NISP Data Center Manager.			
Priscilla Piano	Administrative Manager: Director's office and Tucson site support; NSO grants management.			
Claire Raftery	Head of Education and Public Outreach.			
Mark Warner	DKIST Program Manager.			
Carolyn Watkins	NSO Business Operations Manager.			

#### **Postdoctoral Fellows**

Gabriel DimaCoronal magnetic field measurements; polarimetry; infrared emission line<br/>diagnostics.Joseph PlowmanCoronal and photospheric magnetic field measurements; spectro-<br/>polarimetry; coronal heating and temperature diagnostics; data analysis,<br/>inverse problems, and their application to reconstructing the sources of

#### **Thesis Students**

Elizabeth Butler	University of Colorado	Analysis of solar flare observations from IRIS
Lily Kromyda	University of Colorado	Broadening of hydrogen lines in DST/IBIS data of solar flares.
Momchil Molnar	University of Colorado	Chromospheric dynamics.
Courtney Peck	University of Colorado	Solar irradiance variation.
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.
Xu Yang	New Jersey Institute of Technology	Infrared spectroscopy.

solar data.

Table 3.1 NSO Scientific Staff Estimated Percent FTE by Activity (FY 2017)								
Name	Adm/Mgt <sup>1</sup>	Research <sup>2</sup>	EPO <sup>3</sup>	Project Support	User Support	Internal Comm.	External Comm.	TOTAL
Beck, C.		31.3	3.0	39.2	24.8	1.7		100.0
Bertello, L.		51.0		29.0	20.0			100.0
**Burtseva, O.		100.0						100.0
Criscuoli, S.		68.3	4.6	16.7	9.4		1.0	100.0
*Davey, Alisdair		15.0		85.0				100.0
Dima, Gabriel		47.0	3.0	50.0				100.0
Fehlmann, A.			4.0	96.0				100.0
Giampapa, M.S.	1.0	87.7	4.5	0.0		0.5	6.3	100.0
*Gosain, S.		31.8		60.2	8.0			100.0
Harrington, D.			4.0	96.0				100.0
Harvey, J.W.		5.0		33.0	12.0			50.0
Hill, F.	80.4	2.0		12.9		3.2	1.5	100.0
Jaeggli, S.		20.0		80.0				100.0
*Jain, K.	10.0	31.2		58.3		0.5		100.0
**Kholikov, S.S.		33.0		10.0	7.0			50.0
*Komm, R.W.		95.0		5.0				100.0
<sup>x</sup> Kowalski, A.		76.0	20.0			4.0		100.0
Leibacher, J.W.		10.0		73.1		9.0	7.9	100.0
*Marino, J.	22.0	10.0		68.0				100.0
Martinez Pillet, V.	98.0		2.0					100.0
McMullin, J.P				100.0				100.0
Penn, M.J.		34.4	19.3	36.3	10.0			100.0
*Petrie, G.J.D.		62.0	8.0	30.0				100.0
Pevtsov, A.A.	5.2	70.5	3.2	15.5		0.5	5.1	100.0
*Plowman, J.		70.0		30.0				100.0
Reardon, K.P.		25.0		55.8	19.2			100.0
Rimmele, T.R.	75.8	1.0	1.0	20.2			2.0	100.0
Schad, T.A <sup>-</sup>		48.0	8.0	44.0				100.0
*Schmidt, D.		10.0		90.0				100.0
*Tripathy, S.C.		72.0	0.0	27.0		1.0		100.0
Tritschler, A.		3.2	4.0	92.8				100.0
Uitenbroek, H.		18.7	0.5	36.3	33.2	6.6	4.7	100.0
Woeger, F.	98.0		2.0					100.0

\*Partially grant supported

\*\*Fully grant supported

<sup>1</sup>Administrative and/or Management Tasks.

<sup>2</sup>Research, including participation in scientific conferences.
<sup>3</sup>Educational and Public Outreach.

# 4 SUPPORT TO THE SOLAR COMMUNITY

Fulfilling NSO's mission of providing opportunities to the scientific community and training the next generation of solar researchers for forefront observations of the Sun require that first-class ground-based solar facilities remain available on a continuous basis. Thus NSO developed Long-Range Plans with the flexibility to transition from current facility operations to the period when new facilities are in place without seriously impacting the US solar user community. Through advancements in instrumentation and the implementation of adaptive optics at its focal planes, NSO has maintained its telescopes at the cutting edge of solar physics. They play a key role in the support of US and international solar research and research-based training.

As mandated in the NSF solicitation for the renewal of the NSO's Cooperative Agreement, after 2017 the major telescope facilities managed by NSO will be divested. With late 2019 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. The synoptic program is expected to be operational during this gap, including an upgraded SOLIS instrument suite relocated to BBSO. A number of options are being discussed to fill this gap. One option is to gain access to observing time at the two most competitive solar telescopes that have recently started operations: the New Solar Telescope (NST), a 1.6-m aperture telescope) at Big Bear (California) and the German Gregor telescope (1.5-m aperture) on the Canary Islands (Spain). The NST is an off-axis telescope with coronal capabilities and cryogenically cooled infrared instruments that resemble some of the future DKIST capabilities. The Kiepenheuer Institute built the Gregor telescope for Solar Physics (KIS; Freiburg, Germany) and NSO has started conversations with KIS about establishing a collaboration that would allow NSO to offer Gregor time to the US community. Another option is to internally develop a Webbased search tool for efficient data mining and retrieval of existing high-spatial resolution observations, in particular those made at the DST in Service Mode. Discussion at a recent meeting of the NSO Users' Committee has started to define how to best fill this gap according to the interests and needs of our community, keeping in mind the limited available resources.

# 4.1 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 Bldimensional 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.

In addition to supporting the solar community, the DST supports observations that will drive DKIST high-resolution requirements at visible and near-infrared wavelengths, and refine DKIST science goals. The DST also supports the development of future technologies such as multi-conjugate AO (MCAO), and experimental wavefront sensing on off-limb targets in H-alpha. The first successful on-sky MCAO experiment was performed at the DST in 2009 and further efforts are ongoing. A prototype for off-limb AO in H-alpha was completed in 2014.

The DST supports the US and international high-resolution and polarimetry communities and is often used in collaboration with space missions 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 compete for time on the DST and provide instruments, such as IBIS (Italy) and ROSA (Northern Ireland, UK), that are available as facility instruments to all users. 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.

The NSO instrumentation program is focused on the development of technologies that will be central to the DKIST and a strong program of understanding solar magnetic variability. The primary areas of instrumental initiatives at NSO are high-resolution vector polarimetry in the visible and near-IR. Many of the instruments at the DST can be considered prototypes for DKIST first-light instruments. For example, FIRS (Facility Infrared Spectro-polarimeter) and the new fiber-optic spectrograph SPIES (Spectro-Polarimetric Imager for the Energetic Sun) implement and verify state-of-the-art technologies that will be used for the DL-NIRSP (Diffraction-Limited Near-Infrared Spectropolarimeter) of DKIST. SPINOR is a precursor to DKIST's ViSP (Visible Spectropolarimeter) and ROSA implements and tests concepts that drive the design of the DKIST VBI (Visible Broadband Imager) and camera systems. IBIS, a partner instrument provided to the DST by INAF in Italy is operated by NSO with support from the Italian community. This collaboration does not only provide experience with the design, operations, data handling and processing of such a complex instrument but also teaches valuable lessons on making international partnerships work successfully and with mutual benefit. IBIS can be regarded as a prototype for the Visible Tunable Filter (VTF), which will be provided to DKIST by an international partner as well. Instrument development and scientific applications in these areas rely critically on strong collaborations with university and international partners.

DKIST operational concepts have been tested at the DST with the DST Service-Mode Operations (SMO). Service mode is an operational mode in which the PI of the observing request does not travel to the telescope. Instead, observations are ranked, scheduled and performed by a team of telescope scientists at the DST. This mode of scheduling is more efficient, allows a flexible schedule that maximizes adaptation to solar target availability and atmospheric conditions, and wastes less time waiting for opportunities and changing instrumentation. It is expected that the DKIST will be run in Service Mode for a significant fraction of its operational time. Lessons that need to be learned include how to rank proposals, how to plan and react to target availability, how to disseminate the acquired data, and how to coordinate with solar space missions on a short time scale. Three SMO experiments were conducted for one month each in January/February and October 2013, and October 2014. All three experiments saw high interest from the community, with 21 and 19 observing requests in the first two cycles, respectively, and 10 proposals for the third cycle that was especially targeted to the observation of solar flares.

NSO organized a farewell workshop at Sacramento Peak in August 2017. The workshop topic was "*High Resolution Solar Physics: Past, Present, Future*", including high-resolution observing from space with ALMA, and high resolution in numerical modeling. The aim was to review the present state of the field as a road map to the future with a focus on DKIST. There also were reviews of the outstanding science performed during the past half century at the DST and several reminiscence talks. The meeting was very well attended (see Figure 4.1-1). The program and the presentations are available at the Workshop website, *http://www.nso.edu/workshops/2017/scienceprogram*.



Figure 4.1-1. Participants in the August 2017 workshop on High Resolution Solar Physics: Past, Present, Future.

#### 4.1.1 DST Instrumentation

#### 4.1.1.1 Facility Infrared Spectropolarimeter (FIRS)

This instrument is a collaborative project between the National Solar Observatory and the University of Hawai'i Institute for Astronomy (IfA) to provide a facility-class instrument for infrared spectropolarimetry 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.

#### 4.1.1.2 Spectro-Polarimeter for Infrared and Optical Regions (SPINOR)

SPINOR is a joint 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

#### 4.1.1.3 Interferometric BIdimensional Spectrometer (IBIS)

IBIS is an imaging spectrometer built by the solar group of the University of Florence in Arcetri, Italy, and the solar group at the 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 through FY 2017. 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 prototypes 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.

#### 4.1.1.4 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 Broadband Imager (VBI).

## 4.1.2 Data Reduction Pipelines

Data reduction pipelines have been created for the most used facility instruments, IBIS, FIRS, and SPINOR, and are available through the NSO website (*http://nsosp.nso.edu/dst-pipelines*). These software packages are supported by the NSO science staff and allow users of the instruments to do the complicated reduction of spectro-polarimetric data at their own institution. Reduction of ROSA images is supported by Queen's University.

# 4.1.3 Replacement and Upgrades

#### 4.1.3.1 Critical Hardware

Given the finite time frame for continued DST operations, replacement and upgrades of hardware and software at the telescope are limited to the necessary minimum. The Critical hardware upgrade (CHU) is aimed at preventive maintenance and reducing unscheduled downtime by replacing obsolete and unreliable hardware, such as the vintage 1970s CAMAC, with modern hardware. Critical hardware is defined as follows: hardware elements that fail repeatedly, and/or, hardware elements that cannot be repaired or replaced without significant downtime or re-engineering. Significant downtime (total) is defined as more than two weeks per year. These upgrades will be limited to supporting existing capabilities rather than offering enhanced capabilities.

#### 4.1.3.2 Storage Area Network (SAN)

The high data volumes produced by existing and new instrumentation such as IBIS, SPINOR, FIRS, and ROSA, an instrument to measure Rapid Oscillations in the Solar Atmosphere, require an expansion in data storage and handling capabilities at the DST. The DST data handling system is currently 4 Tb for storage of daily observations, and 20 Tb for long-term (21 days or more) storage. A 10 Gbs network switch allows instruments to write to the SAN at the sustained high data rates required by high-spatial resolution, high-cadence spectro-polarimetry. Furthermore, the obsolete standard storage media, DLT tape, which was used to transfer data to users, has been completely replaced by removable hard drives with the eSATA or USB transfer protocols, for much higher throughput.

## 4.1.4 Current and Future Use of the DST

NSO users and staff will continue to vigorously pursue the opportunities presented by high-resolution, diffraction-limited imaging at the DST, with a goal of testing models of magneto-convection and solar magnetism, while refining DKIST science objectives and ensuring the growth of expertise needed to fully exploit DKIST capabilities. The advent of high-order AO has increased the demand for DST time and has given ground-based solar astronomy the excitement shared by space missions. Part of DST scheduling has been devoted to testing the main envisioned DKIST operation mode (often referred to as Service Mode), where PIs no longer visit the telescope, but rather submit proposals that are then put in a queue that is executed by NSO staff, based on scientific ranking, prevailing observing conditions, and solar conditions. These experiments have provided important information on the adjustments the new observing mode requires of the proposal submission process, the evaluation of proposals, scheduling, and change in staff roles, compared to the PI driven and fixed scheduling that now is standard at the DST. These experiments have now been extensively evaluated.

## 4.1.5 Divestiture Planning

The National Solar Observatory has operated the Dunn Solar Telescope and its full complement of instruments through FY 2017. During the first part of FY 2018, NSO is training the NMSU staff on-site to operate the instrument set-up necessary for the synoptic programs as determined by the Sunspot Solar Observatory Consortium (SSOC). The SSOC synoptic science plan covers various topics that benefit from a relatively large-aperture telescope with sensitive instrumentation and a capable AO system. The science topics are: filament magnetic fields, flare patrol, prominence instabilities, and the chromospheric canopy. A description of the SSOC plans and 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 (*http://nsosp.nso.edu/dst-pipelines*). NSO/Sac Peak TAC meetings are no longer conducted as all of the observing time are focused on training activities. During the first quarter of FY 2018, the combined NSO and NMSU operations crew will perform DST observations aimed at testing the synoptic program instruments' setup.

## 4.2 McMath-Pierce Solar Telescope

The McMath-Pierce Solar Telescope (McMP) facility is a set of three all-reflecting telescopes, with a main telescope with a primary diameter of 1.6 m, and the two auxiliary telescopes (East and West) with diameters of 91 cm and 88 cm. The McMP provides large-aperture all-reflecting systems that can observe across nearly two orders of magnitude, from 350 to 23000 nm; the telescopes are very configurable with light beams that can feed a number of large, laboratory-style optics stations for easy and flexible instrument setup. The McMP is unique since it is the only solar telescope with instrumentation that routinely observes in the infrared beyond 2500 nm, and the only solar facility in the world with instrumentation to observe the Sun at 12000 nm and beyond.

## 4.2.1 Divestment or Closure of the McMP

The NSF/AST has required NSO to ramp down NSO support for the McMP to minimum operations by the end of 2013 with divestment to follow as soon as practicably possible. The McMP has been operated by NSO at this minimal level in FY 2015, FY 2016 and FY 2017. To accommodate the ramp down in NSF support, a group of interested users have donated funds.

Discontinuing NSO operations can be accomplished by divesting the McMP to other groups or by mothballing or removing the facility. NSO, through the services of a contractor, conducted an assessment of the environmental impact of divesting our facilities at Kitt Peak. During FY 2018, NSO plans to operate the McMP for only the first quarter and will temporarily close the facility for the remainder of the fiscal year until a final decision on divestment is made.

# 4.3 Access to NSO Data

## 4.3.1 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 557<sup>th</sup> Weather Wing (previously known as AFWA), AFRL, NOAA/SWPC, and NorthWest Research Associates (NWRA) for space weather prediction applications. The SOLIS data archive includes the VSM, ISS and FDP. In 2017, 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 450 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).

#### 4.4.2 Virtual Solar Observatory

In order to further leverage the substantial national investment in solar physics, NSO is participating in the development of the Virtual Solar Observatory. The VSO comprises a collaborative distributed solar-data archive and analysis system with access through the WWW. The system has been accessed approximately 2.2 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 is 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 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.

NSO will continue to be a central component of the VSO for the foreseeable future.

# **5 DKIST CONSTRUCTION AND OPERATIONS RAMP UP**

# 5.1 Introduction

On 15 December 2013, the 4meter Advanced Technology Solar Telescope was renamed the Daniel K. Inouye Solar Telescope (DKIST). The renaming ceremony took place at the Haleakalā construction site. The DKIST will be the most powerful solar telescope and the world's leading groundbased resource for studying solar magnetism that controls the solar wind, flares, coronal mass ejections, and variability in the Sun's output. The strong scientific case for DKIST was made in two previous decadal surveys (Astronomy and Astro-

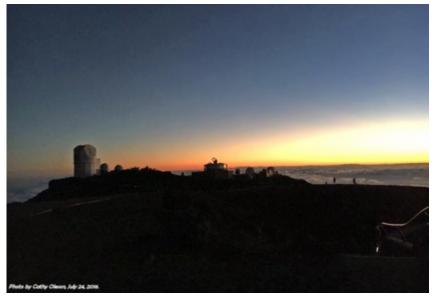


Figure 5.1-1 DKIST at sunset on Haleakalā.

*physics in the New Millennium* (2001) and *The Sun to the Earth—and Beyond* (2003)). The 2011 NSF sponsored *Community Workshop on the Future of Ground-based Solar Physics* reemphasized the "game changing" science DKIST will enable. The detailed science drivers for DKIST are discussed in numerous publications including the science requirements document (*http://dkist.nso.edu-/library*). The science drivers lead to a versatile DKIST design that supports diffraction-limited imaging, spectroscopy and, in particular, magnetometry at visible and near- and far-infrared wavelengths, and infrared coronal observations near the limb of the Sun.

A primary scientific objective of the DKIST is to precisely measure the three-dimensional structure of the magnetic field that drives the variability and activity of the solar atmosphere. The energy released in solar flares and coronal mass ejections was previously stored in the magnetic field. The magnetic field is structured on very small spatial scales and understanding the underlying physics requires resolving the magnetic features at their fundamental scales of a few tens of kilometers in the solar atmosphere. The large 4-m aperture of the DKIST, which represents a transformational improvement over existing solar telescopes, opens up a new parameter space and is an absolutely essential feature to resolve structures at 0."025 (20 km on the Sun) at visible wavelengths.

A main driver for a large-aperture solar telescope is the need to detect and spatially resolve the fundamental astrophysical processes at their intrinsic scales throughout the solar atmosphere. Modern numerical simulations have suggested that crucial physical processes occur on spatial scales of tens of kilometers. Observed spectral and, in particular, Stokes profiles of small magnetic structures are severely distorted by telescope diffraction, making the interpretation of low-resolution vector magnetograms of small-scale magnetic structures difficult to impossible. Resolving these scales is of utmost importance to be able to develop and test physical models and thus understand how the physics of the small-scale magnetic fields drives the fundamental global phenomena. An example is the question of what causes the variations of the solar radiative output, which impacts the terrestrial

climate. The Sun's luminosity increases with solar activity. Since the smallest magnetic elements contribute most to this flux excess, it is of particular importance to study and understand the physical properties of these dynamic structures. Unfortunately, even the most advanced and newest current solar telescopes, such as the 1.6-m New Solar Telescope (NST) or the 1.5-m GREGOR, cannot resolve such scales because of their limited aperture size (Table 5.2-1).

A large photon collecting area is an equally strong driver toward large aperture as is angular resolution. Observations of the chromosphere and, even more so, the faint corona are inherently photon starved. The solar atmosphere is structured on small spatial scales and is highly dynamic. Small structures evolve quickly, limiting to just a few seconds the time during which the large number of photons required to achieve measurements of high sensitivity can be collected. Measurements of the weak coronal magnetic fields are essential to understand the physics of, for example, coronal mass ejections, and aid space weather prediction efforts. Measurements of the coronal magnetic field are desperately needed to make progress but are also extremely difficult. The coronal intensity is only 10<sup>-5</sup> to  $10^{-6}$  of the disk intensity. The polarimetric signal DKIST aims to detect is only  $10^{-3}$  to  $10^{-5}$  that of the coronal intensity. This means that contrast ratios are of the order of 10<sup>-8</sup> to 10<sup>-11</sup> and, thus, are not too different from what planet detection efforts are facing. The large collecting area and low scattered light properties of the DKIST are essential to achieve the chromospheric and coronal science requirements. The magnetic sensitivity of the infrared lines used to measure coronal fields and the dark sky conditions in the infrared are important motivations to utilize the DKIST for exploring the infrared coronal spectrum. The off-axis design was motivated by the coronal science require-ments as well as by technical considerations.

As construction progresses on schedule, NSO is ramping up to DKIST operations. DKIST operations, including data handling and dissemination, will be much more efficient compared to the operations of current NSO or similar facilities. DKIST operational concepts have been developed and will be refined during the ramp-up phase. The community represented by the Science Working Group (SWG) is actively engaged and is providing input to all aspects of DKIST operations planning. New operations concepts build on the lessons learned from recent spacecraft operations such as TRACE, *Hinode* and SDO. Efficient operational modes such as Service Observations will make more efficient use of the available observing time. The NSO Data Center (DC) at NSO headquarters in Boulder will provide well calibrated, science-ready DKIST data products to the solar physics community. An open data policy allows for maximum science productivity.

# 5.2 Daniel K. Inouye Solar Telescope: Construction Project Update

The DKIST is an all-reflecting, 4-m, 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

Telescope Property	Specification or Reason for Property		
Aperture	4 meters		
Diffraction-Limited Resolution			
λ = 430 nm	0.022 arcsec		
λ = 1 μ	0.05 arcsec		
λ = 4 μ	0.2 arcsec		
λ = 12 μ	0.60 arcsec		
Gregorian			
Off-Axis			
Unobstructed Aperture	No Spider Diffraction		
Clean Point-Spread Function	High Strehl		
Alt-Az Mount			
High-Order Conventional Adaptive Optics	MCAO-Ready Optical Design		
Internal Seeing Control	Thermal Control of Optics and Structure		
Dust Control for Low Scattered Light	Coronal Observations		
Polarimetric Sensitivity	>10-5		
Polarimetric Accuracy	5 x 10 <sup>-4</sup>		
Wavelength Coverage	300 nm to 28 micron		

DKIST website, *http://dkist.nso.edu*. The most important capabilities of the DKIST are summarized in Table 5.2-1.

In FY 2017, at the facility site at Haleakalā Observatories (HO), the DKIST completed significant progress on the observatory facilities. Significant progress on Facility Thermal Systems (FTS) was made for the primary distribution system (ice tanks, chilled dynalene), the secondary distribution system (facility distribution of cold fluid) and building HVAC. Despite this progress, over this period, the planned FTS execution fell significantly behind principally due to resourcing issues and contention, with little support from Hawai'i trades; a significant replanned execution is under-



Figure 5.2-1. Site progress as seen in March 2017.

way with activities for the Coudé Environmental Systems and tertiary distribution (telescope distribution) keeping up with the project schedule. Other internal work progress was completed over this period, in particular the electrical systems cabinet installations and transition to permanent power for the major subsystems, completion of conduit runs and outlets throughout the Support and Operations (S&O) building, and progress throughout the building for lighting. Additional work to clean and paint the interior of the building progressed, working toward the final Beneficial Occupancy.

The Telescope Mount Assembly Coudé rotator installation was completed with Site Acceptance completed in the summer. All test results were as good or better than the Factory Acceptance Testing; some areas were only partially compliant due to incomplete dependent systems (e.g., facility cooling). All punchlist items were completed by August 2017. The Mount Base installation began in December 2016 and was completed in September 2017 with Site Acceptance activities scheduled to begin in October.

Off-site, the instrument development projects continued work in procurement and fabrication with the Visible Spectropolarimeter (ViSP), Cryogenic Near-IR Spectropolarimeter (Cryo-NIRSP) and Diffraction-Limited Near-IR Spectropolarimeter (DL-NIRSP) also progressing with subassembly and testing. The Visible Broadband Imager (VBI) continued its integration process, making strides in completing interfaces with facility systems, development of the speckle reconstruction pipeline, and testing of optical systems. The United Kingdom (UK) Consortium camera development made strong progress, delivering



**Figure 5.2-3.** The Telescope Mount completed assembly in September 2017 and began Site Acceptance Testing in October 2017.

incrementally increasing functionality toward the final science camera; these cameras were used to test software controls and other interfaces to support the final camera integration testing in January 2018. The M1 Cell Assembly successfully passed its Factory Acceptance Testing in February 2017 and was shipped to Maui; it, along with the M1 commissioning and science blank, were then successfully transported to the summit in August 2017.



**Figure 5.2-3.** M1 Cell Assembly FAT; AMOS staff and Project team reviewing the handling cart testing (left) and the commissioning blank use in the performance testing of the M1 Cell Assembly (January 2017).

High-Level Software (HLS) The team completed the Instrument Control System Factory Acceptance Testing in December 2016 which was then released to instrument developers. The Telescope Control System successfully interfaced with the Mount Control System and the Coudé Control System; as part of the M1 mirror factory acceptance test, the M1 Mirror Control System simulator was also integrated with the TCS. The TCS was also integrated with the Wavefront Correction Control System (WCCS) simulated control within the testing platform. The Feed Optics Control System (FOCS) successfully passed its Factory Acceptance Testing and was integrated into the regular regression testing framework. The HLS team developed an end-to-end software testing platform, which was deployed



in Boulder for integration of component HLS systems as well as for user testing of operator-driven systems (OCS and DHS); its use has driven the schedule to achieve the Factory Acceptance Testing for the OCS and DHS. The Camera System Software completed the implementation of the Andor Zyla support as well as preliminary Andor Balor (4 K x 4 K camera) support.

**Figure 5.2-4.** Wavefront Correction deployment for integration testing in the National Solar Observatory Boulder Labs.

### 5.2.1 Schedule Status

A subsystem view of intermediate milestone highlights is shown in Table 5.2-2. 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 5.2-2. DKIST Future Major System Milestones				
Support Facilities	2018-Feb	M1 Science blank coating		
	2018-Dec	Site Closeout (apron, water tanks, drainage, parking, etc.)		
Optical Systems	2017-Dec M1 Cell Assembly Site Acceptance Complete			
	2018-Aug	M1 Integration Complete (SIM 2)		
	2019-Jan	Optical Chain (M1-M9) First Light Ready		
Telescope Mount Assembly	2018-Feb	TMA Mount Acceptance Testing Complete		
	2018-Mar	Initial Telescope Pointing Map Complete (SIM 1)		
Facility Thermal Systems 2018-Aug		Facility Plan Equipment Complete		
	2019-Jun	FTS Secondary Distribution Complete		
	2019-Sep	Facility Thermal Systems Complete		
Wavefront Correction	2018-Aug	WFC Boulder Lab Testing Complete		
	2018-Dec	WFC Transport to Summit		
	2019-May	WFC Integration (SIM 6B)		
Software	2018-Mar	Camera Software Final Release (shifted from 2017; delayed camera delivery)		
	2018-Mar	Data Handling System Site Acceptance Testing		
	2017-Jul	Observatory Control Software Final Release		
Instruments	2018-Jul	VBI on Site (Partner instruments received Jan - Mar 2019; VTF TBD)		
	2019-Jun	VBI Integration Complete (SIM 6A)		
	2019-Jul	VBI First Light Demonstration (SIM 7)		
	2019-Oct	Start of Science Operations		

## 5.2.2 Financial Status

Following the Project Re-baseline, the Total Project Cost was established as \$344.1M. To date, the project has received \$306.3M, with an additional \$1.7M of contingency which has been funded but held by the NSF Program Officer; \$146M from the American Recovery and Reinvestment Act (ARRA) of 2009 and \$160.3M 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 2019.

(Enclosure, 1 M	ff-Site Design/Developmer A, Optical Systems, High I	evel Software)				
	Site Work: Excavation, concrete, Steel Erection		Site	Closeout		
		Facility Thermal	Systems Installation			
		Enclosuce SAT & Te	esting De Mount Assembl AT & Testing	L		7.3 Months Float
		Instrument Syste	em Fab & Lab Test	-		
				Optics, Instrur Integration Commission	ment &	
			~	Site IT&C	->	

Figure 5.2-5. DKIST Construction Project summary schedule.

# 5.3 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 Remote Office Building (ROB). 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 continuously during operations.

In FY 2017, operations planning, development of operations processes, support tools and implementation of infrastructure necessary for DKIST operations continued. Emphasis was also given to refining cost models for summit operations. Two Science Operations Specialists were hired and trained at the DST and the Boulder DKIST end-to-end simulator. 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 is preparing for its Preliminary Design Review, which is scheduled for early 2018.

The development of the Critical Science Plan (CSP) continued in FY16. The Chair of the Science Working Group (SWG) is leading the effort supported by NSO staff. A series of CSP workshops has been planned and organized, and the workshops are being held at several US universities over the course of about one year. The goal is to ensure science readiness of the community.

Construction of the ROB began in FY17 and will continue into early 2018. Unfortunately, due to delays with initiating the construction, there is currently no office space available for operations staff on Maui. The leased space that houses the construction staff is already oversubscribed. The six Maui-based DKIST science staff, postdocs and education and public outreach staff are currently housed at the Institute for Astronomy (IfA) Advanced Technology Research Center (ATRC), where they work closely with the instrument partners at IfA. Ramp up of Maui-based staff has been slower than planned for this reason.

Science operations specialists were relocated to Boulder, where they are participating in users' acceptance testing and will be involved 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 staffing plan for the full-up operations phase is as follows. On Maui, a team of approximately 36 FTEs will support telescope operations. Seven scientific FTEs, which at any given time include two postdoctoral fellows, will provide Resident Astronomers (RA) with expertise in DKIST instruments, wavefront correction system, and data handling. 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. A 15-FTE engineering and technical staff will maintain the telescope systems and instruments and provide operational and safety support as needed. Data handling, computing, and system support will be provided by four FTEs. Administrative staff will consist of a site business administrator, one administrative assistant, a safety officer and a buyer/clerk. Additional HR and purchasing support will come from the NSO Headquarters (HQ) staff and AURA staff in Hilo. We plan to contract facility support and janitorial services.

As the operations planning progresses, these initial staffing plans will be refined. During the next two years we plan to deploy partial FTEs from construction staff to operations planning tasks, with construction tasks remaining as the priority. This process has already begun in some areas.

We expect that a significant number of construction project staff will transition to operations; thus we are taking measures to encourage and facilitate such a transition in order to retain and maintain the expert knowledge that exists within the DKIST construction staff into the operations phase.

At NSO HQ in Boulder and at the beginning of full operations in 2019, a science team consisting of staff astronomers, postdoctoral fellows, and graduate students (~13 FTEs) will support the DKIST science

operations. This includes user support at the Data Center, the maintenance and upgrades to first-light instrumentation, and the development of second-generation instruments. The development of multi-conjugate AO is progressing well at BBSO in collaboration with our partners. A long lead upgrade to the VTF, a first-light instrument, has also been initiated.

### 5.3.1 Data Center Development

#### 5.3.1.1 Overview

The DKIST Data Center will provide computational resources supporting the DKIST's 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.

### 5.3.1.2 FY 2017 Accomplishments

During FY 2017, Data Center definition and development continued, leading to a successful Conceptual Design Review (CoDR) in the second quarter (Q2), which enabled further detailed design and planning. The CoDR panel noted that within an overly-constrained budget and compressed schedule, the low-risk design presented was achievable given continued system development and project planning. Development activities leading to, and continuing after, this milestone include 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. Fruitful collaboration with the DKIST Construction project supported the development of instrument and polarimetric calibration strategies and processing workflow techniques. Programmatically, budget, schedule, and risk analysis produced preliminary estimates for system size and cost, required development labor, and supported the definition and elaboration of the Data Center operational lifecycle through development, integration with DKIST, and into DKIST Operations.

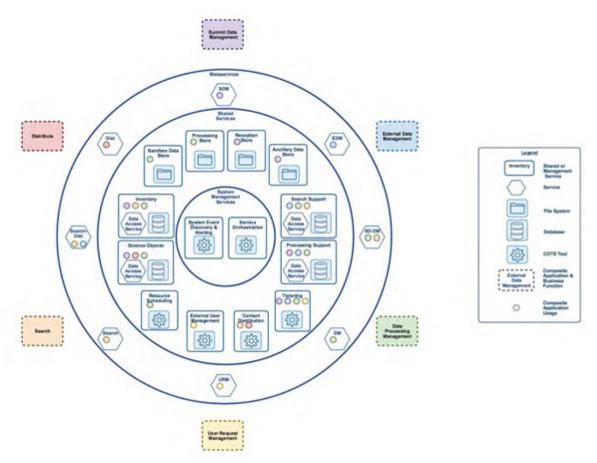
#### FY 2017 Milestones Summary

- Complete Conceptual Design Review (CoDR) (Q1 FY17).
  - Passed successfully in Q2 FY17.
- Complete Preliminary Design Review (PDR) (Q2 FY17).
  - Not completed. Per the CoDR panel, the interval leading to a FY17 PDR was far too short, which led to a preliminary schedule rebaseline resulting in a longer but more realistic preliminary design period, and a tentative Preliminary Design Review in Q3 FY18.
- Complete Final Design Review (FDR) (Q3 FY17).
  - See above; the Data Center FDR did not occur during FY17, and will not occur in FY18.
- Demonstrate Provisioning and Orchestration System (Q4 FY17).
- Completed. This key subsystem has been demonstrated to provide a "hybrid" cloud, capable of deploying configured data analysis, storage, and networking systems for use in support Data Center prototyping, functional and scaling analysis, and calibration development.

### 5.3.1.3 FY 2018 Plan

In FY18, the Data Center staff will complete preliminary design, prototyping, and planning activities, leading to a formal Preliminary Design Review in Q3. Following ongoing risk-mitigation prototyping during Q1 and Q2, subsystem development activities will commence concomitant with final design during Q3 and Q4.

During Q1–Q2, Data Center staff will complete a months-long effort to produce a preliminary design and detailed system architecture (see Figure 5.3-1) traceable to science and engineering requirements. The preliminary architecture includes the following major functional components: the fault-tolerant daily transfer of ~12 TB of DKIST data from Maui to Boulder; characterization, management, and scalable storage of the resulting annual 3.2 PB of raw data; work management systems enabling manual and automated, specification- and workflow-driven data calibration and processing; and data and metadata search and distribution.



*Figure 5.3-1. High-level Data Center service architecture.* 

The preliminary and final design efforts performed in FY18 will be supported by limited riskmitigation-focused prototyping in support of trade studies done to determine the extent to which design choices are technically feasible and cost-effective, and can be customized for Data Center use. This prototyping effort has been underway, and will continue in FY18. Examples of ongoing prototyping work include:

- Use and modification of the Globus Toolkit for data transfer from the summit to Boulder, and for distribution to end-users;
- Integration of open-source system monitoring, provisioning, and orchestration tools, including Elastic, Saltstack, Docker, and OpenNebula;
- Characterization of the high-performance computing workflow systems Airflow and HTCondor/Pegasus;
- Iterated development of prototype calibration codes written in Python;
- Mockups and prototypes of search and data distribution interfaces and processes.

During Q2–Q3, the Data Center staff will prepare for and complete a Data Center Preliminary Design Review, creating architectural and design documents, program planning and execution documents, and supporting cost and schedule estimates. This months-long effort will generate hundreds of pages of documentation and design information for consumption during the multi-day PDR. Following incorporation of feedback from the review, during the remainder of FY18 the staff will simultaneously commence preparation for the Final Design Review, and long-lead system development efforts, particularly focused on data ingestion, management, and search & distribution functionality.

During FY18, Data Center staff will continue to collaborate with the DKIST Construction project in developing preliminary calibration strategies for DKIST instrumental data, and beginning implementation of interface controls to the DKIST and its Operations Tools.

### FY 2018 Milestones

- Q1 FY18: Complete DKIST Data Simulator and Validator Toolkit.
- Q2 FY18: Complete Data Center System and Subsystem Requirements.
- Q3 FY18: Complete Data Center Preliminary Design Review.

# 5.3.2 DKIST Operational Tools Development

### 5.3.2.1 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.

# 5.3.2.2 FY 2017 Accomplishments

During FY17, an in-depth operational and functional definition was undertaken as a collaboration between DKIST software engineering staff and the Operations Scientist, characterizing the extensive use cases that these tools will support. This intensive and collaborative needs analysis significantly narrowed and refined the scope of the Operational Tools, resulting in an improved operational concepts definition, science requirements, and an initial conceptual design. The following toolsets have been defined: Proposal Preparation, allowing users to specify and submit requests for observational

programs using the DKIST and its instruments; Proposal Management, enabling proposal review, time allocation, and approval; Experiment Architect, supporting the creation of observational programs guided by approved proposals for use by DKIST; and an Operations Planning and Monitoring Tool, supporting information aggregation and association for use by DKIST Operations staff. Completed science requirements were delivered in Q4 FY17, enabling preliminary detailed project planning to begin in earnest. A preliminary project plan was drafted and circulated for approval, and hiring was initiated.

### FY 2017 Milestones Summary

- Complete Operational Tools Science Requirements (Q2 FY17).
  - Completed Q4 FY17.
- Complete Operational Tools Engineering Design Requirements (Q3 FY17).
  - Incomplete. An in-depth analysis of scientific and operational needs was performed, from which requirements will be drawn during Agile development.
- Complete Operational Tools Preliminary Design Review (Q4 FY17).
  - Not completed due to resource contention. A development rebaseline and replan is underway, and this review will not be held. Instead, iterative development involving frequent collaboration between science and development staff will implement the required Operations Tools functionality guided by known science requirements.

### 5.3.2.3 FY 2018 Plan

During FY18, dedicated staff will be hired and will initiate development of the Operational Tools. The preliminary focus of their effort will be to develop the Experiment Architect, which will drive the DKIST High-Level Software in executing science observations. An early version of the Experiment Architect is anticipated to be ready by the end of the fiscal year. Juxtaposed with this effort, the front-end proposal-related tools will be prototyped and implemented. The system development effort involves close and frequent collaboration between engineering staff and the Operations Scientist, and will involve frequent communication with other relevant stakeholders who will provide user feedback on functionality, interface design, and performance.

### FY 2018 Milestones

- Q1 FY18: Completion of Science Requirements.
- Q4 FY18: Alpha Release, Experiment Architect.

# 5.3.3 Maui Remote Office Building

The Remote Office Building (ROB) on Maui will serve as the local operational center of the DKIST. In contrast to the DST in Sunspot where all facilities and support infrastructure are on site and near the telescope, the DKIST site does not include all the necessary office, laboratory and data handling infrastructure. The function of this ROB will be similar to Gemini's Base Facility in Hilo, Hawai'i, 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 ROB.

The DKIST ROB's primary function will be to provide 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 ROB 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.



Figure 5.3-2. Rendering of the DKIST Remote Office Building on Maui.



Figure 5.3-3. Remote Office Building construction at Pukalani, Maui.

Once constructed, the ROB will serve as the off-summit center for day-to-day operations of DKIST. We note that remote operations functions from the ROB 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 ROB will provide individual and shared office spaces. On average, 25 to 30 permanent and visiting staff would use the facility daily. Limited instrument/-optics lab and workshop space is provided. In addition to staff and visitor vehicles, it is anticipated that several facility vehicles for the DKIST facility would be staged in the parking lot of the ROB.

During FY17, substantial progress has been made with the construction of the DKIST Remote Office Building. In January 2017, NSF and AURA approvals were completed and a contract was executed with Arisumi Brothers, Inc. of Kahului, Maui. In February, Maui County construction permits were received, after 10 months of review, iteration, and updates; formal site work began on the 13th, with a formal blessing ceremony and groundbreaking for dignitaries hosted on March 3<sup>rd</sup>. Since then, the site has been grubbed and graded, foundations poured, underground utilities connected (including conduit for high-speed data line to UH-IfA, which provides data access to the summit observatory), elevator shaft and stairways formed and built, structural steel erected, roof waterproofing installed, exterior walls framed, and windows installed. Current activities include interior framing and drywall and rough-in of electrical, telecom, plumbing, fire sprinkler, HVAC systems, door access control, and photovoltaic systems. Also underway is the establishment of utility accounts, design of IT infrastructure, fabrication of doors, roofing and PV panels, and procurement of carpet, tile, paint, furniture, and more. The construction project has experienced approximately two weeks of weather delays, but overall is on track for an on-time completion and availability for occupancy in spring of 2018.

# 5.4 DKIST Science Working Group

Community participation in and support of the DKIST effort occurs through the DKIST Science Working Group (SWG) as well as the Data Center and Operations Sub-Working Groups. 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 5.4-1).

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, *http://dkist.nso.edu/CSP*, which describe the science objectives and instrument capabilities and includes links to abstracts of all Science Use Cases currently under development, and *https://nso-atst.atlassian.net/*, which is a collaborative environment for Science Use Case development. 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:

Magnetohydrodynamics and Dynamo Processes

- 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

### Flares and Eruptive Activity

- ▶ 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

In FY17, the SWG was reorganized in order to optimally support the CSP development. The membership was altered to better and more broadly reflect the various science objectives, in particular, those of the US community. The new membership of the SWG is listed in Table 5.4-1. A new charge to the SWG, again reflecting the focus on early science with DKIST, was developed as well. Due to the reorganization as well as the ongoing CSP workshop activities, the annual SWG meeting was delayed and will now be scheduled for spring of 2018. The input from the first CSP workshops will form the basis of SWG activities at this meeting.

The list of the CSP workshops, the dates of the events, and other relevant information can be found in *http://nso.edu/cspw.php*.

### 5.5 Instrumentation Development

In FY 2017, the DKIST MCAO project and the SWG recommendation to upgrade the VTF to a dual etalon system were pursued. In addition, we began to develop a sky brightness monitor that will support daily operations of DKIST on Haleakalā. Sky brightness measurements are needed as an indicator of coronal observing conditions and to guide the scheduling of coronal observations, in particular, coronal magnetometry. Design and prototyping for a SWG recommended prominence or limb AO system has also progressed.

To measure the scattered light sky brightness at DKIST to determine telescope operations, a modified version of the DKIST site survey Sky Brightness Monitor (SBM) will be used. This device will use a large CMOS camera combined with a set of eight color filters, to measure the sky brightness in the visible and at-large distances from the Sun in order to extrapolate to IR wavelengths and regions of the solar corona to be observed by DKIST instruments. Understanding the current sky brightness, and estimating the brightness expected during the observing day, will aid DKIST observers with the selection of DKIST observing programs.

Table 5.4-1 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-l	
23	Knoelker	Michael	HAO	US	Co-l	
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	

Design trade-offs are being investigated. Currently the SBM will use a 5-Mpix CMOS camera and observe the sky from about 3 to 7 solar radii at several colors. The project has received permission to use a freeware software package, Firecapture, to collect the data, and the analysis will be done in almost real-time using site survey analysis programs written in IDL. The sky brightness value, as well as estimates of atmospheric extinction and extrapolations to the position and wavelength of interest will be provided to the Telescope Control System. Solar acquisition and tracking options are being examined, and one technique using accelerometers and a simple Arduino code is also used for an education program with students from the Vail School District near Tucson, AZ. The students are testing the pointing accuracy of an accelerometer and compass Arduino breakout board, which may be used to point the SBM to the roughly 1-degree accuracy needed to acquire the solar target.



The conceptual design for a thermal infrared imager, which in terms of solar observations is a largely unexplored spectral region, was started in FY16 but had to be delayed in FY17 due to the expansive eclipse effort. Both eclipse and thermal infrared imager projects are led by NSO Astronomer Matt Penn. The eclipse presented a unique opportunity not only for public outreach and education but also from a scientific perspective.

Figure 5.4-1. Vail High School students testing Arduino board pointing accuracy.

The unique data set obtained during the eclipse will be used to guide the development of coronal use cases for DKIST. Spectral information obtained during the eclipse at relatively unexplored infrared wavelengths have provided much needed (measured vs modeled) brightness information for spectral lines that will be used by DKIST's coronal instruments. This information has been worked into the instrument performance calculators.

Penn continues work in collaboration with the New Jersey Institute of Technology (NJIT), which has led to science observations with the Cryogenic Infrared Spectrograph (CYRA) instrument at Big Bear Solar Observatory. The CYRA instrument is a cooled-grating slit spectrograph with a detector that is sensitive from about 1000 nm to 5000 nm. Scientific goals for the CYRA instrument include photospheric magnetic studies at 4135 nm, temperature minimum investigations using the CO lines at 2333 nm and 4666 nm, chromospheric observations with H I lines, and perhaps coronal studies using the 3934 nm line.

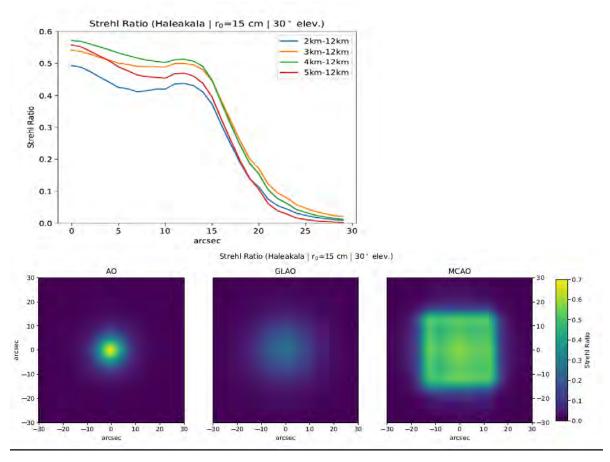
A strong partnership continues with the NJIT and the Kiepenheuer Institute for Solar Physics (KIS) for development of adaptive optics and multi-conjugate adaptive optics (MCAO). Solar MCAO will provide diffraction-limited imaging over a large field of view, a capability that NSO is pursuing with high priority for implementation at DKIST as part of second-generation instrument development. In FY17 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.

After a breakthrough achieved in FY16, several additional on-sky engineering runs with MCAO were performed in FY17 at the Goode Solar Telescope at BBSO in order to fully understand and document the performance of the MCAO system, its limitations and opportunities for optimization. NSO scientists Jose Marino and Dirk Schmidt are leading a significant part of the development effort. The complex prototype system, comprising three deformable mirrors and multi-field wavefront sensor still requires significant work to arrive at an operational system. However, guided by a simulator tool developed in house that can simulate the BBSO system as well as envisioned DKIST MCAO implementations, significant progress was made. For example, the automated reference update procedure was improved and now avoids field distortion and boosted the stability of the control loop. With the new method, we were able to run the MCAO control loop continuously for 53 minutes involving many reference update procedures.

A focus of FY18 will be to evaluate the MCAO system for its performance at near-infrared wavelengths.

A publication summarizing the system design and recent results has been published (Schmidt et al., *A&A* **597**, L8, 2017; see also Section 2.3 of this document). The MCAO collaboration is laying the ground-work for implementation of MCAO at DKIST. Based on the BBSO experience and the aforementioned simulator tool, the conceptual design of a DKIST MCAO system, which will be orders of magnitude more complex, has progressed. Initial optical design work was performed but has not progressed as quickly as anticipated due to resource contention. The procurement process for a deformable mirror (DM) system for the DKIST MCAO has been started. There is a single vendor currently capable of producing these systems with a long lead time (~ two years). The vendor has been slow in responding to a RFQ. We expect to conclude the procurement process for the first MCAO DM in early FY18, with a second DM procurement to follow at the end of FY18.

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. The prominence prototype system was developed by a graduate student from NMSU and demonstrated feasibility of the concept. In FY17 we planned to recruit a postdoc to help advance the prototype performance characterization and optimization. The search for a postdoc is ongoing but recruitment of this rather rare expertise has proven challenging. Nevertheless, progress was made with defining requirements for cameras and identifying available off-the-shelf options. Procurement of parts will continue into FY18.



**Figure 5.4-2.** Simulation of the DKIST MCAO system. The NSO developed versatile AO simulator tool was used to estimate the expected Strehl performance of the DKIST MCAO for a field of view of 60 arcsec x 60 arcsec comparing MCAO, GLAO, and CAO correction. The Haleakalā turbulence profile was used. The performance is evaluated at 500 nm and at an elevation of 30 degrees.

# 6 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) that will provide substantial operational support to NISP for at least five years. 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 2017 and 2018 have been and continue to be heavily impacted by relocation efforts as well as several large special initiatives. In addition to completing the migration of its staff to Colorado, NISP is completing the relocation of its Data Center from Tucson to Boulder and moving both SOLIS and the GONG engineering site. In parallel, NISP continues work on a major refurbishment of the GONG network, is migrating its space weather data processing to NOAA/SWPC, and is completing additional instrument upgrades. Loss of personnel resulting, in part, from NISP's relocation and budget uncertainties have made carrying out this ambitious agenda challenging; however, a dedicated and resourceful staff is committed to NISP's forward progress on each of these fronts.

# 6.1 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  $2K\times 2K$  H $\alpha$  intensity images are produced in near-real-time. These data are used by the US Air Force (USAF) 557<sup>th</sup> 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, and by the NASA Community Coordinated Modeling Center (CCMC) to initiate many of its models. 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 H $\alpha$  images are an increasingly popular data product, and have been used to study filaments, flares, and the oscillations of the chromosphere.

# 6.1.1 Relocation of the GONG Engineering Site

The relocation of NISP from Tucson to Boulder includes the GONG engineering site. Final site selection resulted in a location near the NSO Headquarters (see Figure 6.1-1), allowing for potential educational outreach use as well. Construction of the new site began in September of 2017 and, despite delays related to soil testing results, is expected to be finished in November. The two GONG engineering units were shipped from Tucson to Boulder in October. Once their installation at the new site is complete, they will again be available for supporting remote site and the GONG Refurbishment project.

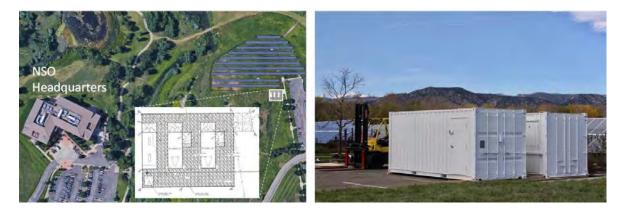


Figure 6.1-1.

# 6.1.2 GONG Refurbishment

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 6.6), is developed. In consultation with the NSO Users' Committee and community space weather forecasters, the upgrades listed below are underway. As of the writing of this report, it is anticipated that this project will be completed by the end of 2018.

- Replacement 1K×1K cameras An initial model was selected and tested; however, it was unexpectedly discontinued prior to purchase. A second model has now been evaluated, and a test kit for a third is being procured.
- Improved polarization modulators Replacement modulators have been purchased and tested. One has been installed at the Mauna Loa site, and deployment of the remaining is being coordinated with future site visits.
- Tunable H $\alpha$  filters –A source for these filters has been identified; however, testing and procurement was delayed due to temporary unavailability related to the 2017 total solar eclipse.
- 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 Aging workstations that currently handle H $\alpha$  and 676.7 nm observations separately will be replaced with more-powerful redundant instrument computers that will accommodate both. After initial testing, these new workstations have been ordered.
- Magnetic zeropoint improvements After extensive review and testing, the Data Acquisition System software at all of the GONG sites was modified to exclude the initial integration frames following modulator transitions.
- Additional improvements Weather station upgrades, replacement site maintenance kits, and restocked spare components have been procured. Deployment to the remote sites is underway. Network bandwith at the Learmonth site in western Australia has been upgraded.

# 6.2 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  $2K \times 2K$  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 H $\alpha$ , 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, H $\alpha$  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.

### 6.2.1 Relocation of SOLIS

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 6.2-1). 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. After a protracted permitting process, the County of San Bernardino issued conditional approval for the project on 29 September 2017. However, a four-month moratorium on construction activity near the Big Bear lakeshore begins on December 1. As of this writing, SOLIS is being prepared for shipment to BBSO. Its last day of observations in Tucson was on 22 October 2017.



**Figure 6.2-1.** The aerial view (left) of Big Bear Solar Observatory indicates the future location of SOLIS relative to the existing GONG site. The ground view (right) of the SOLIS site shows the soil bore testing performed prior to construction.

# 6.3 NISP Data Center

Between SOLIS and GONG (post-refurbishment), NISP acquires (depending on the observing cadence of the SOLIS/FDP) approximately 370K - 470K full-disk observations in an average month. That corresponds to 900K - 990K raw data files that are transferred from the remote sites to the NISP Data Center. Those observations are processed, for both science research and space weather applications, through various pipelines resulting in roughly 10M - 11M derived data products (including inter-mediate 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.

### 6.3.1 Relocation of the NISP Data Center

The total archival GONG and SOLIS data sets amount to roughly 600 TB at the beginning of FY18. Due to technical and logistical limitations associated with preserving a growing archive of this size using traditional RAID systems, NISP researched expandable file systems and invested in a DELL EMC Isilon data storage cluster in late 2016. At the same time, the combination of deferred maintenance for aging hardware and the need to relocate the NISP Data Center without substantial interruption of services lead NISP to acquire replacement equipment for the rest of its Data Center operations as well. This provided an opportunity to redesign the Data Center hardware plan and remedy a variety of bottlenecks, conflicts, and vulnerabilities that had accumulated over many years.

After being configured in Tucson, this new hardware was relocated to Boulder in February 2017 and installed in the SPSC Data Center (see Figure 6.3.1), which is located on the first floor of the NSO Headquarters building. Following an extensive vetting process of the resulting data products, the various data processing pipelines were switched from production operations in Tucson to Boulder. This was concluded in October 2017; however, all NISP data products have been served out of Boulder since June 2017. As the final phase of the NISP Data Center relocation, a subset of older hardware that is not yet end-of-life, is being migrated from Tucson to Boulder in November 2017 to support additional non-production services (e.g., software development and scientific research).



**Figure 6.3-1.** Photos of the new 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 expandable data storage cluster rack (right).

# 6.4 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 zeropoint improvements, inversion of the new SOLIS/VSM chromospheric vector data, photospheric vector synoptic maps, H $\alpha$  limb maps, and mean polar field time series.

Research into the use of local helioseismology to detect active regions before they emerge continues, and helioseismic measurements of subsurface vorticity as a forecast of flare activity are being

developed. Both of these approaches hold out considerable promise of success, but also have proven to be challenging. Global 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 next activity cycle, number 25, may be even weaker than the current cycle. 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 22 years, as well as data from other ground- and space-based experiments.

Using helioseismology ring diagrams from GONG, NSO scientists can separate the behavior of the large-scale flows and the oscillation frequencies between the northern and southern hemispheres of the Sun. These observations are being used to understand the north-south asymmetric behavior of solar activity. With time-distance techniques, GONG data have revealed that the meridional north-south flows deep inside the Sun are far more complicated than assumed for dynamo models of the solar activity cycle. Thus, NISP scientific staff are participating in a NASA Grand Challenge Project to constrain dynamo models of the solar cycle using internal flows inferred from GONG and surface magnetic field measurements from SOLIS.

# 6.5 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 \$792K to support operation of the GONG sites in FY18. 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 being observed by NASA's Interface Region Imaging Spectrograph (IRIS) have been acquired regularly in order 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.

# 6.5.1 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 has hired postdoc Joseph Plowman 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 functional 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 to present at the AGU Fall Meeting, New Orleans, 11-15 December 2017. A peer-reviewed publication will follow. 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.

### 6.6 Towards a Multi-Purpose Global Network

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.

There are a number of new 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.

It is important to note that existing and future space missions often propose to combine helioseismic observations made from different vantage points to better map layers inside the Sun such as the tachocline. While we have long benefited from continuous Earth line-of-sight helioseismic observations from space that could be combined with observations made from a different perspective, the best way to secure such observations in the long run is through a ground-based network similar to GONG. The ESA/NASA Solar Orbiter mission (to be launched in 2018) will provide helioseismic observations made from a variety of perspectives including from out of the ecliptic. These observations will be made at particular mission orbits that are of interest for the study of the meridional flows near the poles and will occur well into the last phases of the mission (late next decade). Combining such data with observations made from the Earth line-of-sight will bring new insights about fundamental ingredients of the dynamo problem. Similarly, the combination of magnetic field observations from different perspectives, such as would be provided by the L5 Carrington mission proposed in the United Kingdom, allow for disentangling of complex projection effects that occur when observing crucial locations on the Sun such as the solar poles or the eastern limb. For example, SOLIS-like synoptic vector observations and similar Solar Orbiter measurements can be combined to clarify the distribution and strength of the magnetic fields at the

solar poles. We thus remain convinced that these opportunities will surely enhance the value of a ground-based synoptic network such as the one proposed here by NSO.

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 557<sup>th</sup> 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,  $H\alpha$  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. SPRING was also discussed at a workshop on Solar Synoptic Observations, held in October 2017 at the Max Planck Institute in Göttingen, Germany. The presentations from that meeting can be found at *http://science-media.org/conferencePage.php?v=26*.

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, and used funding from the 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 a full proposal for a new network in the next two to four years. Additional US agency partners are likely to be the USAF 557<sup>th</sup> Weather Wing, NOAA/SWPC, and NASA. In addition, the Atmospheric and Geospace Sciences Division (AGS) of the NSF Geosciences Directorate supports space weather research, which necessarily uses solar synoptic data as inputs for models.

KIS has held three workshops so far to discuss the project with partners. The websites for these meetings are at:

http://www3.kis.uni-freiburg.de/~mroth/spring.html http://www.astro.sk/SOLARNET\_2ND\_WORKSHOP/solarnet/first\_announcement http://www.astropa.unipa.it/Solarnet2015/Solarnet2015.html An approximate timeline of the network effort is:

- 2016 2020 Work with KIS, HAO and other partners to develop concept.
- 2016 2020 Advocacy for agency, international, and research partnerships.
- 2018 Submit instrument development proposal to the NSF.
- 2018 Submit infrastructure development proposal to European opportunities.
- 2019 2020 Assuming success, begin development of infrastructure and first-light instrument.
- 2018 2020 Continuing advocacy with AFWA, NOAA, NASA, NSF/AGS, etc.
- 2021 Submit proposal for network infrastructure plus first-light instrument.
- 2024 Initial deployment.

The NSF's Mid-scale Research Infrastructure Program represents an excellent opportunity to put SPRING on a firm funding line in the US. On 05 October 2017, the NSF released a Dear Colleague Letter (DCL; NSF 18-013), requesting information on existing and future needs for mid-scale research infrastructure projects from the US-based NSF science and engineering community. The DCL (08 December 2017 deadline) is available at:

https://www.nsf.gov/pubs/2018/nsf18013/nsf18013.jsp?utm\_medium=email&utm\_source=FYI&dm\_i=1ZJN, 586FF,P6USJ4,K4COK,1

# 7 EDUCATION AND PUBLIC OUTREACH AND BROADENING PARTICIPATION

In preparation for the total solar eclipse of 2017, and with the imminent arrival of DKIST, the NSO has significantly increased efforts in education, public outreach and broadening participation through the establishment of the Office of Education and Outreach (OEO), headed by Dr. Claire Raftery. Following on from this, additional staff have been added to the OEO.

- Tishanna Ben is a former middle and high school teacher from Kauai, Hawai'i, and is now the NSO's Maui-based Education and Public Outreach Assistant. Tishanna is working with the title "Community Outreach and Education Programs Leader for Hawai'i" in order to reflect the role she will play in engaging with the community.
- John Williams has been employed on a short term basis to redesign and rebuild the NSO website. John's experience as a web designer and a science journalist, uniquely positison him to create an appealing and engaging website full of focused and well-pitched content.

The total solar eclipse was a major focus for us this year. In order to provide a clear, coherent source of information, we developed a dedicated website, *eclipse2017.nso.edu*. On this page, we provided safety information about how to view the eclipse (taking our lead from the American Astronomical Society).

# 7.1 Eclipse Efforts

# 7.1.1 Citizen CATE

The summer's total eclipse presented a special opportunity for a group of citizen scientists including scientists, high school students, and educators. The Citizen Continental-America Telescopic Eclipse (CATE) Experiment monitored the outer atmosphere of the Sun, the corona, using a network of 68 identical telescopes located at various places along the path of totality. The individual high-quality images taken during the approximate two minutes of totality at each site are being combined to create an uninterrupted 93-minute sequence of the inner solar corona. Each of the volunteer groups were trained via a set of 11 workshops run at locations across the country. CATE has been funded with support from a combination of federal, corporate and private sources, including the National Science Foundation.

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

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

### 7.1.1.1 CATE Training Workshops in States along the Path

Twelve training workshops were held from 22 April through 28 May in locations across the path of totality. The CATE equipment was distributed to the CATE site volunteers, and the State coordinators, teaming with a CATE student, guided the volunteers through the solar observing sequence. In some states where there was a lot of travel, two workshops were held. Tennessee and Kentucky combined their workshops into one location, and a workshop was held in Tucson, Arizona for several groups from the southwest.

Table 7.1-1. CATE Training Workshops in 2017					
Date	Location	Number of Sites	Number of Participants		
22 – 23 Apr	Wyoming 1	5	10		
29 – 30 Apr	Illinois (Carbondale, IL)	6	21		
29 – 30 Apr	Missouri 1 (Columbia, MO)	4	10		
29 – 30 Apr	Wyoming 2	5	11		
29 – 30 Apr	Tennessee & Kentucky (Cookeville, TN)	10	40		
06 – 07 May	Arizona (Tucson, AZ)	4	25		
13 – 14 May	Missouri 2 (Atchison, Kansas)	2	5		
20 – 21 May	South Carolina	6	12		
20 – 21 May	Idaho 1	5	11		
27 – 28 May	Nebraska (Kearney, NE)	5	12		
27 – 28 May	Oregon	7	7		
27 – 28 May	Idaho 2 (Boise, ID)	3	12		

### 7.1.1.2 Extended CATE Training: Network Testing and Debugging

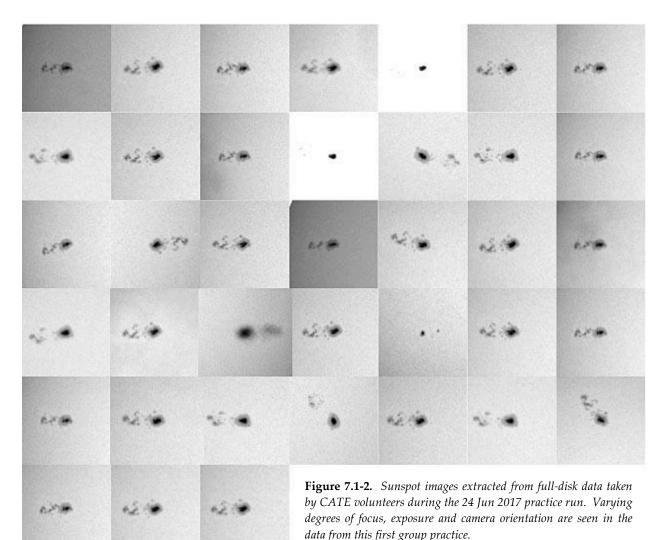
In addition to the training sessions held at the CATE workshops, five network-wide training dates were established to provide more practice for the CATE site volunteers and to encourage them to use their equipment from their home locations. After each session, the CATE volunteers would upload some of their practice data to a web page, and the CATE students ran diagnostic software to measure how well the volunteers were collecting data. Several parameters were used to determine the quality of the data from the volunteer, and then the CATE students provided feedback to the volunteers about their observations, along with suggestions for improvement, before the next training date observing session. In this way, we improved the ability of the site volunteers during hands-on practice with the equipment.

Participation in the first three practice sessions was at the 50% level or greater, with 34 or more sites practicing out of the 68 sites total. During all of the five practice runs, there was an increase in the

median **Focus** value (which is good), a decrease in the image **Drift** (caused by misalignment of the polar axis) by a factor of two, the camera alignment **Angle** moved much closer to the desired value of 270 degrees (an improvement by a factor of 10), and the pointing **Offset** also improved from the first measurement at 19 pixels.



**Figure 7.1-1.** Myles McKay (standing, right) from the Space Telescope Science Institute and Joseph Wright (center) of the University of Missouri-Kansas City Warkoczewski Observatory with site volunteers at the Missouri CATE meeting in Columbia, MO on 29 April 2017.



### 7.1.1.3 Analysis of 2017 Eclipse Data

Principle Investigator Matt Penn has constructed sample images from many sites, and several sample movies. Some sample movies can be seen on the project web page, *https://citizencate.org*. Initial analysis suggests that the CATE teams collected images during more than 80% of the 93 minutes that were available from coast to coast. Quick-look movies show that there are slow outflow events (about 10 km/s) in the SE streamer, and more rapid outflow events (about 100 km/s) in both the north and the south coronal holes. A small chromospheric surge on the west solar limb seems to be heated to coronal temperatures and then join the outflow of the solar wind. Polar plumes in the southern coronal hole evolve and seem to split. More analysis is required, and work on image alignment is progressing.

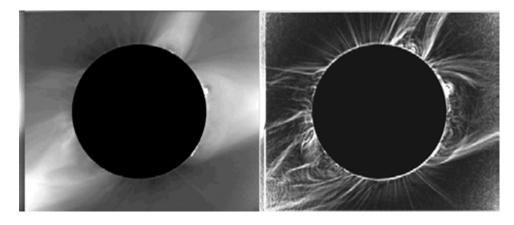


Figure 7.1-3. Early analysis of Citizen CATE data. Left shows the unfiltered, raw image. Right shows the highly-processed image designed to enhance scientific detail.

#### 7.1.1.4 Dissemination Activities

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

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

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

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

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

### 7.1.2 Eclipse Events

In addition to supporting the 68 Citizen CATE sites, NSO directly hosted two eclipse events on August  $21^{st}$ .

Working in conjunctions with the American Astronomical Society's Solar Physics Division (SPD), the EPO team ran a large public outreach event at Willamette University in Salem, Oregon. Partnering with the Willamette Academy—a minority serving after school program—we trained 15 Hispanic high school students on the fundamentals of the solar eclipse and how to run 12 different table-top demonstrations. On the day of the eclipse, the Willamette Academy students worked side-by-side with professional solar physicists from NSO and SPD to engage with their local community members who came to Willamette University to view the eclipse. The event was extremely successful with 2,000-3,000 people estimated to be in attendance. The students noted their appreciation for the opportunity to participate in such an active way during the momentous event. Following the eclipse, the Director of NSO presented each of the students with a certificate of appreciation.

The second event supported by NSO was held in Glendo, Wyoming. It was estimated by the Platte County Sheriff's office that about 185,000 people attended the eclipse in the Glendo area (it was estimated that there were 60,000 in Glendo State Park, 60,000 at the Town of Glendo Airport viewing area and the remaining 65,000 were scattered within the Town of Glendo itself and the neighboring ranch lands.) At one point, traffic on Interstate 25 was backed up for 11 miles as cars were exiting at Exit 111 in Glendo.

### NATIONAL SOLAR OBSERVATORY



**Figure 7.1-4.** Students from Willamette Academy worked with NSO staff to run a public outreach event in collaboration with AAS/SPD. Clockwise from top left: NSO Director with Willamette Academy Students; The crowd at the eclipse public outreach event; Willamette Academy student during the pre-eclipse training workshop; One of the activities administered by Willamette Academy students during the eclipse.

For the eclipse, the NSO provided Solar Safety visor hangars for every car entering Glendo State Park, and numerous additional "pop-up" style solar viewing safety seminars were presented to the public. The National Solar Observatory claimed premiere exhibit space highlighting its mission and the construction of the Daniel K. Inouye Solar Telescope at the Town of Glendo's limited exhibition hall. Current and retired Emeritus NSO staff also presented public talks throughout eclipse weekend.

Inclusive during this event was the attendance of Dr. France Cordova, Director of the National Science Foundation, who was able to witness first hand NSO public outreach efforts.

The Glendo Total Solar Eclipse culminated efforts for the past five years to prepare this tiny community of 200 for the thousands expected for the eclipse. Media reports attributing the NSO's efforts to support Glendo appeared



**Figure 7.1-5**. *NSF Director, Dr. France Cordova, at the NSO-supported Glendo eclipse celebration.* 

on *ABC* News, Nightline, the Washington Post, the China Global Television Network (CGTN), KTWO-TV (the ABC, Casper, Wyoming) affiliate), KCWY-TV (the NBC Casper, WY affiliate), Air and Space Magazine, the American Geophysical Union's "EOS" magazine, FiveThirtyEight, a digital publication of Nielsen Digital media and Sky and Telescope magazine. Additionally, approximately 54,000 "hits" were made on the 2017 Glendo Total Solar Eclipse website built and managed by former NSO employee Jackie Diehl who also assisted the Town of Glendo in raising about \$25,000 for expenses related to the eclipse.

# 7.1.3 Eclipse Website

We also developed an interactive eclipse map that allowed the general public to identify the degree of partiality at any place in the United States (*https://eclipse2017.nso.edu/eclipse-map/*). Although there are other interactive eclipse maps available, to our knowledge, this is the only one that provides times in local time rather than universal time (e.g., *http://xjubier.free.fr/en/site\_pages/solar\_eclipses-/TSE\_2017\_GoogleMapFull.html*). From the website analytics, it is clear that people came directly to NSO for information, with direct access (tying in the web address) or a Google search accounting for 80% of the traffic. The two most popular hits on the website were Citizen CATE and the interactive eclipse map, together accounting for almost 50% of the page views.

The focus of all our eclipse efforts was on science. We leveraged our large pool of solar experts to educate and inform the public on why the solar eclipse was of interest, what was happening during the eclipse, and the solar phenomena behind why the corona looks the way it does. This transpired in a number of ways. The new website provided an excellent forum for general context: *https://eclipse2017.nso.edu/science/*.

### 7.1.3.1 Eclipse Webcast

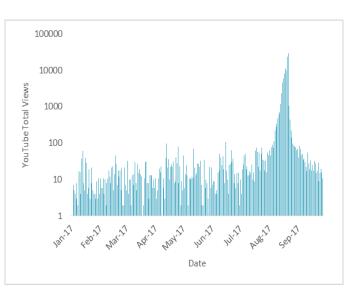
Following the 2017 AAS Eclipse Taskforce meeting in Carbondale, Illinois, it became clear that there was a lack of scientific understanding of solar science and the eclipse amongst eclipse event coordinators. In order to address this need, NSO produced a monthly webcast preparing for the eclipse.

Each month covered three topics:

**1. Solar Spotlight**: What do you *really* need to know about the Sun to understand what's happening during the eclipse?

**2.** Eclipse Tips: Learn about some fun ideas to engage kids (and adults!) in eclipse fun, fitting for the run up to eclipse day, and also for the main event!

**3. Straight from the Scientists**: Learn about cutting edge research being done in the field of solar science, straight from the researchers!



**Figure 7.1-6.** Total Views of NSO YouTube videos for 2017. Views peak in the weeks leading up to the solar eclipse.

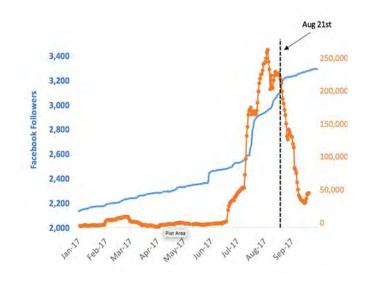
The list of Eclipse Webcast topics covered each month, including science focus, activity demonstrated, invited speaker and total number of views (as of October 2017), are shown in Table 7.1-2. The webcasts exist in their full ~30-minute format on the NSO *YouTube* page (*www.youtube.com/nationalsolarobservatory*), as well as each segment (approximately five minutes) broken out separately, allowing viewers to watch the elements most relevant to them. The response to these webcasts has been strong, with most interest occurring within days of the solar eclipse (see Figure 7.1-6).

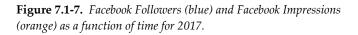
Table 7.1-2. Eclipse Webcast Topics, Invited Speaker, and Science Focus					
Solar Spotlight	Eclipse Tips	Straight from the Scientists	Total Views		
The Sun as a Star	Sun-Earth Scale Model	Adam Kowalski (NSO/CU)	1,076		
Layers of the Sun	Build Your Own Eclipse	Frank Hill (NSO)	494		
The Sun is Magnetic	Mapping Magnetic Fields	Gianna Cauzzi (NSO)	452		
Introducing Solar Activity	CME Slingshot	Alex Young (NASA)	250		
Observing the Solar Eclipse	Make a Pinhole Viewer	Shadia Habbal (UH)	493		
Using Eclipses to Prove General Relativity	Build Your Own Coronagraph	Laurent Pueyo (STScI)	473		
Mapping Solar Eclipses	Yardstick Eclipse (ASP)	Michael Zeilier (Great American Eclipse.com) & Xavier Jubier (Interactive Eclipse Mapper)	458		
The Sun's Effect on Earth (Energy Source, Space Weather, Habitability)	The Energy Game	Robert Steenburgh (NOAA/SWPC)	148		
What to Expect on Eclipse Day	Viewing the Eclipse Safely	Rick Feinberg (AAS)	222		

### 7.1.3.2 Social Media

We maintained an active and engaging social media presence throughout the year, with interest piquing throughout the summer. Our Facebook followers increased by approximately 50% though the year, with the majority of followers joining during the summer.

One of our major focuses on Social Media was the #60DaysofCitizenCATE campaign. Each day for 60 days, we featured one of the Citizen CATE sites, drawing attention to the hard work being done by small communities and dedicated volunteers. In addition to featuring them on social media, we also contacted press in the area, sharing a pre-drafted press release for them to edit and personalize. This campaign with a great success, with Citizen CATE having more than 30,000 hits on Google in 2017.



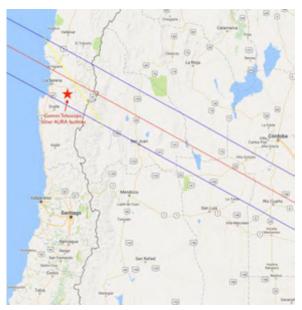


### 7.1.3.3 Future Eclipses

Discussions have begun regarding future eclipses. With 2024 on the horizon, lessons learned are being collated across many institutions including NSO. More urgent than that is the preparations for the 2019 eclipse in Chile. Given that totality will pass over some of the AURA facilities in Chile, NSO is planning to work with AURA-O to reuse some of our materials by translating them into Spanish. Those materials will then be ready for use in both Spanish and English during the 2024 eclipse which will pass through predominantly Spanish speaking parts of Texas.

#### 7.1.3.4 Solar Eclipse Teacher Workshops

In collaboration with CU Boulder's Fiske Planetarium's Education Department, we designed and ran four teacher professional development



**Figure 7.1-8.** *Path of 2019 eclipse through Chile with AURA telescope location marked.* 

workshops in Boulder for local K-12 teachers. The first of the four was a stand-alone test case focusing on eclipse preparation and using this momentous event as a teachable moment to engage students in STEM.

The remaining three workshops were orchestrated in collaboration with the Boulder Valley School District (BVSD) as part of their Professional Pathways Teacher Education series. This series was attended by 19 teachers ranging from 3<sup>rd</sup> grade to 12<sup>th</sup> in subjects including science, math, social science and general education (elementary). The timing of the first workshop (dictated by BVSD) coincided with the first week of school and the solar eclipse. This workshop therefore focused on the science behind the eclipse, and how to view the eclipse safely. The second workshop (October) focused on solar storms and space weather, with the third focused more broadly on the role of the Sun in the solar system and its role in planetary habitability.

The feedback received from the anonymous evaluations administered by the School District shows these to be extremely successful, with comments such as "Best professional development that I've had in years! Thank you!"; "Today's professional development has filled me with new ideas and exciting ways to explain and teach students about the upcoming solar eclipse"; "I REALLY love this professional development. We learned about the Sun yesterday, and I couldn't stop talking about it with folks"; "Today's professional development has filled me with new ideas and exciting ways to explain and teach students about the upcoming solar eclipse"; "I REALLY love this professional development. We learned about the Sun yesterday, and I couldn't stop talking about it with folks"; "Today's professional development has filled me with new ideas and exciting ways to explain and teach students about the upcoming solar eclipse."

# 7.2 Education and Public Outreach in Hawai'i

As mentioned previously, NSO has hired a full-time staff member in June 2017 to conduct EPO activities in Hawai'i on the center's behalf. Activities have included:

## 7.2.1 Public Outreach in Hawai'i

We have attended two Astro Days on the Big Island of Hawai'i, both of which were organized by the University of Hawai'i's Institute for Astronomy (IfA). In addition, NSO/DKIST participated 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 at each event.

#### 7.2.1.1 Kula A Ka Lā

Using a gift of \$20,000 from Sting, the performer, NSO has purchased solar telescopes for every middle school in Maui County (including the islands of Maui, Lāna'i and Moloka'i). Leveraging this gift, we have developed a curriculum designed to integrate modern astronomy using the personal solar telescopes, with Hawaiian culture and traditional practices. This approach leverages ancient ways of navigating, chants (Oli), Proverbs ('Ōlelo No'eau), and stories (Mo'olelo) to engage students in modern day observations and scientific practices.

We have begun the process of engaging local science teachers who will enroll in the program. We will first pilot test the lessons in one or two classrooms before holding a teacher training workshop to disseminate the curriculum and telescopes across the county. Once county-wide dissemination has begun, we will continue to interact and provide support for teacher during their implementation. This will be through ongoing workshops and class visits. We are also considering hosting an annual symposium where teachers and students can display their work, learn from each other, and hear from solar physics experts.



## 7.2.2 Planning for DKIST First Light

We have begun the process of creating a Communications and Outreach plan for DKIST first light. With this date planned mid 2019, we have identified a series of milestones and dates to work to, based on the delivery dates of optical components and instruments. We will aim to leverage the engagement achieved by the eclipse to educate and inform the general public, government officials, educators, and other interested parties in the scientific objectives of DKIST. This will be a multimedia format including video interviews, photography, infographics, written blog posts and press releases.

## 7.3 Other EPO Activities

#### 7.3.1 NSO Website Redesign

With the operationalization of DKIST imminent, the eyes of the solar physics community, the general public, and policy makers will turn to NSO. In order to provide the best outward facing interface with these audiences, we are redesigning the NSO (including DKIST and NISP) websites. Given the divestment from Sunspot and Kitt Peak, this activity is a timely opportunity to streamline our website and reset our priorities of information transmitted to the public. This new, modern site will be created in-house with input from all science and engineering teams interfacing through the EPO team. This will ensure that information is accurate but also accessible by non-experts. Soft launch of the new site is expected in late spring of 2018.

#### 7.3.2 Blog

In lieu of a bi-annual newsletter like NSO has disseminated in the past, we have decided to move to a more frequent blog format. This is temporarily hosted at *eclipse2017.nso.edu/blog* until the new website has been developed. The goal of the blog is to keep NSO employees, the solar physics community, general public, and other stakeholders informed about happenings at NSO. The content is widely varying, from paper summaries, to construction updates and congressional meetings. We aim to have this as a dynamic and engaging way of staying informed about happenings at NSO.

#### 7.3.3 Undergraduate Research

2017 saw the first year of NSO's participation in the Boulder Solar Alliance (BSA) Research Experience for Undergraduate (REU) program. This move away from an NSO-led program is a step towards integrating NSO into the broad solar physics community that is already in existence in Boulder, CO. The program is administered through CU Boulder's Laboratory for Atmospheric and Space Physics (LASP), but leans heavily on the support and input of EPO lead, Claire Raftery. Although the BSA program has been running for a decade, the proposal was renewed



**Figure 7.3-1.** Boulder Solar Alliance REU cohort in the lobby of the NSO and LASP building.

beginning in 2017 with some major changes to accommodate NSO. One of the most significant is the goal to increase participation by Hawaiian students. This is of particular interest to NSO due to our desire to increase the number of qualified applications for Hawai'i-based positions with DKIST.

In line with shifting priorities communicated by the NSF program officer, we are also increasing the participation by community college and underrepresented students. The participation rate by female students has been 78% for the BSA program, but ethnic minority participation has been minimal. Based on experience and input from NSO, changes to the application form, recruitment strategy, and mentor preparation have been implemented. These include three videos designed to explain the program by students themselves that were developed by NSO:

- 1. Will I be prepared for the program? *https://youtu.be/U6u-J3E8WJ8*
- 2. What is the work environment like? *https://youtu.be/I0bTpShn4jc*
- 3. Living away from home; Life in Boulder https://youtu.be/-wu0LWjGMpA

This program takes 12 NSF-funded students and approximately 25 students in all, of which NSO hopes to accommodate three to six each year (depending on project availability). The remaining students are placed at other solar and space physics institutions around Boulder such as LASP, NOAA, and the High Altitude Observatory.

In addition to the REU program, NSO also participated in the Akamai Workforce Initiative (AWI) – a program designed to develop a workforce that reflects the diverse population of Hawai'i through mentorship, internship and on-site training. NSO scientists and engineers mentored or co-mentored five out of 29 Akamai interns, with two students dedicated to DKIST. Of particular note is the recruitment of Akamai alumnus, Brialyn Onodera, as a full-time engineer for the DKIST project. Brialyn makes the third Akamai alum to be recruited by NSO for DKIST. This explicitly shows that continuing to invest in training and preparation of local students is a worthy investment as they are now prepared to take on the roles available by technical projects such as DKIST.

#### 7.3.4 Interactions with Congress

Throughout 2017, we had three separate interactions with members of Congress or their staffers:

1. NSO was invited to represent the American Astronomical Society (AAS) at the Coalition for National Science Funding (CNSF) conference in the Rayburn House Building on 16 May 2017, during which time NSO delagates interacted with staffers, members of Congress and the Director of NSF, Dr. France Cordova. In conjunction with this visit, NSO and AAS delagates met with staffers from a number of senate and representatives offices. Those of particular interest to NSO are Senator Brian Schatz (D-HI), Represenative Ed Perlmutter (D-CO), and Representative Jarid Polis (D-CO).



**Figure 7.3-2.** NSO Delegate Claire Raftery discusses the eclipse with Dr. France Cordova during the CNSF conference in May 2017.

2. Following the eclipse, NSO astronomer Dr. Matt Penn and AURA Executive Vice President Dr. Heidi Hammel were invited to testify at the House of Representatives' Subcommittees on Research and Technology and Space for a hearing on "The Great American Eclipse: To Totality and Beyond". The focus of the hearing was on safety, science, public engagement, and preparation for the future. Dr. Penn, one of our tenured astronomers, testified on behalf of NSO with a focus on Citizen CATE. Dr. Hammel spoke of NSO's work in educating the general public on the scientific elements of the eclipse. Link to the entire hearing is at https:-//www.youtube.com/watch?v=P3Z8hbyFWUg.



**Figure 7.3-3.** *Dr. Hammel (left) and Dr. Penn testifying during the House Hearing on "The Great American Eclipse: To Totality and Beyond".* 



**Figure 7.3-4.** *Ms. Albright (center with arms folded) listening to an explanation of the DKIST active optics system by engineers Luke Johnson and Erik Johannsson.* 

3. On 23 October, NSO received a visit from Ms. Leslie Albright, staff member of the Commerce, Justice, Science (CJS) subcommittee of the House Appropriations Committee. She has been working on the science issues of the bill (NASA, NSF, and OSTP) since Rep. John Culberson became the Chairman CIS subcommittee of the (January 2015). Prior to that, she worked on the Commerce Department budget for CJS. She has also worked on the committee in other capacities and worked at the Department of Commerce budget office. During the 1.5-hour visit, NSO Director,

Dr. Valentin Martinez Pillet, presented some early results from the Citizen CATE campaign, the current on-budget and on-time status of DKIST, the importance of DKIST for understanding the fundamental processes involved in space weather, and how the NSO GONG network is integrating into NOAA's Space Weather Prediction Center (SWPC). Following the conversation, the DKIST Project Manager lead a tour of the optical clean rooms, demonstrating the talent and prowess of the DKIST engineering teams in pushing technology to the limit in order to provide excellence in the acquisition of scientific data.

# 8 NSO TRANSITION UPDATE

FY 2017 marked the end of the NSO's Headquarters transition to the University of Colorado, Boulder (CU-Boulder). A total of 69 employees are now based in Colorado. This group includes a mixture of DKIST construction and NSO base-funded staff. NSO-Maui ranks second with 52 employees onsite, with the majority involved in DKIST construction. In Sunspot, seven employees operate the facility, including telescope operations at a reduced level. As planned, the DKIST construction team still maintains a considerable presence in Tucson with 16 employees, including astronomer Matt Penn. Because of the delays in SOLIS relocation, NISP also has had a significant presence in the Tucson offices. Including scientists, technical and administrative staff, 10 basefunded employees are still in Arizona. After the first quarter (Q1) of FY 2018, base-funded employees in Sunspot, Tucson, and Kitt Peak will support transition and site closeout activities.

## 8.1 NSO Headquarters at the University of Colorado

Early this decade, AURA and NSO decided that the advent of a unique facility such as DKIST could only be fully exploited by drawing the Observatory closer to younger generations of astronomers and engineers. Through an open-call process, the AURA Board in 2011 selected the University of Colorado, Boulder as the new site for NSO's Headquarters, which would serve as the scientific hub for DKIST. CU-Boulder was considered the best location to foster NSO's mission of advancing knowledge of the Sun, both as an astronomical object and as the dominant external influence on Earth. The collocation in Boulder of the two NSO Programs, DKIST and NISP, is also intended to promote the synergies between these Programs and enable common science in ways that have not been possible thus far.

In FY 2017, NSO and CU-Boulder have continued with collaborations through various faculty positions, the George Ellery Hale (GEH) postdoctoral and graduate fellowships, and the COLLAGE graduate program as described in the NSO/CU-Boulder Cooperative Agreement (CA). The second, and last, joint NSO and CU-Boulder faculty position was successfully filled in FY 2017. The selected candidate, Dr. Maria Kazachenko (UC Berkeley), brings to NSO a wealth of knowledge in coronal modeling based in novel applications of first principles that can easily adapt to the high-resolution observations that DKIST will provide. The depth and breadth of her research is unusual for a junior scientist. Dr. Kazachenko has agreed with NSO and CU-Boulder to postpone her starting date in Boulder until August 2018. Another key component of the CA, the GEH Program, provides funding for two three-year graduate student fellowships and one two-year postdoctoral fellowship each year (six graduate student fellows and two postdoctoral fellows in residence at any one time). In FY 2017, the two GEH graduate fellows selected NSO as their primary research center and regularly commute between the main campus and our facilities. Dr. Feng Chen, a graduate of the Max Planck Institute for Solar System Research (Gottingen, Germany), started as the 2017 GEH postdoctoral fellow in early September. Dr. Cheng has worked on simulations on flux emergence in the upper convection zone and solar photosphere using the MURaM radiative MHD code. The simulations from this code have enough realism to allow a direct comparison with the detailed observations DKIST will provide.

Six GEH graduate students currently use LASP or NSO as their research center. The student rotation element, which started last year, exposes them to a diverse pool of research topics that they

evaluate as potential themes for their PhDs. Several such rotations occurred in FY 2017 and will continue next year.

NSO's scientists regularly contribute to the pool of research projects offered to the students for their consideration.

With over 60 employees on the third floor of the SPSC, NSO has fully occupied the Boulder facilities. Office and cubicle spaces are becoming scarce. Last year we started minor remodeling that transformed common areas into additional offices. This pressure for office space coincides with the peak of hirings for DKIST construction and will lessen when construction ends. Space at the optical laboratory on the first floor is also in high demand. In addition to the Visible and Broad Band Imager (VBI) and the High-Order Adaptive Optics (HOAO) system, DKIST instruments currently in that lab, a new area has been allocated to the telescope's Polarimetric Analysis and Calibration (PA&C) unit. All of these instruments move to Maui over the next year or so. NISP uses an optical bench in this laboratory for GONG refurbishment activities.

The DKIST and NISP Data Centers both use space in the room provided by the CU-Boulder Office of Information Technology (IT) in the SPSC Data Center, located on the first floor and across the hall from the NSO optical laboratory. While the NISP Data Center is already a reality and serves data from the Boulder HQ, the DKIST Data Center currently uses only prototyping machines and will ramp up its presence as they pass through the preliminary and final reviews in FY 2018.



Figure 8.1-1. NSO machine shop at the off-campus site in Boulder.

In FY 2017, NSO relocated the machine shop from Sunspot to a Boulder offcampus location (see Figure 8.1-1). Early the transition, NSO initiated in discussions with LASP about co-locating our machines at their facilities in the LASP engineering building. Because of prevailing International Traffic in Arms Regulations (ITAR) at LASP and complex liability concerns, it was decided to search for a new off-campus machine shop location. NSO/AURA has leased 2757 square feet of usable space at an industrial warehouse on Longbow Drive in Boulder, and the machines from Sunspot arrived on 01 September 2017.

The DKIST construction project has had an ongoing need for what has been oversubscribed machine shop time. As such, DKIST will continue to have priority for use of the machine shop until the end of the project. NISP has relocated some equipment from Tucson that are used for various GONG refurbishment tasks. NISP machining needs will either wait until opportunities appear on the DKIST planning schedule or services will be sought elsewhere. After completion of DKIST construction, the machine shop will be an Observatory-wide service.

## 8.2 The NSO Remote Office Building in Maui

In Maui, the DKIST construction workforce continues to increase at the expected pace. About 32 NSO employees are residents on the island. The ramp up for operations, however, is moving at a slower pace than the staffing plan presented in the Cooperative Agreement proposal. Delays in the availability of the Remote Office Building (ROB) have prevented NSO from increasing the operations workforce at the pace described in the original CA proposal. This slower hiring pace is partly responsible for the DKIST project's unusually large amount of carry forward funds.

Details about the Remote Office Building are presented in Section 5.3-3. When the ROB becomes available in spring 2018, NSO will relocate personnel for DKIST operations from its mainland sites to the island of Maui, including the telescope operators trained at the DST.

### 8.3 Sunspot Divestiture and Future DST Operations

The Cooperative Agreement proposal submitted by AURA in 2013 for the management of NSO contains provisions for the divestiture of Sunspot in FY 2018. It states explicitly that \$0.561M would be available for *'completing the transfer to another organization or to aid with closure and reclamation.'* Accordingly, the Sunspot budget in FY 2018 allocates this amount (and the corresponding indirect costs) to activities in support of the New Mexico State University (NMSU)-led consortium and to some closeout actions discussed with NMSU.

In Sunspot, there is one telescope operator, one telescope support engineer, two facilities maintenance staff, one administrative person and a part-time site manager. Housing and the Visitors Center also use part-time personnel. The departure of NSO has impacted our onsite personnel in different ways. The AURA Human Resources Office has assisted with the preparation of a package of material for each person with formal notification of the date of employment termination and applicable benefits (accrued vacations payout, health insurance after separation, etc.). The package follows AURA best practices from past reduction-in-force (RIF) processes. NSO has included these costs as transition funds in the Director's budget. NSO estimates that the FY 2018 Sunspot budget can cover personnel salaries and the usual cost of utilities until the end of Q2, FY 2018. At that time, all funds would be near depletion. The budget also includes the Boulder-based DST scientist's salary and some carry forward funds. The expense plan for FY 2018 also provides for necessary mothballing activities, such as repairing the roof of the Evans Solar Facility; the ultimate use of these funds, however, will depend on ongoing conversations with the NSF and NMSU.

At the time of this writing, it is unclear whether the NMSU-led consortium, Sunspot Solar Observatory Consortium (SSOC), will succeed in starting operations of the DST in 2018. The consortium has been only partly successful in securing the funds needed for the estimated yearly operations. Since early 2017, the SSOC has two employees on-site, a telescope operator and an IT person, who have been trained by the equivalent NSO staff. The other job opportunities advertised by the SSOC have not been formally filled yet waiting for clarification on the future of the consortium. Given the level of support confirmed thus far, NMSU has decided to postpone any further hire until the State of New Mexico decision on their operations proposal.

During each of the past two years, NMSU has submitted a proposal to the State of New Mexico Higher Education Department requesting support for operating the site. In both instances, the proposal was ranked with the highest priority but not approved by the State due to lack of funding. As a result, the NSF provided a grant that allowed NMSU to have some presence onsite since early FY 2017. This bridge funding ceases at the end of FY 2018. Given these circumstances, NMSU has decided to wait for this year's final go/no-go decision from the State of New Mexico to operate the DST (and other site facilities such as the Visitors Center). NMSU expects to receive the response from the State by late February/early March 2018. Thus, and after consultation with the NSF and the NMSU, NSO has decided to use FY 2018 funds to operate the facility at the current minimum level to ensure a relatively smooth hand-over if an affirmative decision is reached.

If the State of New Mexico decision is negative, the consortium will most likely dissolve. At this point, further conversations with the NSF will have to occur to decide on the future of the facility, including site closure.

### 8.4 Divestiture of Kitt Peak Facilities and Tucson Office Space

At Kitt Peak, the NSO operates the McMath-Pierce Solar Telescope (McMP) and the Kitt Peak Vacuum Tower (KPVT) that hosted the SOLIS instrument. 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.

Following a similar model to the one used for Sunspot, NSO has decided to continue operating the facility until the end of calendar year 2017. This time, however, no new base funding has been allocated, and all any balance of available funds are from McMP carry forward, mostly generated through users' contributions. Two observing runs at the McMath were scheduled during Q1-FY 2018. No operations will occur during the remainder of the year. NSO has initiated discussions with the NSF as to how any potential closeout activities would be supported.

The Kitt Peak Vacuum Tower is extraneous to the needs of the NSF and NSO as the SOLIS instrument is being relocated to Big Bear Solar Observatory (BBSO). Thus, a potential demolition of the tower—without impacting the McMP—is under consideration. In collaboration with AURA Central Administrative Services (CAS) and with NOAO, NSO will prepare in FY 2018 a general scope of work document highlighting the primary requirements and concerns for the demolition project. An open bidding process will identify a contractor with the engineering staff capable of addressing the issues posed by the demolition.

NISP has been moving equipment from the Tucson building and from the "Farm" to Boulder Headquarters during FY 2017. The two GONG engineering shelters arrived at their new CU-Boulder East Campus location on 17 October. A third shelter will serve as an additional storage site. At the University of Arizona Farm, the SOLIS facility is ready for its final relocation to BBSO. Office and lab space at the Tucson building have been incrementally vacated by NSO and transferred to NOAO and LSST, and the remaining NSO space will be completely vacated by the end of calendar year 2017. Carry forward funds from Tucson accounts are being used to cover the cost of office and lab space in Q1-FY 2018. The presence of NSO base-funded personnel will no longer exist in the Tucson building effective 01 January 2018, and impacted staff will transfer to remote-worker status or will terminate employment with NSO. As in Sunspot, AURA HR will provide these individuals with a formal notification package of employment termination and applicable benefits or, if applicable, details of new employment.

#### 8.5 Transition Timeline, FY 2017 Milestones, and Transition Risks

The Cooperative Agreement proposal explains the timeline for NSO's transition (see Figure 8.3-1). An update on the status of the various milestones is presented in this section. Three major guidelines included in the Request for Proposals from the NSF dictated the timing for NSO's transition milestones. These guidelines are part of a recommendation of the 2012 Portfolio Review Committee to the NSF/AST and are:

- The end of NSO operations of the DST and McMP by late 2017.
- A decrease of the NSF/AST contribution to the NISP budget to \$2M by FY 2016.
- The beginning of DKIST operations in 2019.

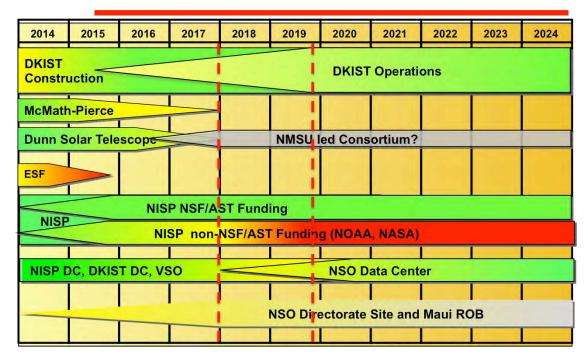


Figure 8.3-1. NSO transition timeline and major milestones (red dashed lines).

In Table 8.3-1, we outline in green the transition milestones that have been successfully achieved, and in orange those that have suffered a delay of about one year. Milestones for the years FY 2014-2016 are in green. In FY 2017, NISP recovered a large part of the delays incurred in the past, and the only remaining milestone that is not on time is the relocation of SOLIS to BBSO. SOLIS site

preparations and the re-start of operations will occur before summer 2018. For DKIST, the delays incurred are related to the late availability of the ROB and the subsequent delays in building the operations workforce on the island. NSO presence in Tucson and Sunspot has been extended for the first quarter of FY 2018 to facilitate a smoother transition at both sites. While NSO presence in Sunspot might need to continue for closeout activities over the remainder of FY 2018, in Tucson the end of NSO base-funded presence will occur on 01 January 2018.

		Table 8.3-1. Trans	sition Milestones*		
	2014	2015	2016	2017	
NSO HQ	<ul> <li>Lease with CU-Boulder signed (Lol).</li> <li>NSB Action Item</li> <li>Director is Boulder- based</li> <li>Sac Peak Site Leader</li> <li>Transition Plan Draft</li> </ul>	<ul> <li>New CA starts</li> <li>Tucson Site Leader</li> <li>Update Transition Plan</li> <li>3rd-floor remodeling starts</li> <li>3rd-floor inauguration</li> <li>NSO Sac Peak moves</li> </ul>	<ul> <li>Update Transition Plan (Q1)</li> <li>Continue moves from NSO sites (Q2-3)</li> <li>Library relocation (Q1)</li> <li>CA signed with CU (Q2-3)</li> <li>Decision on NMSU consortium (Q2-3)</li> </ul>	<ul> <li>Update Transition Plan (Q1)</li> <li>Continue moves from NSO sites (Q2-3)</li> <li>Decision on McMath (Q3-4)</li> <li>NSO base-funded presence in Tucson ends (Q4)</li> <li>Transfer of Sac Peak operations to NMSU (Q4)</li> </ul>	
DKIST	<ul> <li>DCPM hired</li> <li>DKIST AD is Boulder- based</li> </ul>	•Operations funding wedge •DC core team formed •First science position, Maui •WFC team starts relocation	<ul> <li>Support &amp; operation teams in Boulder/Maui build up (Q2-3)</li> <li>Continue moves of science team to Boulder/Maui (Q2-3)</li> <li>ROB construction approved (Q3)</li> </ul>	<ul> <li>Support &amp; operation teams in Maui build up (Q1-4)</li> <li>Continue hires in Maui (Q1-3)</li> <li>DKIST ops is Boulder-based (Q2)</li> <li>ROB available (Q4)</li> </ul>	
NISP	<ul> <li>SOLIS relocates from KP to Tucson</li> <li>SOLIS overhaul starts</li> </ul>	<ul> <li>SOLIS RFP announcement</li> <li>NISP scientific staff relocation starts</li> <li>NISP AD relocates to Boulder</li> </ul>	<ul> <li>Relocation of NISP DC starts (Q2)</li> <li>SOLIS site selection (Q2)</li> <li>NISP scientific staff relocation (Q2-3)</li> <li>Relocation of GONG engineering unit starts (Q4)</li> </ul>	<ul> <li>SOLIS relocates to final site (Q4)</li> <li>NISP DC in Boulder (Q2)</li> <li>Relocation of GONG engineering units (Q3)</li> <li>NISP is Boulder-based (Q4)</li> </ul>	

\*In green are the milestones that have been fully achieved; orange, those that are postponed by a year or less; and in black, those that are unchanged with respect to the previous year.

Table 8.3-2 summarizes the identified Observatory risks, all related in various ways to the transition, and their potential mitigations. It is a summary of a more thorough risk register for NSO's operations that uses the AURA provided simplerisk tool (*https://aura.simplerisk.it/*). Note that this table does not address directly the DKIST construction risk register that manages the project contingency. This table represents an update of what was included in last year's Annual Program Plan. The second column (Likelihood) provides the probability of occurrence and the third (Impact) the severity of the various risks, both following a five-grade scale. The most severe risks identified (ranked at 6 or higher) correspond to (a) losing key staff, in particular, top level managers; (b) potential funding shortfalls in the DKIST operations funding ramp up; and (c) reduced services at key facilities. The first risk (rank 8) primarily arises from the wearing out of personnel involved in the development of a state-of-the-art facility while, at the same time, the Observatory is executing a rather complex transformation. The second risk (rank 8), funding shortfalls, has increased with respect to last year given the prevailing budget atmosphere. A budget shortfall impacts various aspects of the operations scope and has the Data Center as the most critical element. We note that the design of the DKIST data calibration and distribution system started only about two years ago,

and was not included in the original MREFC scope (unlike the LSST case). While other similar facilities dedicate fractions for their data systems of about 20% of their total cost, the DKIST Data Center percentage budget is in single digits. The community has repeatedly requested that the DKIST Data Center distribute data products beyond level 1, including physical parameters deduced from inversions. Right now, the Data Center budget does not include the resources needed to provide such complex data products. The third risk, reduced services at key facilities, has also increased compared to last year. It reflects the delays associated with the SOLIS relocation that occurs now at a time when NSO has suffered significant losses of expertise from staff that are no longer available to support the move, in particular, to help bring the facility back into full operations at an entirely new site.

Та	ble 8.3-2. NS	O Operatio	ns Risks and Mitigation Strate	egies (09/17)		
Risk <sup>1</sup>	Likelihood <sup>2</sup>	Impact <sup>3</sup>	Implications	Mitigation		
Losing key staff 8	5 (→)	4	Delays in transition to Operations. Degraded services	Communications. Internal promotions. Re-hire vacancies		
Insufficient Ops. budget 8	4 (♠)	5	First light instruments cost overruns implications. Degraded services Data Center.	Operations scope negotiation with stakeholders. DKIST visibility (AAS, etc.)		
Maui workforce (ROB delays) 3.6	3 (→)	3	Workforce buildup delays. Impact on the transition to Operations.	Budget re-profiling. Extended NSO presence in Sunspot.		
Staff disengagement 4.8	4 (→)	3	Decreased productivity. Degraded services.	Communications plan. Top-level manager's engagement.		
Reduced service at key facilities 6.4	Reduced service at key facilities4(^)		Fewer observing days/data products offered to the community. SOLIS continuity.	User's Committee involvement.		
Sunspot divestiture 4.8	4 (↑)	3	Training of DKIST operations staff. DKIST instrumentation development.	Collaboration with potential partners (NMSU).		
Integration in CU- Boulder $2 (\rightarrow)$ 4 3.2		4	Reduced DKIST community user base	Improved students flow. Engage other Departments & Universities		

<sup>1</sup>Risk=Likelihood×Impact×4/10. Maximum risk is 10.

<sup>2</sup>Likelihood: 1 less probable and 5 most probable. Arrows mark trends: increasing ( $\uparrow$ ), stable ( $\rightarrow$ ) and decreasing ( $\downarrow$ ). <sup>3</sup>Severity: 1 less severe and 5 most severe.

Sunspot divestiture risk has also increased (4.8). If the DST is finally not available during the time gap until DKIST is online, there will be no platform to train the new telescope operators. Doing this directly at DKIST will come as an additional overhead to what will be a busy period marked by the start of operations.

#### 8.6 FY 2017 Transition Budget

FY 2018 is the first year when the NSO transition does not utilize the DKIST funding wedge. The funds available for transition purposes are all remnants from previous years. The continuation of activities in Sunspot and Tucson into the first quarter of FY 2018 has postponed payments of the accrued vacation and the benefits included in the separation process. The estimated current cost of

these expenses is \$273K, but the final number is uncertain as it depends on the actual vacations earned and other benefits.

The ROB delays have prevented hiring and relocating personnel to Maui as originally planned. The unspent funds from delayed hiring processes are part of the transition budget carry forward. Similarly, the move of hardware to the island depends on the ROB availability and has not occurred yet. Additional moves of material and equipment from Sunspot and Tucson to Boulder are taking place during Q1-FY 2018. The final costs of these moves depend on the details of the divestiture processes at both sites. These transition funds were discussed during the original CA negotiations.

#### 8.7 Communications and Staff Feedback

Communications with the NSO staff have continued along the lines described in last year's Program Plan. We have convened specific informational gatherings at each of the impacted sites. This model better serves the transition at this stage, as it is clear that the information pertinent to one site is less relevant to the others. During FY 2017, two such meetings were held in Sunspot (one in conjunction with the August workshop) and one in Tucson (NISP specific). The topics presented at these gatherings were divestiture updates, the remote working policy, benefits packages at the end of employment, retention bonuses, etc. A summary of the status of the NSO transition and future plans was presented at a science staff retreat in Boulder, the second in four years. This retreat discussed at length the service time allocations expected for science- and tenure-track scientists.

In FY 2018, AURA/HR has resubmitted letters of information to those employees for whom employment terms have changed. Given the dynamic situation of the divestiture process in Sunspot, practically all employees there received new letters from HR this past year. The transition website, *http://www.nso.edu/relocation*, continues to be updated with information about relocation policies, new open positions, and the transition schedule. The online anonymous feedback form for NSO staff continues to be available, and the FAQ was updated after the one-on-one meeting series, primarily addressing HR-related concerns.

# 9 FY 2018 SPENDING PLAN

The NSO spending plan is based on receiving the President's FY 2018 Budget Request of \$19M 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 Remote Office Building (ROB) in Maui. These repayments occur over the next five years, ending in FY 2022. The NSO's Program allocations presented here follow the guidelines in Table 8.4-2 of the Cooperative Agreement proposal submitted by AURA in October 2013.

Figure 9.1 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.

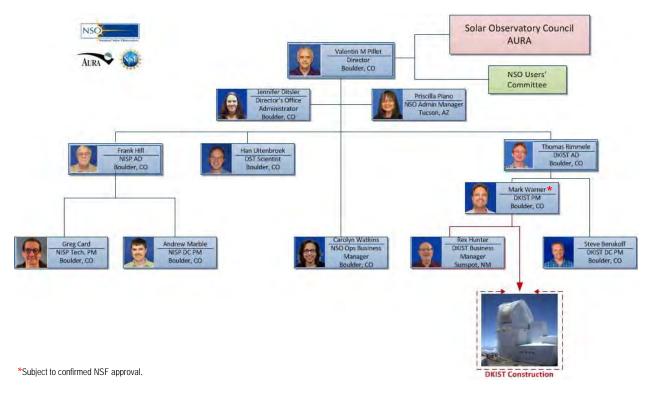


Figure 9.1. NSO organizational chart of cost-account managers.

## 9.1 Total Budget: FY 2018 NSF New Funds, Carry Forward, and Grants

Table 9.1-1 summarizes the funding that NSO expects to receive as new NSF funding, as well as anticipated non-NSF support for operations in FY 2018. The NSO Program in FY 2018 was developed based on receiving \$5,000K of NSF funding for the regular base program (which represents a reduction of \$1000K with respect to the previous year), and \$14,000K corresponding to this year's funding wedge for ramping up DKIST operations, totaling \$19,000K. In contrast to the past three years, no fraction of the DKIST operations funding wedge in FY 2018 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 (see also Section 8.6).

Table 9.1-1 NSO FY 2018 Funding	
(Dollars in Thousands)	
NSF Astronomy Division Funding	\$19,000
NISP Grants (VSO, NASA Infrastructure, etc.)	\$637
NOAA Support	\$800
Sunspot Revenue (Housing, Kitchen, VC)	\$48
Total NSO Funding	\$20,485

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.

As described in the CA proposal, FY 2018 is the final year of NSO presence in Sunspot. The budget allocated to Sunspot this year aims at supporting transfer of the facility to another entity for operations, or for performing closeout activities. Recent discussions with the NSF/AST have converged with an agreement to have NSO operating Sunspot at a minimum level for the first half of FY 2018. There are no plans to offer the DST to the community through regular open calls unless specific requests are received. The activities at the telescope will concentrate on preparing the synoptic observations planned by the Sunspot Solar Observatory Consortium. Operating the facility for the first half of the year will generate revenues from housing and the Visitors Center at an expected level of \$48K.

NSO 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 2018 budget includes an estimated \$637K from grants associated with various activities within NISP, with most of the funds corresponding to two NASA grants, one to support NISP infrastructure and another covering the participation of NISP in the Virtual Solar Observatory (VSO).

During Q1-FY 2018, NSO is maintaining a presence in Tucson to support SOLIS relocation activities. All funds used in Tucson and at Kitt Peak correspond to the site's carry forward. This year, NSO does not use new NSF funds for McMath operations or for the Tucson offices. In FY 2017, NSO received \$500K of Phase 1-funds to initiate the demolition of the Kitt Peak Vacuum Tower (KPVT; aka KP SOLIS Tower). These funds reside in a dedicated account in the Director's carry-forward budget and are intended to cover the initial costs of the activity.

In collaboration with AURA Central Administrative Services (CAS), NSO has continued to develop 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 Basis of Estimates (BOE) to document the various costs. In FY 2018, several improvements have been included in WEBUD; the most important being the possibility to select, after login to the web portal, one of the three funding sources: new NSF funds corresponding to the specific year (also selectable), grant funding, or carry forward (see Tables 9.1-2, 9.1-3, and 9.1-4). These three funding sources are now budgeted separately but with similar references to the various work packages and BOE entries.

	Table 9.1-2 NSO Spending Plan											
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	CarryForward/NSF Supplemental	Variance	Owner		
NSO	NSO HQ	NSO Headquarters	No	7.3	\$2,213,223	\$2,167,000	\$0	\$0	(\$46,223)	Pillet, Valentin J		
NSO	DKIST OP	DKIST Operations	No	43.1	\$13,967,729	\$14,000,000	\$0	\$0	\$32,271	Rimmele, Thomas R		
NSO	NSO TUC	NSO Tucson	No	0.0	\$0	\$0	\$0	\$0	\$0	Piano, Priscilla		
NSO	NSO NISP	NSO NISP	No	10.4	\$2,202,151	\$2,200,000	\$0	\$0	(\$2,151)	Hill, Frank		
NSO	NSO SP	NSO SP	Yes	3.3	\$680,036	\$633,000	\$47,718	\$0	\$682	Hunter, Rex G		
			Total	64.1	19,063,139	19,000,000	47,718	-	15,421			

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

Table 9.1-2 shows the five program areas that receive NSF FY 2018 funds: NSO Headquarters, DKIST Operations Program, NISP, Sunspot Operations (NSO SP), and Tucson Operations. As previously mentioned, NSO Tucson does not receive any new funding this year. As in FY 2017, the respective programs budgets now include indirect-cost payments which is why there are no allocations in the AURA Business Support line. 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 total of column 7 corresponds to the FY 2018 NSF budget of \$19M. Sunspot housing appears in column 8 as other revenues. The carry- forward column is a leftover from past WEBUD versions that is now a separate table provided below. Column 10 indicates the variance between the spending plan and the sum of the total revenues. The respective program allocations in column 7 follow the original budget presented in the CA proposal, but here they include indirect costs. The program variances are positive overall, except for the NSO Headquarters. The corresponding surplus in the HQ carry-forward budget compensates for this deficit, but this shortfall in HQ base funding points to the need for prorating the payments among the programs for common space at Boulder Headquarters.

			Table 9.	1-3 NSC	D Distribution o	f Carry-Forwa	rd Funds	5		
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	CarryForward/NSF Supplemental	Variance	Owner
NSO	NSO HQ	NSO Headquarters	No	3.6	\$2,685,517	\$2,731,890	\$0	\$0	\$46,373	Pillet, Valentin J
NSO	DKIST OP	DKIST Operations	No	2.8	\$8,338,495	\$8,417,636	\$0	\$0	\$79,141	Rimmele, Thomas R
NSO	NSO TUC	NSO Tucson	No	0.0	\$33,903	\$56,953	\$0	\$0	\$23,050	Piano, Priscilla
NSO	NSO NISP	NSO NISP	No	3.0	\$1,751,139	\$1,751,702	\$0	\$0	\$563	Hill, Frank
NSO	NSO SP	NSO SP	Yes	0.0	\$82,402	\$82,399	\$0	\$0	(\$3)	Hunter, Rex G
			Total	9.3	12,891,457	13,040,580	-	-	149,123	

Table 9.1-3 provides the distribution of carry-forward funds for each program. This table replaces the budget reconciliations included in past editions of the APRPP. The unspent budget originates primarily from delays in implementing various aspects of the transition. The NSO HQ budget continues its presence in Sunspot and Tucson for the first quarter of FY 2018; closeout costs for those

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sites have not yet occurred. Relocation expenses to Maui are on hold until the ROB becomes available. The HQ line also includes the KPVT decommissioning budget; if that amount is subtracted, the total HQ carry forward is similar to carry forward of previous years. The DKIST program carries forward funds that also result from the inability to implement the hires as described in the CA in the absence of a place to accommodate personnel in Maui. DKIST carry forward also includes costs for the Data Center that are on hold until the project and its scope are defined and consolidated after this year's scheduled reviews. For NISP, the \$1.75M balance results from the SOLIS relocation delays and unused GONG refurbishment funds. All facilities costs in Tucson (including the McMath Joint Use Fee for Q1- FY 2018) are covered from the site's carry-forward funds.

	Table 9.1-4 NSO External Funds											
Division	Sub-Division	Name	Locked	FTE	Spend Plan	NSF Base Funding	Other Revenue	CarryForward/NSF Supplemental	Variance	Owner		
NSO	NSO HQ	NSO Headquarters	No	0.0	\$0	\$0	\$0	\$0	\$0	Pillet, Valentin J		
NSO	DKIST OP	DKIST Operations	No	0.0	\$0	\$0	\$0	\$0	\$0	Rimmele, Thomas R		
NSO	NSO TUC	NSO Tucson	No	0.0	\$0	\$0	\$0	\$0	\$0	Piano, Priscilla		
NSO	NSO NISP	NSO NISP	No	8.9	\$1,733,822	\$1,807,061	\$0	\$0	\$73,239	Hill, Frank		
NSO	NSO SP	NSO SP	Yes	0.0	\$0	\$0	\$0	\$0	\$0	Hunter, Rex G		
			Total	8.9	1,733,822	1,807,061	-	-	73,239			

Table 9.1-4 shows the currently available grant funding, including the NOAA/SWPC FY 2018 contribution and associated past year's carry forward for NISP, and the number of NISP FTEs that are grant supported.

We note that as part of the new business practices, NSO continues to develop a change control process that will be finalized in FY 2018 and used for documenting changes to the budget presented in this report.

## 9.2 Work Package Breakout

The online WEBUD tool allows various modes of visualizing the budget distributions and BOE used in each of the NSO's Programs. In this section, we present an overview of the most significant expenses projected for each program. Tables 9.2-1 through 9.2-9 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 2018 funds, carry forward, and grants.

## 9.2.1 Director's Office (NSO HQ)

Table 9.2-1 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 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, one astronomer, 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 (\$0.5M) is used to pay for about half of the lease of the 3<sup>rd</sup> floor at

the CU-Boulder SPSC building. This cost includes all common areas. Insurance payments refer to all costs incurred for vehicles and liability at the operational sites.

	Figure 9.2-1	Director's Off	ice Budget			
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO HQ	7.3	\$1,248,298	\$964,925	\$2,213,223	\$0	\$2,213,22
Directors Office	1.9	\$488,409	\$92,354	\$580,763		\$580,76
AURA Corporate Direct Charges			\$0	\$0		\$
AURA Committees			\$105,503	\$105,503		\$105,50
Business/Administration	1.9	\$246,914	\$74,587	\$321,501		\$321,50
Recruit/Relo - New Positions			\$0	\$0		\$
Recruit/Relo - Existing Positions			\$0	\$0		\$0
Carryforward			\$0	\$0		\$
Insurance			\$72,029	\$72,029		\$72,02
CU Recharge Fees			\$6,367	\$6,367		\$6,36
Science Staff - Research	1.0	\$206,439	\$16,784	\$223,223		\$223,22
Research Assistants			\$0	\$0		\$
NSO Science-Collaborations			\$0	\$0		\$
NISP Operations Service			\$0	\$0		\$
DKIST Operations Service			\$0	\$0		\$
CSP Activities			\$0	\$0		\$
EPO - Scientists			\$0	\$0		\$
Joint CU/NSO			\$0	\$0		\$
Hale Post Doc			\$0	\$0		\$
HQ Operations			\$519,656	\$519,656		\$519,65
Boulder Computing IT	0.5	\$71,535	\$35,332	\$106,868		\$106,86
Vehicles			\$2,759	\$2,759		\$2,75
HQ Development & Relocation			\$0	\$0		\$
Instrument Development			\$0	\$0		\$
Education and Public Outreach	2.0	\$235,002	\$39,553	\$274,554		\$274,55
Total:	7.3	\$1,248,298	\$964,925	\$2,213,223	\$0	\$2,213,223
Target:						\$2,167,000
Variance:						(\$46,223)

Table 9.2-2 discloses the Director's Office carry forward from FY 2017 (\$2.7M). 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 Critical Science Plan Workshops (described in Section 5.4). A total budget of \$194K has been allocated to organizing the workshops. Eleven events with a combined total of over 160 participants will occur at various US universities and centers overseas. Additionally, \$56K has been budgeted for NSO staff travel to the workshops and related activities. A CSP Workshop coordinator has been hired part-time (50%) and funded with the Director's carry-forward budget.
- 2. Start-up package for the second shared faculty position with CU-Boulder. The corresponding funds were budgeted last year but remain unused due to Dr. Maria Kazachenko's late starting date (August 2018). The total amount is \$210K, including relocation costs.
- 3. Equipment moves to Boulder and Maui that have not occurred yet because of delays in divestiture of the facilities and with the ROB construction. The transition budget carries \$150K for these hardware moves.
- 4. An additional FTE for the EPO Department totaling about \$100K. This person is in charge of the NSO website redesign and provides additional graphics support.
- 5. Science support (\$200K). The end-to-end magnetograph calibration described in Section 6.5-1 is part of this budget.

- 6. Reduction in force costs totaling \$270K.
- 7. The EPO start-up package (\$94K).
- 8. SOLIS tower (KPVT) demolition \$500K.
- 9. New hires and relocations (\$200K).

The Boulder Computing IT line (both new funds and carry forward) covers a minimal scientific support infrastructure required during the transition. Long-term IT scientific support stays within the DKIST and NISP budgets. After the transition, this IT infrastructure remains available to visitors and students.

The NSO EPO Program under the Director's Office hired an assistant in Maui in FY 2017. Together with the Boulder-based Head of Education and Public Outreach, this new position completes the NSO EPO team. The Maui assistant focuses on promoting solar physics within the local community, in particular with K-12 students and teachers on the island. In FY 2018, the NSO EPO team will lead the NSO website redesign and will start a plan for communications and outreach of the DKIST first light. The late hire of the EPO positions has provided some carry-forward funds that are being rebudgeted as a start-up package for the program. The use of these resources targets increasing the visibility of NSO in general, and of DKIST in particular. About \$20K of this start-up package is expected to support a summer school on Stokes inversions co-organized with NCAR.

	Figure 9.2-2 Dir	ector's Office	Carry Forward			
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	CarryForward Base Revenue
NSO HQ	3.6	\$402,230	\$2,283,287	\$2,685,517	\$0	\$2,685,517
Directors Office			\$102,737	\$102,737		\$102,737
AURA Corporate Direct Charges			\$0	\$0		\$0
Solis Tower Demolition			\$500,000	\$500,000		\$500,000
AURA Committees			\$0	\$0		\$0
Business/Administration	0.8	\$85,306	\$5,221	\$90,527		\$90,527
Recruit/Relo - New Positions			\$74,284	\$74,284		\$74,284
Recruit/Relo - Existing Positions			\$201,628	\$201,628		\$201,62
Carryforward			\$0	\$0		\$0
Insurance			\$0	\$0		\$0
CU Recharge Fees			\$0	\$0		\$0
Science Staff - Research	1.8	\$222,923	\$99,460	\$322,383		\$322,383
Research Assistants			\$0	\$0		\$0
NSO Science-Collaborations			\$50,993	\$50,993		\$50,993
NISP Operations Service			\$0	\$0		\$0
DKIST Operations Service			\$0	\$0		\$0
CSP Activities			\$267,144	\$267,144		\$267,14
EPO - Scientists			\$0	\$0		\$0
Joint CU/NSO			\$223,170	\$223,170		\$223,170
Hale Post Doc			\$47,754	\$47,754		\$47,75
HQ Operations			\$52,411	\$52,411		\$52,41
Boulder Computing IT	0.5	\$47,000	\$34,712	\$81,713		\$81,713
Vehicles			\$0	\$0		\$0
HQ Development & Relocation			\$494,614	\$494,614		\$494,614
Instrument Development			\$26,530	\$26,530		\$26,530
Education and Public Outreach	0.5	\$47,000	\$102,629	\$149,630		\$149,630
Total:	3.6	\$402,230	\$2,283,287	\$2,685,517	\$0	\$2,685,517
Target:						\$2,731,890
Variance:						\$46,373

### 9.2.2 DKIST Operations Program

The DKIST Operations Program is under the direction of Thomas Rimmele as DKIST Associate Director. In FY 2018, the DKIST Operations Program, with 45 FTEs, is the largest operational program at NSO. Table 9.2-3 presents the new NSF funds for FY 2018 divided into work packages, and the program's carry forward is shown in Table 9.2-4.

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 two years. Two scientists are already based in Maui, where they interact with our instrument partners on the island. For operations, we have hired two observers who trained at the DST in Sunspot and are now Boulder-based. New hires will occur in FY 2018 in all DKIST work packages. With the availability of the ROB 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 telescope operators, including a chief science operator; personnel for the Data Center and operations tools; technical staff for the next generation of instruments, including MCAO; and additional 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 more than ten positions in FY 2018. Some of the new hires for Maui might require training periods at the Boulder Headquarters. DKIST payroll in FY 2018 totals \$6M.

Plans for transitioning employees from construction to operations will start in FY 2018. Two work packages that increased significantly in FY 2017 are Operations Development (\$700K) and the Instrumentation Program, 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 accelerates its implementation for the DKIST and makes this capability available as soon as practicable after the beginning of operations. The FY 2018 budget includes various full-time and part-time experts for MCAO development and the cost of the MCAO wavefront sensor. In total, we dedicate \$2.7M of FY 2018 funds to this key augmentation of DKIST capabilities.
- 2. *Prominence AO.* Regular AO cannot work near the limb due to the lack of constrast 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.
- 3. *IR instrumentation*. Exploiting the unique thermal IR capabilities of DKIST requires an imager that extends to the unexplored mid-IR spectral region. A first effort to develop such capacity is being kicked off in FY 2018. The total cost is budgeted at near \$2M.

As in FY 2017, all aspects of the Data Center are ramped up this year in both Boulder and Maui. The Data Center continues with six additional personnel hires, and there are plans to recruit two personnel for Operational Tools development. The Data Center team will concentrate on finalizing

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Fig	Jure 9.2-5 DKis	ST Operations	Frogram buug	σι		
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
DKIST Operations	43.1	\$5,932,371	\$8,035,357	\$13,967,729	\$0	\$13,967,72
Operations Management			\$0	\$0		5
Directorate	0.3	\$88,700	\$60,341	\$149,042		\$149,04
Business/Administration	0.6	\$51,497	\$19,153	\$70,651		\$70,6
Quality Control			\$40,810	\$40,810		\$40,8
Carryforward			\$0	\$0		
DKIST Science			\$0	\$0		
DKIST Science Staff - Research	9	\$1,069,112	\$479,610	\$1,548,723		\$1,548,7
Science - Operations Support Staff	2.8	\$403,033	\$210,549	\$613,582		\$613,5
Science - DKIST Maui Operations Service			\$0	\$0		
Science - DKIST Data Center Service			\$0	\$0		
Science- DKIST EPO	0.2	\$33,956	\$30,963	\$64,919		\$64,9
Joint CU/NSO			\$94,794	\$94,794		\$94,7
Science - Development (New Programs)			\$0	\$0		
Science- FL Data Center Development	0.8	\$146,512	\$37,116	\$183,627		\$183,6
Science - FL Ops Tools Development	0.6	\$83,363	\$5,102	\$88,465		\$88,4
Science - MCAO development	1.5	\$170,527	\$10,436	\$180,963		\$180,9
Science - Next Generation Instruments			\$0	\$0		
Science - Data Center enhancements	0.8	\$99,164	\$21,808	\$120,971		\$120,9
Facilities			\$0	\$0		
Facilities Maui			\$0	\$0		
DKIST Facility			\$0	\$0		
DKIST Facility Engineering			\$0	\$0		
ROB Facility			\$244,076	\$244,076		\$244,0
ROB Engineering	1	\$138,236	\$8,460	\$146,696		\$146,6
Facilities Boulder			\$0	\$0		
HQ expenses			\$107,126	\$107,126		\$107,1
HQ Engineering			\$0	\$0		
Boulder Computing - IT	2	\$283,397	\$188,637	\$472,033		\$472,0
Data Center Ops			\$0	\$0		
Development (New Programs)			\$0	\$0		
First Light Data Center Development	8.4	\$1,329,271	\$738,713	\$2,067,983		\$2,067,9
Operations Development	2.6	\$450,566	\$274,387	\$724,953		\$724,9
FL Operations Tools Development	2.3	\$412,374	\$126,971	\$539,346		\$539,3
Operator Training	4	\$416,012	\$63,162	\$479,175		\$479,1
MCAO development	2.5	\$285,112	\$2,117,436	\$2,402,548		\$2,402,5
Next Generation Instruments	3	\$384,460	\$2,580,732	\$2,965,192		\$2,965,1
Data Center Enhancements	1	\$87,078	\$111,406	\$198,484		\$198,4
Ops Tools Enhancements			\$7,794	\$7,794		\$7,7
Remote Office Building - Development			\$455,776	\$455,776		\$455,7
Fotal:	43.1	\$5,932,371	\$8,035,357	\$13,967,729	\$0	\$13,967,7
Farget:						\$14,000,0
Variance:						\$32,27

the reviews that will consolidate the scope definition that would pave the way for equipment acquisitions expected in FY 2019. In FY 2018, only minor equipment for prototyping activities will occur (\$200K). While the effort concentrates on the first-light disponibility, planning for enhancements beyond the current scope of the Data Center will occur in FY 2018, in particular in the area of image reconstruction capabilities (\$320K).

FY 2018 will see a significant effort in finalizing construction of the Remote Office Building in Pukalani. ROB construction funds have been encumbered in FY 2017 and are therefore not included here. After conversations with the NSF, however, we are budgeting in FY 2018 \$416K of new funds with a complexity cost factor to account for the uncertainties and risks in the Maui construction market. The first payment for ROB utilities and custodial services is also included in this budget (\$230K).

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. As already mentioned, the delays with the ROB 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 in excess of \$8M.

Re-profiling of the Data Center equipment acquisitions has impacted the expectations for how the program will ramp up the second-generation of instruments. Therefore in FY 2018, capital equipment acquisitions concentrate more aggressively on the instrumentation program instead of the Data Center. Carry-forward funds of \$600K in FY 2018 for the Data Center contains a complexity factor similar to that applied to the ROB construction. This complexity factor should help mitigate some of the risks—but not all—identified by the Conceptual Review Panel. The ROB uses \$200K in carry forward that includes, as in FY 2017, the cost of Maui personnel to supervise the building construction. Additionally, ROB furniture and IT infrastructure were initially budgeted in FY 2017 with a total cost of \$380K and are part of this year's carry forward.

Package Group /	9.2-4 DKIST O				011	o -
Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	CarryForward Base Revenue
DKIST Operations	2.8	\$443,628	\$7,894,867	\$8,338,495	\$0	\$8,338,49
Operations Management			\$0	\$0		\$
Directorate			\$0	\$0		\$
Business/Administration			\$0	\$0		\$
Quality Control			\$0	\$0		\$
Carryforward			\$0	\$0		ç
DKIST Science			\$0	\$0		ç
DKIST Science Staff - Research			\$0	\$0		
Science - Operations Support Staff			\$0	\$0		Ş
Science - DKIST Maui Operations Service			\$0	\$0		\$
Science - DKIST Data Center Service			\$0	\$0		Ş
Science- DKIST EPO			\$76,530	\$76,530		\$76,53
Joint CU/NSO			\$0	\$0		:
Science- FL Data Center Development			\$0	\$0		
Science - FL Ops Tools Development			\$0	\$0		
Science - MCAO development			\$0	\$0		
Science - Next Generation Instruments			\$0	\$0		
Science - Data Center enhancements			\$0	\$0		
Facilities			\$0	\$0		
Facilities Maui			\$0	\$0		
DKIST Facility			\$0	\$0		
DKIST Facility Engineering			\$0	\$0		
ROB Facility			\$0	\$0		
ROB Engineering			\$0	\$0		
Facilities Boulder			\$0	\$0		
HQ expenses			\$0	\$0		
HQ Engineering			\$0	\$0		
Boulder Computing - IT			\$0	\$0		
Data Center Ops			\$0	\$0		
Development (New Programs)			\$0	\$0		
First Light Data Center Development	2.3	\$344,900	\$298,779	\$643,679		\$643,6
Operations Development			\$0	\$0		
FL Operations Tools Development			\$0			
Operator Training			\$0			
MCAO development			\$5,136,972	\$5,136,972		\$5,136,9
Next Generation Instruments			\$1,878,298			\$1,878,2
Data Center Enhancements			\$0			
Ops Tools Enhancements			\$0			:
Remote Office Building - Development	0.5	\$98,729	\$504,288			\$603,0
Fotal:	2.8	\$443,628	\$7,894,867		\$0	
Target:						\$8,417,63
Variance:						\$79,14

The bulk of the DKIST FY 2018 carry forward is allocated to the second-generation instrument program and supports the efforts already mentioned above. The MCAO program uses two additional deformable mirrors, conjugated at different heights, each costing \$2.5M. These mirrors

are long-lead items for which procurement must start as soon as possible. Some support is also provided for the thermal IR instrument and the prominence AO. Finally, following a recommendation of the DKIST SWG, the DKIST program carry forward includes funds needed for the second etalon of the Visible Tunable Filter (VTF), the first-light instrument provided by the Germans. The cost of this etalon contract is slightly more than \$1M.

## 9.2.3 NSO Integrated Synoptic Program

The NISP combines staff from SOLIS and GONG under Frank Hill as Associate Director. Following the recommendation of the Portfolio Review Committee, the NSF base funding for NISP in FY 2018 continues at the \$2M level (excluding indirect payments). The total budget for the Program is augmented by the NOAA contribution of \$800K and by grants at a level slightly above \$600K. The Program continues to use the \$2.5M one-time contribution received in FY 2016 for GONG refurbishment, and the unused funds are part of the Program's FY 2018 carry-forward budget.

The NISP base funding budget breakdown is presented in the Tables 9.2-5, 9.2-6 and 9.2-7. Currently, NISP has a total of 22 FTEs. The NSF base funding covers 10 FTEs, 9 FTEs are partially grant supported; 3 FTEs are allocated to GONG refurbishment and SOLIS relocation activities. The NOAA funds are included in the grants and support 4 FTEs. The NISP total payroll in FY 2018 is \$2.8M, with 40% of these funds coming from grants, including the NOAA contribution. NISP has hired two engineers to cover aspects of the GONG refurbishment project and some of the expected program attrition that occurs at the end of the calendar year 2017.

Figure 9.2-5	NSO Inte	egrated Synop	tic Program Bu	ıdget		
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue
NSO NISP	10.4	\$1,415,017	\$787,134	\$2,202,151	\$0	\$2,202,151
NISP Directorate	0.5	\$104,998	\$22,238	\$127,236		\$127,236
Scientific Staff	6.0	\$774,823	\$130,330	\$905,153		\$905,153
Data Center	2.9	\$377,627	\$208,799	\$586,425		\$586,425
Engineering Operations	0.3	\$41,471	\$2,538	\$44,009		\$44,009
SOLIS Operations/Support			\$291,542	\$291,542		\$291,542
SOLIS Relocation			\$10,930	\$10,930		\$10,930
Admin	0.5	\$47,921	\$116,584	\$164,505		\$164,505
GONG Refurbishment			\$0	\$0		\$0
Boulder HQ Computing-IT	0.3	\$68,178	\$4,172	\$72,350		\$72,350
Total:	10.4	\$1,415,017	\$787,134	\$2,202,151	\$0	\$2,202,151
Target:						\$2,200,000
Variance:						(\$2,151)

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 their upgrades as required. 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 2018 is used to cover scientific support to the program, administrative staff, NISP Data Center activities, and SOLIS operations at Big Bear Solar Observatory (BBSO) (Table 9.2-5).

The \$800K from NOAA/SWPC covers what's needed to operate the GONG network. Payroll includes technical maintenance, scientific validation, and Data Center costs (Table 9.2-6), and totals \$615K. The remaining \$200K is used to cover facilities costs at the six stations and the preventive maintenance trips to each site.

Figure 9.2-6 NISP Budget With External Funds								
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	Grants Base Revenue		
NSO NISP	8.9	\$1,076,991	\$656,831	\$1,733,822	\$0	\$1,733,822		
SWPC Payroll	4.4	\$602,487	\$13,255	\$615,741		\$615,741		
SWPC Learmonth (LE)			\$36,600	\$36,600		\$36,600		
SWPC Udaipur (UD)			\$27,845	\$27,845		\$27,845		
SWPC Tenerife (TD)			\$32,093	\$32,093		\$32,093		
SWPC CTIO (CT)			\$11,599	\$11,599		\$11,599		
SWPC Big Bear (BB)			\$55,391	\$55,391		\$55,391		
SWPC Mauna Loa (ML)			\$67,791	\$67,791		\$67,791		
SWPC Tucson			\$10,259	\$10,259		\$10,259		
SWPC Network			\$9,171	\$9,171		\$9,17		
SWPC GONG Relocation			\$228,972	\$228,972		\$228,972		
NASA Infrastructure	1.5	\$121,293	\$2,668	\$123,962		\$123,963		
VSO	0.5	\$60,679	\$154,750	\$215,429		\$215,429		
NWRA Farside	0.3	\$25,049	\$551	\$25,600		\$25,600		
Georgia State Dynamo	1.0	\$113,354	\$2,494	\$115,848		\$115,848		
Pevtsov No.1	0.6	\$71,699	\$1,577	\$73,277		\$73,27		
Pevtsov No. 2	0.6	\$63,160	\$1,390	\$64,550		\$64,550		
Pevtsov No. 3	0.2	\$19,270	\$424	\$19,694		\$19,694		
Total:	8.9	\$1,076,991	\$656,831	\$1,733,822	\$0	\$1,733,822		
Target:						\$1,807,061		
Variance:						\$73,239		

Table 9.2-6 also shows the various scientific and infrastructure	e grants obtair	ned by the program.
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NISP carry-forward funds in FY 2018 (Table 9.2-7) total \$1.7M, with \$1.3M allocated for GONG refurbishment and \$0.4M for SOLIS relocation to BBSO. SOLIS relocation appeared in the FY 2017 budget, but updated expenditures will occur in FY 2018. The main activities associated with the GONG refurbishment budget remain unchanged:

- Improved zero-point stability of GONG magnetograms (new liquid crystal modulators).
- Upgraded new cameras.
- Upgraded H-alpha filters to acquire Doppler shifts.
- Data Center updates to cope with new data products (H-alpha Doppler shifts).
- Improved HVAC in shelters.

	Figure 9.2	-7 NISP Carry	Forward			
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	CarryForwar Base Revenu
NSO NISP	3.0	\$315,620	\$1,435,519	\$1,751,139	\$0	\$1,751,13
SWPC Payroll			\$0	\$0		9
Scientific Staff			\$0	\$0		:
SWPC Learmonth (LE)			\$0	\$0		
Data Center			\$149,016	\$149,016		\$149,0
SWPC Udaipur (UD)			\$0	\$0		
Instru Devel and Maint			\$0	\$0		
SWPC Tenerife (TD)			\$0	\$0		
SOLIS Relocation			\$273,773	\$273,773		\$273,7
SWPC CTIO (CT)			\$0	\$0		
Admin			\$0	\$0		
SWPC Big Bear (BB)			\$0	\$0		
GONG Refurbishment	3.0	\$315,620	\$1,012,731	\$1,328,351		\$1,328,3
SWPC Mauna Loa (ML)			\$0	\$0		
SWPC Tucson			\$0	\$0		
SWPC Network			\$0	\$0		
SWPC GONG Relocation			\$0	\$0		
VSO			\$0	\$0		
NWRA Farside			\$0	\$0		
Georgia State Dynamo			\$0	\$0		
Pevtsov No.1			\$0	\$0		
Pevtsov No. 2			\$0	\$0		
Pevtsov No. 3			\$0	\$0		
Pevtsov No. 4			\$0	\$0		
ſotal:	3.0	\$315,620	\$1,435,519	\$1,751,139	\$0	\$1,751,13
larget:						\$1,751,70
/ariance:						\$50

Some of the new liquid crystal modulators already have been deployed to their respective sites. GONG refurbishment is expected to end in FY 2018, except perhaps the H-alpha upgrades that suffered a delay in FY 2017 due to the late acquisition of the tunable filters.

#### 9.2.4 Tucson/McMath-Pierce

Table 9.2-8 shows the budget breakdown for Tucson and support for the McMath-Pierce Solar Telescope facility (McMP) in FY 2018. It covers only the first quarter as NSO plans to have no base-funded presence in Tucson and at Kitt Peak after 01 January 2018.

Figure 9.2-8 NSO Tucson / McMath-Pierce Budget							
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	CarryForward Base Revenue	
NSO Tucson	0.0	\$0	\$33,903	\$33,903	\$0	\$33,903	
Scientific Staff			\$0	\$0		\$0	
Telescope Ops			\$4,245	\$4,245		\$4,245	
Admin			\$3,184	\$3,184		\$3,184	
Kitt Peak Support			\$12,679	\$12,679		\$12,679	
NOAO Facilities Use Fee			\$13,796	\$13,796		\$13,796	
Total:	0.0	\$0	\$33,903	\$33,903	\$0	\$33,903	
Target:						\$56,953	
Variance:						\$23,050	

#### 9.2.5 Sacramento Peak

In FY 2018, NSO will operate the Sunspot facilities and the Dunn Solar Telescope at a minimum level in Q1 and, potentially, in Q2. The operations at Sacramento Peak during this period will not include regular observing runs at the telescope, but only preparatory activities for a potential transfer to a University consortium. The budget breakdown is presented in Table 9.2-9 and it corresponds to new NSF funds received in FY 2018, not carry forward.

The budget in Table 9.2-9 includes two relatively high-cost items related to closeout activities. \$45K is allocated for a full range of transition activities, which includes things like scanning and/or shredding/disposing documents, and a quote of \$60K has been received for roof repairs of the Evans Solar Facility, Hilltop Dome, Main Lab and machine shop building. A minimal amount of carrying forward (\$82K) exists and is available for additional closeout activities.

Figure 9.2-9 NSO Sacramento Peak Budget								
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	NSF Base Revenue		
NSO SP	3.3	\$291,361	\$388,675	\$680,036	\$47,718			
Administrative Services	0.8	\$75,590	\$62,311	\$137,901		\$137,901		
Scientific Staff	0.3	\$44,852	\$11,078	\$55,930		\$55,930		
Telescope Operations	0.5	\$52,979	\$30,052	\$83,031		\$83,031		
Instrument Development and Telescope Maintenance	0.3	\$31,637	\$44,066	\$75,703		\$75,703		
Computing Support			\$15,047	\$15,047		\$15,047		
Facility Maintenance	0.7	\$41,881	\$201,861	\$243,742		\$243,742		
Housing	0.6	\$38,387	\$16,088	\$54,475	\$44,400	\$10,075		
Visitor Center	0.2	\$6,035	\$8,172	\$14,207	\$3,318	\$10,890		
Total:	3.3	\$291,361	\$388,675	\$680,036	\$47,718	\$632,318		
Target:						\$633,000		
Variance:						\$682		

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Figure 9.2-10 NSO Sacramento Peak Carry Forward							
Package Group / Package	FTE	Staff Cost	Non-Staff Cost	Spend Plan	Other Revenue	CarryForward Base Revenue	
NSO SP	0.0	\$0	\$82,402	\$82,402	\$0	\$82,402	
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			\$82,402	\$82,402		\$82,402	
Housing			\$0	\$0		\$0	
Kitchen			\$0	\$0		\$0	
Visitor Center			\$0	\$0		\$0	
Sac Peak Carryforward			\$0	\$0		\$0	
Total:	0.0	\$0	\$82,402	\$82,402	\$0	\$82,402	
Target:						\$82,399	
Variance:						(\$3)	

#### 9.2.6 AURA Fees, Fringe Benefit Rate, and Management Fee

Tables 9.2-10 and 9.2-11 show the expenses NSO incurs for AURA Facilities and Administrative (F&A) costs, Central Administrative Services (CAS), and Human Resources (HR) for FY 2018 NSF Funds and the Observatory carry-forward, respectively.

Table 9.2-10 AURA Fees (FY 2018 NSO Base Funds)					
Indirect Cost Type	Charge				
AURA CAS&HR Support	\$612,503				
AURA Corporate F&A	\$343,752				
Total	\$956,255				

Table 9.2-11 AURA Fees NSO Carry Forward)					
Indirect Cost Type	Charge				
AURA CAS&HR Support	\$215,286				
AURA Corporate F&A	\$120,824				
Total	\$336,110				

A Management Fee has been submitted to the NSF and is not included in this budget pending its approval.

# APPENDICES

APPENDIX A. NSO 2020 – 2025 VISION APPENDIX B. OBSERVING & USER STATISTICS APPENDIX C. ORGANIZATIONAL PARTNERSHIPS APPENDIX D. PUBLICATIONS APPENDIX E. MILESTONES FOR FY 2018 APPENDIX F. STATUS OF 2017 MILESTONES APPENDIX G. FY 2018 STAFFING SUMMARY APPENDIX H. SCIENTIFIC STAFF RESEARCH & SERVICE APPENDIX I. ACRONYM GLOSSARY

## APPENDIX A. NATIONAL SOLAR OBSERVATORY 2020–2025 VISION<sup>1</sup>

NSO will support and lead community research into the nature of the Sun by providing critical groundbased 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<sup>1</sup> 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<sup>2</sup>. 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<sup>4</sup>;

<sup>&</sup>lt;sup>1</sup>See NSO 2012-2016 Long Range Plan for science goals (*http://www.nso.edu/reports*)

<sup>&</sup>lt;sup>2</sup>NWNH, p. 64

<sup>&</sup>lt;sup>3</sup> NWHH, pp. 29, 37,38, 60,61, 115

<sup>&</sup>lt;sup>4</sup> 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<sup>5</sup>, 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 will6:

- 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.

<sup>&</sup>lt;sup>5</sup> NWNH, p. 29: Serving the Nation

<sup>&</sup>lt;sup>6</sup> NWNH, Chapter 4

## APPENDIX B. OBSERVING AND USER STATISTICS

#### (October 1, 2016 – September 30, 2017)

In the 12 months ended 30 September 2017, 27 observing programs, which included four thesis programs involving seven graduate students, were carried out at NSO. Associated with these programs were 61 scientists, students and technical staff from 24 US and foreign institutions.

NSO Observing Programs by Type (US and Foreign)		
12 Months Ended September 2017	Nbr	% Total
Programs (US)	18	67%
Programs (non-US)	5	19%
Thesis (US, involving 3 grad students)	2	7%
Thesis (non-US, involving 4 grad students)	2	7%
Total Number of Unique Science Projects*	27	100%

\*Includes observing programs conducted by AURA staff scientists.

Users of NSO Facilities by Category						
		Visi	AURA Staff			
	US	Non-US	Total	% Total		
PhDs	20	20	40	66%	12	
Graduate Students	3	4	7	11%	0	
Undergraduate Students	5	0	5	8%	0	
Other	8	1	9	15%	7	
Total Users	36	25	61	100%	19	

Institutions Represented by Visiting Users**							
US Non-US Total % Total							
Academic	9	7	16	67%			
Non-Academic	4	4	8	33%			
Total Academic & Non-Academic 13 11 24 100							

\*\*Note: Total number of institutions represented by users do not include Departments or divisions within an institution as separate entities (e.g., U.S. Air Force and NASA are each counted as one institution even though different sites/bases/centers are separately listed in the data base.

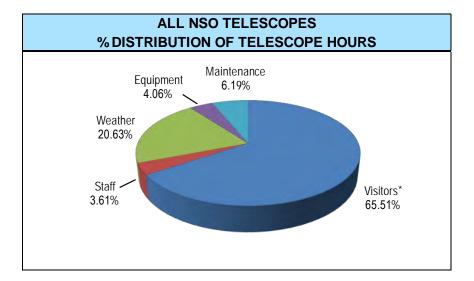
Number of Users by Nationality						
China	1	Italy	10			
England, UK	1	Japan	1			
France	4	Mexico	1			
Germany	1	United States	36			
Ireland, UK	7					

Institutions Represented by Users
Foreign Institutions (11)
University of Nice Sophia Antipolis
University of Côte d'Azur
University College London
Queen's University Belfast
Catania University, Catania Astrophysical Observatory
University of Tokyo
Universidad de Monterrey, Mexico
Max Planck Institute for Solar System Research
Nanjing Institute of Astronomical Optics & Technology
INAF - Osservatorio Astronomico di Roma
INAF - Arcetri Astrophysical Observatory
US Institutions (13)
California State University, Northridge
Catholic University
Embry Riddle Aeronautical University, Daytona
Dickinson College
Regis University, Colorado
New Mexico State University
University of Colorado, Boulder
University of Hawaii, IFA
University of Wisconsin
NASA/Goddard Space Flight Center (NASA/GSFC)
National Radio Astronomy Observatory, Socorro
Raytheon
Southwest Research Institute

## FY 2017 USER STATISTICS – TELESCOPE USAGE & PERFORMANCE DATA

In the fiscal year ended 30 September 2017, 65.5% of the total available telescope hours at NSO/Sacramento Peak, NSO/Kitt Peak, and the SOLIS/GONG "Farm" in Tucson went to the observing programs of visiting principal investigators; 3.6% were devoted to those of NSO scientists. Scheduled maintenance (including instrument tests, engineering, and equipment changes) accounted for 6.2% of total allotted telescope hours.

Total "downtime" (hours lost to weather and equipment problems) for NSO telescopes was 24.7%. A significant portion of these lost observing hours were due to bad weather (20.6%), with 4.1% lost to equipment problems.



NSO TELESCOPES Percent Distribution of Telescope Hours (Scheduled vs. Downtime) 01 October 2016 - 30 September 2017								
<b>T</b>	Hours	% Hours Used By:		% Hours Lost To:		% Hrs. Lost To:		
Telescope	Scheduled	Visitors <sup>a</sup>	Staff	Weather	Equipment	Scheduled Maintenance		
Dunn Solar Telescope/SP	2,885.8	25.6%	14.4%	31.1%	4.2%	24.7%		
McMath-Pierce*	1,747.0	74.9%	0.0%	20.4%	4.7%	0.0%		
SOLIS "Farm", Tucson <sup>a,b</sup>	6,886.0	<b>79.9</b> %	0.0%	16.3%	3.8%	0.0%		
FTS Lab <sup>c</sup> *	0.0	0.0%	0.0%	0.0%	0.0%	0.0%		
Evans Solar Facility	0.0	0.0%	0.0%	0.0%	0.0%	0.0%		
Hilltop Dome	0.0	0.0%	0.0%	0.0%	0.0%	0.0%		
All Telescopes	11,518.8	65.5%	3.6%	20.6%	4.1%	6.2%		

<sup>*a*</sup>Includes synoptic programs for which all data are made available immediately to the public and scientific community at large.

<sup>b</sup>SOLIS was relocated from Kitt Peak to the University of Arizona agricultural campus (or "Farm") in Tucson.

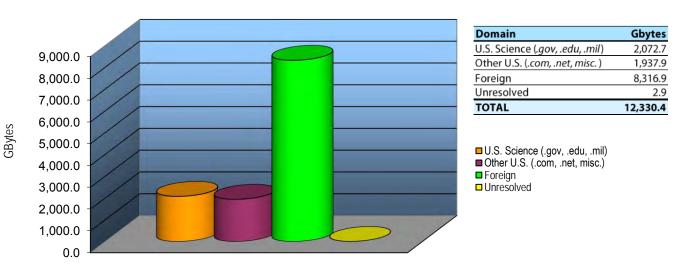
<sup>c</sup>During FY12, the FTS was moved out of the McMath-Pierce Facility and to a university campus.

\*Totals include both day and night hours. (All others are day only.)

## FY 2017 USER STATISTICS – ARCHIVES & DATA BASES

## (October 1, 2016 - September 30, 2017)

All statistics *exclude* the use of NSO archives and data bases from within the NSO Local Area Network in Tucson and at Sac Peak, and from AURA/NOAO as a whole.



#### DATA (Gbytes) DOWNLOADED FROM NSO FTP & WWW SITES 01 October 2016 - 30 September 2017

#### PRODUCT DISTRIBUTION BY DOWNLOADED GBYTES 01 October 2016 - 30 September 2017

Site	Product Type	Gbytes	%
Т	NISP/GONG H-alpha	5,305.7	46.4%
Т	NISP/GONG (Magnetograms, spectra, time series, frequencies)	2,298.3	20.1%
Т	NISP/GONG Helioseismology	1,934.5	16.9%
SP & T	Other	1,765.6	15.4%
SP	Staff Pages	44.8	0.4%
Т	NISP/SOLIS (VSM, ISS, FDP)	38.0	0.3%
SP	Press Releases	26.7	0.2%
SP	General Information	10.4	0.1%
Т	KPVT (magnetograms, synoptic maps, helium images)	5.8	0.1%
SP	DST Service Mode Support	4.0	0.0%
Т	FTS (Spectral atlases, general archive)	2.6	0.0%
SP	SMEI Experiment & Data Pages	0.1	0.0%
SP	Icon & Background Images	0.1	0.0%
Т	Evans/SP Spectroheliograms (Hα, Calcium K images)	0.0	0.0%
TOTAL		11,436.7	100.0%

# APPENDIX C. ORGANIZATIONAL PARTNERSHIPS

#### C1. 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 H $\alpha$  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 Hawai'i, 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 C.1. Joint Development Efforts					
Telescope/Instrument/Project	Collaborators				
Daniel K. Inouye Solar Telescope (DKIST)	HAO, U. Hawai'i, 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)	НАО				
Spectropolarimeter for Infrared and Optical Regions (SPINOR)	НАО				
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. Hawai'i, 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				

NSO sponsored several community workshops and forged an alliance of 22 institutions to develop the proposal for the design of the DKIST and its instrumentation. NSO worked closely with this group in leading the successful completion of the design and transition to construction of the telescope. Since 2009, the DKIST project has conducted a series of workshops on DKIST science operations to provide guidance for developing a sound plan for exploiting the full potential of the DKIST.

## APPENDIX D. PUBLICATIONS

### (OCTOBER 2016 THROUGH SEPTEMBER 2017)

Author-NSO StaffAuthor-REUAuthor-RETAuthor-Grad StudentAuthor-Non-REU Undergrad

The following is a list of known refereed papers, conference proceedings and non-refereed papers published during FY 2017 by NSO staff, REU and RET program participants, graduate students, and non-REU undergraduates, as well as papers resulting from the use of NSO facilities.

#### **Refereed Publications**

- 1. Alberti, T., Laurenza, M., **Cliver, E. W.,** Storini, M., Consolini, G., Lepreti, F., "Solar Activity from 2006 to 2014 and Short-term Forecasts of Solar Proton Events Using the ESPERTA Model", *ApJ* **838**(1): id.59, 11 pp., 03/2017.
- 2. Alissandrakis, C. E., Patsourakos, S., Nindos, A., and Bastian, T. S., "Center-to-limb observations of the Sun with ALMA", *A&A* 605, A78, 2017.
- Andretta, V., Giampapa, M. S., Covino, E., Reiners, A., and Beeck, B., "Estimates of Active Region Area Coverage through Simultaneous Measurements of the He I λλ 5876 and 10830 Lines", *ApJ* 839(2): id.97, 04/2017.
- 4. Balasubramaniam, K. S., and Henry, T.W., "Sunspot Numbers from ISOON: A Ten-Year Data Analysis", *SoPh* **291**(9-10): 3123, 11/2016.
- 5. Battams, K., Gallagher, B. M., and Weigel, R. S., "A Global Survey of EUV Corona Power Spectra", *ApJ* arXiv, arXiv:1707.02448, 22 pp., 2017.
- 6. Berdyugina, S.V., Kuhn, J. R., **Harrington, D. M.**, Santl-Temkiv, T., Messersmith, E. J., "Remote Sensing of Life: Polarimetric Signatures of Photosynthetic Pigments as Sensitive Biomarkers", *IJAsB* **15**(1): 45-56, 2016.
- 7. Bertello, L., Pevtsov, A. A., Tlatov, A. G., and Singh, J., "Correlation Between Sunspot Number and Ca uc(ii) K Emission Index", *SoPh* 291(9): 2967 2979, 2016.
- 8. Bertello, L., Pevtsov, A. A., Tlatov, A. G., and Singh, J., "Solar Ca II K Observations", *AsJPh* 25(3), 2016.
- 9. Bhatt, H., Trivedi, R., Sharma, S. K., and Vats, H., "Variations in the Solar Coronal Rotation with Altitude Revisited", *SoPh* **292**, 55, 2017.

- 10. Bolsée, D., Pereira, N., Cuevas, E., García, R. A., and Redondas, A., Comments to the Article by Thuillier et al. "The Infrared Solar Spectrum Measured by the SOLSPEC Spectrometer Onboard the International Space Station" on the Interpretation of Ground-based Measurements at the Izaña Site", *SoPh* Online First, 2016.
- 11. Böning, V. G. A., Roth, M., Jackiewicz, J., and **Kholikov, S.**, "Inversions for Deep Solar Meridional Flow Using Spherical Born Kernels", *ApJ* **845**(1): id.2, 08/2017.
- 12. Böning, V. G. A., Roth, M., Jackiewicz, J., and **Kholikov**, S., "Validation of Spherical Born Approximation Sensitivity Functions for Measuring Deep Solar Meridional Flow", *ApJ* **838**(1): id.53, 03/2017.
- 13. **Brandenburg, A., Petrie, G. J. D.**, and Singh, N. K., "Two-scale Analysis of Solar Magnetic Helicity", *ApJ* **836**(1): id.21, 02/2017.
- 14. Broomhall, A.-M., "A Helioseismic Perspective on the Depth of the Minimum between Solar Cycles 23 and 24", *SoPh* **292**, 67 (2017).
- 15. **Burtseva**, **O.**, **Gosain**, **S.**, and **Pevtsov**, **A. A.**, "Search for a signature of twist-removal in magnetic field of sunspots in relation with major flares", *ApJ* **849**(2): id.103, 9 pp., 2017.
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- 18. Chandra, R., Filippov, B., Joshi, R., and Schmieder, B., "Two-Step Filament Eruption during 14 15 March 2015", *SoPh*, **292**, 81 (2017).
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- 20. **Cliver, E. W.** and von Steiger, R., "Minimal Magnetic States of the Sun and the Solar Wind: Implications for the Origin of the Slow Solar Wind", *SSRv* **210**(1-4), 227-247, 09/2017.
- 21. Cliver, E. W., "Flare vs. Shock Acceleration of High-energy Protons in Solar Energetic Particle Events", *ApJ* 832(2): id. 128, 8 pp., 12/2016.
- 22. Cliver, E. W., "Sunspot Number Recalibration: The 1840-1920 Anomaly in the Observer Normalization Factors of the Group Sunspot Number", *JSWSC* 7: id.A12, 11 pp., 03/2017.

- 23. Collet, R., **Criscuoli, S.,** Ermolli, I., Fabbian, D., Guerreiro, N., Haberreiter, M., <u>Peck, C.</u> Pereira, T. M.D., Rempel, M., Solanki, S. K., Wedemeyer-Boehm, S., "Lower Solar Atmosphere and Magnetism at Ultra-high Spatial Resolution", arXiv:1612.02348, 12/2016.
- 24. Cranmer, S. R., "Mass-loss Rates from Coronal Mass Ejections: A Predictive Theoretical Model for Solar-type Stars", *ApJ* **840**, 114, 2017.
- 25. **Criscuoli, S.** and Foukal, P., "A Study of Solar Photospheric Temperature Gradient Variation Using Limb Darkening Measurements", *ApJ* **835**(1): id.99, 01/2017.
- 26. **Criscuoli, S**., Norton, A. A., and <u>Whitney, T.</u>, "Photometric Properties of Network and Faculae Derived from HMI Data Compensated for Scattered Light", *ApJ* 847(2): id.93, 10/2017.
- 27. Cunnyngham, I., Emilio, M., Kuhn, J., Scholl, I., and Bush, R., "Poynting-Robertson-like Drag at the Sun's Surface", *PhRvL* **118**, 051102, 2017.
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- 32. Fiacconi, D. and Rossi, E. M., "Light or Heavy Supermassive Black Hole Seeds: the Role of Internal Rotation in the Fate of Supermassive Stars", *MNRAS* 464, 2259, 2017.
- 33. Gaulme, P., Rowe, J. F., Bedding, T. R., Benomar, O., Corsaro, E., Davies, G. R., Hale, S. J., Howe, R., Garcia, R. A., Huber, D., and 17 coauthors ...Leibacher, J..., "A Distant Mirror: Solar Oscillations Observed on Neptune by the Kepler K2 Mission", *ApJ* 833(1): id. L13, 7 pp., 12/2016.
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# **APPENDIX E. MILESTONES FY 2018**

This section describes the major project milestones for 2018.

### E1. Daniel K. Inouye Solar Telescope (DKIST)

- Carryover
  - Mount Commissioning Complete (Scheduled for Feb. 2018).
  - Coat Science M1 (Scheduled for Jan. 2018 due to resource contention for M1 Cell Assembly SAT).
  - PA&C FDR (Scheduled for 1Q FY18; individual mini reviews have taken place to ensure long-lead procurements are in-hand).
  - VBI Science Camera Integration Testing Complete (Scheduled for Jan. 2018 due to delays in Andor Balor camera delivery).
- ♦ 2018
  - M1 Commissioning Blank coating.
  - M1 Cell Assembly Site Acceptance Test.
  - SIM 1: Telescope Pointing Map complete.
  - SIM 2: M1 Integration complete.

### E2. DKIST Data Center Development

- In 2018, the Data Center development effort will comprise the completion of preliminary design and prototyping activities in Q1, leading to a formal Preliminary Design Review in Q3. During Q3 and Q4, the effort will include initial subsystem development activities concomitant with final design.
- In 2018, the Operational Tools development effort will commence in earnest following the hire and onboarding of dedicated staff. The completion of science requirements early in the year will support rapid prototyping efforts leading to an initial, functional release of the Experiment Architect, a key component supporting the creation of detailed observational programs to be used by summit software systems.

### **E2.1 Data Center Milestones**

- Q1 FY18: Complete DKIST Data Simulator and Validator Toolkit.
- Q2 FY18: Complete Data Center System and Subsystem Requirements.
- Q3 FY18: Complete Data Center Preliminary Design Review.

### E2.2 DKIST Instrument and Operations Tools Development

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

### E4. NISP/SOLIS

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

### E5. NISP/GONG

- Relocate GONG engineering site to Boulder.
- Recommission GONG engineering units in Boulder.
- Continue multi-year refurbishment of the GONG network.

### E6. NISP Data Center (DC)

- Repurpose former production hardware for reprocessing/R&D.
- Support the migration/adaptation of GONG's space weather data processing for production operation at NOAA/SWPC.
- Implement upgraded backup tape system and protocols.
- Complete the automation of GONG VMBICAL processing.
- Reprocess archival SOLIS/VSM observations to homogeneously reflect data processing improvements.

# E7. Virtual Solar Observatory (VSO)

- Acquire and implement a second (failover) SDO netDRMS system at NSO.
- Incorporate new data sets/providers into the VSO.
- Maintain/support existing VSO data providers.
- Revamp web user interface.

### E8. Dunn Solar Telescope

In early 2017, the Astronomy department of the New Mexico State University (NMSU) at Las Cruces received a two-year transition grant from the NSF in support of setting up an NMSU-led consortium (called the Sunspot Solar Observatory Consortium, SSOC) to take over the DST from the NSO as a research instrument, solar synoptic telescope, and education platform. The current tentative deadline for the DST operations to be taken over by the SSOC is 01 January 2018. The first quarter of FY 2018 will be mostly dedicated to preparing the facilities for the transition, performing necessary maintenance to ensure handing over a safe, healthy and operational telescope, as well as training of NMSU personnel. Milestones for the last three months of the calendar year 2017 is, therefore, focused on ensuring a smooth transition of operations of the DST and its suite of user instruments to the SSOC.

### E8.1. Spectropolarimeter for Infrared and Optical Regions (SPINOR)

- Ensure operability of the instrument.
- Train NMSU personnel on operating the instrument with the telescope.
- Test setups for planned synoptic observations by the SSOC.

### E8.2. Facility IR Spectropolarimeter (FIRS)

- Ensure operability of the instrument.
- Train NMSU personnel on operating the instrument with the telescope.
- Test setups for planned synoptic observations by the SSOC.

### E8.4. Rapid Oscillations in the Solar Atmosphere (ROSA) Imaging System.

- Ensure operability of the instrument.
- Train NMSU personnel on operating the instrument with the telescope.
- Test setups for planned synoptic observations by the SSOC.

### E8.5. Interferometric Bidimensional Spectrometer (IBIS)

- Ensure operability of the instrument.
- Train NMSU personnel on operating the instrument with the telescope.
- Test setups for planned synoptic observations by the SSOC.

### E9. Establish NSO Headquarters

- Finalize establishment of the HQ IT program (e-mail servers, web servers, etc.).
- Continue developing basic infrastructure for scientific support.
- Continue implementing the transition plan.

# APPENDIX F. STATUS OF FY 2017 MILESTONES

This section describes the progress of current projects relative to the milestones established in the FY 2017 Program Plan. (FY 2017 milestones appear in italics below.)

### F1. Daniel K. Inouye Solar Telescope (DKIST)

- Carryover
  - M1 Cell Assembly FAT
  - Achieved; FAT was executed in January 2017 with additional actions completed by May 2017, enabling on time shipment to Maui and transport to the summit where it awaits SAT in November 2018.
  - WFC FDR
  - Not fully achieved; incremental reviews of sub-areas have been completed and the formal (delta) FDR has been scoped. The project is waiting to schedule this as key resources are available to support.
  - Enclosure SAT
  - Not fully achieved; there were several quality issues that were caught in testing that required additional work, in particular the behaviors of the Rear Door and the Aperture; these have been underway and are current acceptable for early IT&C. In addition, some resources were required for TMA Mount Acceptance.
  - *S&O BOD*
  - Not fully achieved; delays in Facility Thermal Systems installations impacted the overall schedule; however, the building is in active use and is building toward a more formal BOD.
  - WFC CV System Validation
  - Achieved in March 2017.
  - FIDO PDR
  - Not fully achieved; substantial work was performed to review the requirements and go out for bid on the fabrication and testing contract; this was completed in September 2017.
- ♦ 2017
  - Commission TCS control of Enclosure
  - Achieved.
  - Coudé Installation Complete
  - Achieved.
  - Mount Commissioning Complete
  - Not fully achieved; it is currently underway with expected completion in February 2018.
  - Coat Science M1

- Not achieved; however, the MOA with the AF was negotiated and signed enabling a test coating of the commissioning blank during the time the science blank was scheduled. This activity will increase the probability of a success with the science M1.
- PA&C FDR
- Not fully achieved; currently this is scheduled for 1Q FY18; individual mini reviews have taken place to ensure long-lead procurements are in-hand.
- VBI Science Camera Integration Testing Complete
- Not fully achieved; currently this is scheduled for Jan. 2018 due to delays in Andor Balor camera delivery; we have worked closely with the UK DKIST Consortium to minimize the impact of their scheduling on the project. The Alpha releases of their camera have been received by the project and integrated with the control software.

# F2. DKIST Data Center Development

### F2.1 Data Center Milestones

- Complete Conceptual Design Review (CoDR) (1Q FY17)
  - The CoDR was passed successfully in March 2017.
- Complete Preliminary Design Review (PDR) (2Q FY17)
  - Recommendation from the CoDR panel was that the CoDR-PDR interval was far too short, leading to a preliminary schedule rebaseline. This resuled in a longer and realistic preliminary design period, and a tentative Preliminary Design Review for Q3 FY18.
- Complete Final Design Review (FDR) (3Q FY17)
- See above; the Data Center FDR did not occur during FY17, and will not occur in FY18.
- Demonstrate Provisioning and Orchestration System (4Q FY17)
  - Completed. This key subsystem has been demonstrated to provide a "hybrid" cloud, capable of deploying configuration data analysis, storage, and networking systems.

### F2.2 DKIST Instrument and Operations Tools Development

- Complete Operational Tools Science Requirements (2Q FY17)
  - Due to staff contention, the Operations Tools Science Requirements will be completed in Q1 FY18.
- Complete Operational Tools Engineering Design Requirements (3Q FY17)
  - A set of Engineering Design Requirements were not produced during FY17. Instead, a deep analysis of scientific and operational need was performed, from which requirements may be drawn.
- Complete Operational Tools Preliminary Design Review (4Q FY17)
- Was not completed. At this time, a development replan has been agreed to, and this review will not take place, replaced instead by an Agile-style, iterative paired-development model involving frequent collaboration between scientific and development staff.

- Completion of the AO simulation software package. The simulation package is expected to be in a sufficiently developed state where it can be used routinely and possibly distributed.
  - Completed.
- Finish simulation study of the MCAO performance applied to the system developed at BBSO. The study will explore the effects of different wavefront sensing geometries and the effects of different atmospheric configurations.
  - 60% complete. These simulations require massive parallel computing. Additional hardware will be procured to accelerate iteration cycles. Results were presented at the 2017 SPIE conference.
- Finish simulation study of DKIST adaptive optics performance. Explore system performance under a range of parameters, such as seeing conditions and reconstruction methods.
- 60% complete. These simulations require massive parallel computing. Additional hardware will be procured to accelerate iteration cycles.
- Conduct 2-3 on-sky observing campaigns with solar MCAO at the BBSO NST. Develop improved strategy for dealing with the continuously evolving solar image structure seen the wavefront sensor.
  - Completed.
- Perform numerical simulations to predict MCAO and ground-layer AO performance in different seeing situations, and to assess and to further improve the control loop performance and stability.
  - 50% complete. These simulations require massive parallel computing. Additional hardware will be procured to accelerate iteration cycles.
- Initiate collaboration with Andres Guesalaga (Pontificia Universidad Católica de Chile) to utilize Gemini SLODAR turbulence profiling method for MCAO at BBSO and eventually DKIST. Continue student training.
  - Completed.

#### F3. NISP/SOLIS

- Installation of SOLIS canopy remote open/close control.
- In process. The design has been completed, with installation deferred until SOLIS is relocated to its new permanent location.
- Completion of VXWorks removal from remaining SOLIS instruments.
- In process. Elimination of VXWorks dependencies has been completed for the SOLIS mount and FDP instrument, but is pending for the VSM and ISS.
- Complete installation of visible tunable filter (VTF) and pre-filters into SOLIS Full-Disk Patrol (FDP) instrument.
  - Deferred. Demonstration of VTF functions was retested in the lab; however, commissioning of it in the FDP will be done with the rest of the instruments once SOLIS is relocated to its new permanent location.
- Complete Guider signal from Vector SpectroMagnetograph (VSM) instrument to VSM M2 fast tip/tilt mirrors.

- Deferred. Guider progress was negatively impacted by relocation-related staff turnover; however, declination drift in the VSM pointing was mitigated via correction of historical coordinate errors.
- Implement Guider error from VSM instrument to VSM declination drive.
- Deferred. Guider progress was negatively impacted by relocation-related staff turnover.
- *Prepare and relocate SOLIS from GONG Farm to new selected site.* 
  - In process. The relocation of SOLIS to Big Bear Solar Observatory suffered multiple significant delays as a result of the San Bernardino County permitting process; however, the final resolution is anticipated in October 2017 and SOLIS will be moved from Tucson in Q1 of FY18.

#### F4. NISP/GONG

- Relocate GONG test sites TE and TC from GONG Farm to CU-Boulder campus.
  - In process. Final site selection (adjacent to the NSO Headquarters in Boulder) was made, and construction was completed in Q4 of FY17. The TE and TC engineering units are scheduled for delivery in October 2017.

*GONG refurbishment, 2-year program.* **Note:** Given the multi-year nature of this project, the various corresponding milestones are largely ongoing.

- Install new  $H\alpha$  tunable filters.
  - In process. A preliminary optical path redesign was completed; however, filter acquisition was delayed by the vendor due to the 2017 solar eclipse.
- Install new cameras with new 1K x 1K detectors.
- In process. Two replacement camera candidates were tested. The first subsequently ceased to be available from the vendor, and the second did not meet specifications. A third candidate was identified and an evaluation kit has been ordered.
- Replace tunable modulators with new, tighter tolerance modulators.
- In process. The modulators were ordered, received, and validated. The first installation was completed at the Mauna Loa site. Further deployment is pending site visit scheduling.
- *Replace aging optical elements.*
- In process.
- Upgrade Data Center for new H $\alpha$  and additional data cluster storage.
- Complete. Two additional Isilon cluster nodes were purchased to accommodate ten years' worth of anticipated data growth resulting from the Hα upgrade.
- Enhance network bandwidth at GONG sites.
- In process. A symmetric 5Mbps bandwidth upgrade was negotiated for the Learmonth site, and its implementation is pending.
- *Replace Hα and GONG workstations.*
- In process. A replacement system appropriate for both workstations was identified, final testing is underway, and the purchase of the full order is pending.

- *Replace wind birds with new ultrasonic anemometer.*
- In process. The anemometers have been purchased and received. Deployment to the GONG sites is pending site visit scheduling.
- Replace UPS interfaces.
  - In process. The UPS interfaces have been purchased and received. Deployment to the GONG sites is pending site visit scheduling.
- Update remaining GONG shelters and split unit HVAC units.
  - Deferred. HVAC unit replacement is scheduled for the final year of this project.
- *Provide preventive maintenance kits, supplies, and spares for the next 10 years of site support.* 
  - In process. All circuit boards have been fabricated and tested, approximately 85% of the corresponding supplies have been procured, and shipment to the GONG sites is underway.

### F5. NISP Data Center (DC)

- Install new NISP DC hardware in Boulder.
  - Complete. The new NISP DC hardware (seventeen servers, a DELL/EMC Isilon data storage cluster, and a backup tape system) acquired/configured in FY16 was shipped from Tucson to Boulder and installed in the SPSC Data Center (on the ground floor of the NSO Headquarters building) in February 2017.
- Transition NISP DC production operations to Boulder.
  - Complete. Production SOLIS data processing and provision began in Boulder on April 2017. GONG near-real-time data processing and provision of all GONG data commenced the in May 2017. GONG helioseismology and full-calibration data processing has been tested in Boulder and is now ready for production operation there.
- *Relocate remaining NISP DC staff to Boulder.* 
  - Complete. After a relocation in January 2017, two anticipated retirements in June 2017 and September 2017, and one unanticipated departure in July 2017, no NISP Data Center staff relocations are pending. Two staff persons will transition to remote worker status in FY18.
- *Complete installation of GONG space weather pipelines at NOAA.*
- In Process. We have successfully installed and run the GONG space weather pipelines in multiple NOAA "development" environments. However, the process of fully establishing new processing at NOAA has proven to be a multi-year endeavor that has been driven by NOAA's schedule.
- Complete improvements to GONG zeropoint pipeline.
  - In Process. Significant improvements to the GONG zeropoint were realized through software modifications to the Data Acquisition System, which were implemented at the last remaining GONG site in April 2017. Potential additional improvements to the downstream pipelines for future reprocessing were investigated, with marginal results. The staff person primarily involved in this work retired in FY17 after transferring responsibility for this code, and further follow-up is planned.

- Implement alternative VMBICAL processing due to staff retirement.
- In Process. The staff person historically responsible for VMBICAL processing retired in September 2017. The automation of this processing has necessarily been delayed as a result of higher relocation-related priorities. However, it is currently in development, VMBICAL output is approximately 30 days ahead of subsequent post-processing, and a temporary pause in GONG helioseismology processing (if needed) has been deemed acceptable.

### F6. Virtual Solar Observatory (VSO)

- Complete installation of VSO's NSO node in Boulder.
- Complete. The hardware for the VSO's new NSO node was installed in the SPSC Data Center (as part of the NISP Data Center) in February 2017, and the VSO team completed the switchover of services from Tucson to Boulder in July 2017. This applies to NSO's netDRMS functionality as well.
- Continue to incorporate data sets into the VSO by developing new data provider software, as well as maintaining existing data providers.
  - Complete. Data from UCAR's HAO were restored online, and their historical eclipse data archive is now being referenced. The SUVI instrument on GOES-16 is in the initial stages of incorporation.
- Improve system robustness by developing autonomous monitoring systems.
- Ongoing. Tools that monitor VSO systems are being developed, resulting in the recent detection of an issue at the JSOC that required remediation.
- Continue to investigate methods for upgrading the user interface.
- Ongoing. Staff transition within the VSO team have made significant progress on this front challenging.
- Continue to investigate spatial searching techniques.
  - Ongoing. Discussions have continued, but competing priorities have precluded significant progress.

### 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. Spectropolarimeter for Infrared and Optical Regions (SPINOR)

- Maintain instrument and keep available as user instrument.
- Instrument is operational.

- *Keep instrument available to perform telescope matrix measurements over broad range of wavelengths.* 
  - Instrument is available for telescope matrix measurements.
- Maintain user-friendly data reduction/calibration software, provide software support to users.
- Reduction pipeline software is available via the NSO website.

### F9. Facility IR Spectropolarimeter (FIRS)

- Maintain instrument and keep available as user instrument
  - Instrument is operational.
- Maintain user-friendly data reduction/calibration software, provide software support to users.
- Data reduction software is available via the NSO web site.
- Install thermal control for LCVR modulation unit in Infrared branch for more accurate polarimetry.
- Thermal controls have been installed and the control software has been updated. Test observations will be performed in Nov 2017.

### F10. Dunn Solar Telescope Control and Critical Hardware (Systems Upgrade)

- *Perform necessary maintenance to keep telescope available for the solar community.*
- The telescope is fully operational.
- Continue efforts to proactively upgrade telescope and other critical hardware systems to the extent possible given financial and personnel constraints.
  - No upgrades have been performed in light of the imminent transition of the telescope and facilities to NMSU.
- Provide first draft of plan to ugrade telescope control to more modern technology, in preparation to handover of telescope to the NMSU consortium at the end of FY 2017.
  - Telescope control software has been extensively documented and sanitized, providing a clear path to potential upgrades the SSOC might want to undertake.

### F11. Rapid Oscillations in the Solar Atmosphere (ROSA) Imaging System

- Work with Queen's University, Belfast to maintain as user instrument.
  - The instrument is fully functional.
- Work towards integration into DST data storage for better transfer of data.
- No work has been done, given the uncertainty of the modes of operation of the instrument in the upcoming era of SSOC stewardship of the DST.
- Work with Queen's University to provide software support to users.
  - Queens University has expressed full willingness to support NSO and future SSOC clients with data reduction support.

### F12. Interferometric Bidimensional Spectrometer (IBIS) Camera Upgrade

- Maintain instrument and keep available as user instrument.
  - The instrument is fully functional.
- Maintain user friendly data reduction/calibration software, provide software support to users.
  - Software for the data reduction pipeline is available on the NSO website.
- Provide option and connectivity to run instrument from the DST control room, aka the bridge.
  - No efforts have been undertaken as a result of limited personnel resources and the need to dedicate the time of available personnel to efforts supporting the transition of the DST and instruments to the SSOC.

### F14. Establish NSO Headquarters

- Hire a Business Manager for Operations.
  - Achieved.
- Implement matrix structure for administrative personnel.
- In process.
- Establish IT program for Headquarters (e-mail servers, web servers, etc.).
- In process.
- Continue developing basic infrastructure for scientific support.
- Ongoing.
- Fill second CU-NSO shared faculty position.
  - Achieved.
- *Continue implementing transition plan.* 
  - Ongoing.

# APPENDIX G. NSO FY 2018 STAFFING SUMMARY

	Director's Office		NSO/Sunspot		NSO	DKIST				NISP			TOTAL
-	Tucson	Boulder	Sunspot	Boulder	Tucson	Tucson	Sunspot	Maui	Boulder	Tucson	Sunspot	Boulder	
Scientists	1.20	2.00	2.00			0.80	-	3.00	15.00			6.00	30.00
Engineering/Science Support Staff	-	0.50	4.00			6.00	3.00	8.00	11.00	3.00		3.20	38.70
Administrative Staff	0.75	6.00	2.00			2.00	1.00	2.00	1.00			1.00	15.75
Technical Staff	1.00		0.30			8.00	-	26.00	13.00			11.00	59.30
Maintenance & Service Staff	-		4.00					3.00					7.00
Graduate Students													1
Undergraduate Students	-	-											1
													0.00
Total Base Program	<i>2.9</i> 5	8.50	12.30	0.00		16.80	4.00	42.00	40.00	3.00	0.00	21.20	150.75
AF Supported Science Staff	-					-				-			0.00
AF Supported Technical Staff	-					-				-			0.00
Other NSF Projects (AO, FTS/CHEM)	-					-				-			0.00
Graduate Students (NASA Supported)	-					-				-			0.00
NASA Supported Science Staff	-					-						2.00	2.00
NASA Support Engineering Staff	-		-			-							0.00
NASA Supported Technical Staff	-		-			-				-			0.00
Emeritus Science Staff	2.00	2.00				-				-			4.00
Visiting Scientists	-		-			-				-			0.00
Total Other Support		2.00	0.00	0.00						0.00	0.00	2.00	6.00
Total FTEs	4.95	10.50	12.30	0.00	0.00	16.80	4.00	42.00	40.00	3.00	0.00	23.20	156.75

(In Full-Time Equivalents)

# APPENDIX H. SCIENTIFIC STAFF RESEARCH AND SERVICE

(\*Grant-supported staff)

### Christian Beck, Associate Scientist

#### Areas of Interest

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

### **Recent Research Results**

Dr. Beck and colleagues published a paper on the magnetic field in the quiet Sun (*ApJ*, **842**, 37, 2017) based on a combination of observations and numerical simulations. A publication on the successful realization of a subtractive double-pass imaging spectrometer at the Dunn Solar Telescope (DST) has been submitted to *Solar Physics*. One paper on the detection of Alfven waves in sunspots resulting from a collaboration with Queen's University Belfast is currently under review at *Nature*. The REU project of A. Derks in 2015 and the subsequent observations at the DST triggered by it have revealed a novel method for the polarimetric calibration of solar telescopes based on spectral lines without intrinsic linear polarization signals. These results were submitted to *Astronomy and Astrophysics* for publication. In collaboration with D. P. Choudhary (California State University Northridge; CSUN), a paper on the properties of the chromospheric inverse Evershed effect near sunspots was submitted to *ApJ*.

### Future Research Plans

With the full-time commitment to the Daniel K. Inouye Solar Telescope (DKIST) project, the main focus for the near future will be on DKIST instrumentation and polarimetric calibration approaches. The collaboration with CSUN will continue, with the study 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. Future observations at the 1.5-m GREGOR (Spain) and Goode Solar Telescope (BBSO) will be aimed at identifying potential DKIST science topics that cannot be addressed at the current spatial resolution because they require the resolution of a 4-m solar telescope.

### <u>Service</u>

C. Beck was a member of the DST time allocation committee up to the end of NSO operations in Oct. 2017. A few observation campaigns at the DST for external investigators were still conducted in 2017. During the past year, Beck has reviewed publications for *Solar Physics* and *The Astrophysical Journal*. C. Beck is a DKIST representative for the DKIST Critical Science Plan workshops and specifically a point of contact for the DKIST Visible Spectro-Polarimeter (ViSP).

### Luca Bertello, Scientist

### <u>Areas of Interest</u>

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 2017, Dr. Bertello has been involved in several projects related to the update of the NISP data catalog. A major task he has undertaken is the improvement of current Carrington synoptic maps derived from both SOLIS/VSM full Stokes and longitudinal measurements of the solar magnetic field. Those maps are the main drivers for current coronal and heliospheric models and play a critical role for space weather predictions. 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 analysis can indeed improve the diagnostic capability of coronal models.

Recently, Dr. Bertello has also joined an international collaboration aiming to determine the internal rotation of the Sun with unprecedented precision. His responsibility on this project is to calibrate the SOHO/GOLF time series and determine the rotational splitting of the low-angular degrees acoustic modes, with a particular emphasis on the low-frequency range below 1.5 mHz.

Several results from Bertello's recent research activity have been published in a series of papers and presented at various venues. They include, among others, studies of the correlation between the chromospheric Ca II K index and the new sunspot number time series, the estimation and impact of uncertainties in the fully disambiguated SDO/HMI Carrington vector synoptic maps, and an investigation about using magnetic observations from the L5 advantage point of view. New projects, mostly in collaboration with other colleagues, include 1) the recalibration of several SOLIS/ISS spectral bands using a more advanced flat-fielding procedure and accounting for the contribution of scattered light; 2) studies of the photospheric activity of the Sun using data from the SOHO/VIRGO and SOHO/GOLF instruments and comparison with standard activity proxies; 3) a determination of the Mount Wilson S-index of the Sun, the most commonly used index of stellar magnetic activity. Accurately placing the Sun on the S scale is important for comparing solar activity to that of the Sun-like stars; 4) working jointly with several other members of the solar and heliophysics community, an initial assessment of the importance of having a magnetograph in an L5 mission to improve space weather prediction capabilities.

### <u>Future Research Plans</u>

The main focus of L. Bertello's future research is on improving the quality of current SOLIS 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 recently added to the VSM instrument. Dr. Bertello maintains strong collaborations with several national and international institutes. This synergy has grown consistently over the years, and has opened several new research channels.

### <u>Service</u>

As the Data Scientist for SOLIS, Bertello's major responsibility is to provide the solar and helio-physics community with high-quality and reliable data. During 2017, Bertello has been a reviewer of publications for *Solar Physics* and other journals.

### \*Olga Burtseva, Associate Scientist

### Areas of Interest

Flares; magnetic fields; local helioseismology; solar activity.

### **Recent Research Results**

Dr. Burtseva continues working on the evolution of magnetic field associated with solar flares. In collaboration with S. Gosain and A. Pevtsov, she had been working on cylindrical symmetry of round sunspots that could be used as a proxy for flare-related changes in pseudo-vector magnetic field derived from line-of-sight magnetograms, when vector data are not available. Vertical, radial, and tangential components of vector magnetic field as a function of the distance from the sunspot center have been reconstructed from LOS magnetic field observed by HMI for two sunspots at the X2.2 flare site in the NOAA active region 11158 on Feb 15, 2011 and their evolution around the time of the flare is compared with vector magnetic field data. Simple round sunspots are analyzed for validation of the technique. A paper on the results of this work is in preparation.

O. Burtseva has resumed analysis of flux cancellation events during major flares using HMI vector magnetic field data (in collaboration with G. Petrie). She has been also working on construction of synoptic maps of the pseudo-radial chromospheric magnetic field from SOLIS/VSM.

#### Future Research Plans

O. Burtseva plans to continue working on the synoptic maps product. She will also continue the flux cancellation study in conjunction with analysis of Doppler velocity shifts at the cancellation sites which might help to distinguish between physical processes that could stand behind flux removal from the photosphere in flaring active regions.

### Serena Criscuoli, Associate Astronomer

#### Areas of Interest

High-spatial resolution spectroscopy and spectropolarimetry of the photosphere and chromosphere; post-focus instrumentation; 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. In particular, she led two meetings of an international Team at ISSI, Bern, Switzerlad, "Toward New Modeling of Solar Spectral Irradiance with the Use of 3D MHD Simulations". The two meetings occurred in March and October of 2016, and were aimed at comparing radiative properties of MHD snapshots of the solar atmosphere as obtained by different codes, as well as comparing the mentioned radiative properties as obtained by different radiative transfer techniques. Dr. Criscuoli also employed MHD simulation of the solar photosphere to investigate variation of the solar limb darkening function over the 11-year magnetic cycle. Dr. Criscuoli also employed observational data to investigate the variation over the magnetic cycle of the distribution of faculae and network, to investigate the dynamic properties of sunspot penumbrae and the properties of a white light flare. The results of her investigations have been published in *Solar Physics* and *The Astrophysical Journal* and have been presented at international conferences.

### <u>Service</u>

Dr. Criscuoli is a member of the Sac Peak telescope allocation committee and is responsible for user support, as well as improvement, of the IBIS data calibration software. She is a scientific consultant for the DKIST and is responsible for developing one of DKIST's critical science cases. In 2017, she was a referee for scientific journals. She was also on the Scientific Organization Committee of the "2016 Solar and Heliophysics Italian Community, 2016" and of the splinter session, "Variability of Solar/Stellar magnetism", at the Cool Stars 19 Conference.

### Gabriel Dima, Postdoctoral Research Associate

### <u>Areas of Interest</u>

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

### **Recent Research Results**

G. Dima finished analyzing polarimetric results from a 2006 solar eclipse developing new diagnostic tools based on emission line ratios to distinguish between magnetohydrodynamic models of the solar corona.

### **Future Research Plans**

Dr. Dima is currently analyzing ground-based polarimetric observations of the FeXIII 1075 nm and SiX 1430 nm emission lines to determine how the information can be used to resolve line-of-sight ambiguities.

#### <u>Service</u>

Dima is becoming involved with educational outreach for the local Maui community.

### Andre Fehlmann, Assistant Scientist

#### Areas of Interest

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

#### **Recent Research Results**

Fehlmann assembled and aligned the Cryogenic Near-Infrared Spectropolarimeter, a DKIST firstgeneration facility instrument. Fehlmann is also involved in developing the polarization calibration plan for DKIST.

#### Future Research Plans

Fehlmann will help refining and implementing the DKIST calibration plan and integrate and commission the facility instruments on the telescope. As a participant of the coronal science work group he will be involved in developing a critical science plan for early DKIST observations.

### <u>Service</u>

Fehlmann is a member of the DKIST science team and infrared instrumentation specialist for DKIST facility instruments. He supervises students participating in the AKAMAI internship program.

### Mark S. Giampapa, Astronomer

### <u>Areas of Interest</u>

Solar and stellar magnetic activity; stellar dynamo properties; star-exoplanet interactions.

### **Recent Research Results**

Dr. Giampapa is leading a collaboration with A. Brandenburg (CU/NORDITA), A. M. Cody (NASA-Ames), B. Skiff and J. Hall (Lowell Observatory) on an analysis of the magnetic activity and broad band photometric variability of solar-type stars in the solar-age and metallicity cluster, M67, based on NASA *K*2 data and NN-EXPLORE Ca II spectroscopy, respectively. A manuscript is in preparation for submission to *ApJ*. Giampapa and collaborators found that the solar-type stars in their sample that are classified as single members and that also exhibit rotational modulation of their light curves a mean

rotation period of 23.0 days with a standard deviation for the sample of 2.7 days. With few exceptions, they do not detect solar-like rotation periods of 26 days or longer in the K2 data. Among the binaries with a solar-type primary in our sample, they find a faster mean rotation period of 15.4 days. A general decline in chromospheric activity with increasing rotation period is present though with considerable scatter among the single members with rotation periods greater than about 19 days. The single solartype M67 stars exhibit a correlation of activity with Rossby number that is opposite to that seen in the inhomogeneous (in age and metallicity) sample of field stars from the Mt. Wilson HK Survey. This appears to be due primarily to an inverse correlation of activity with convective turnover time combined with similar rotation periods in the range  $\sim 20 - 25$  days for the solar-type sample. Giampapa and collaborators also find that single solar-type members warmer than the Sun tend to have enhanced chromospheric emission than would otherwise be predicted by empirical relations for chromospheric decay combined with rotational evolution models. Finally, they estimate stellar ages based on gyrochronology relations and age-activity correlations, respectively, determining a mean chromospheric age of  $4.5 \pm 1.9$  Gyr and a mean gyroage of  $4.2 \pm 1.0$  Gyr. They discuss these methods for stellar age determination particularly in the context of their applicability for identifying stars in the field with ages similar to that of the Sun.

#### Future Research Plans

Dr. Giampapa intends to extend the M67 investigation, in collaboration with A. Brandenburg (CU), in a comparative study of theoretical facets of these results with others obtained for a sample of field stars. In another investigation, Giampapa is collaborating with PhD thesis student, Benjamin Rackham (U. Arizona/NSF Graduate Fellow) and his advisor, Prof. Daniel Apai (U. Arizona), on the potential effects of inhomogeneous atmospheres (i.e., spots and faculae) in solar-type stars on the interpretation of exoplanet atmospheric transmission spectra in transiting systems. This work is based on a recently completed study (Rackham, Apai & Giampapa 2017, *ApJ*, in press) of this effect as it may occur specifically in M dwarf transiting systems, which will have critical application in the anticipated discoveries of such systems by the forthcoming NASA TESS mission. In other research, Giampapa is collaborating with NSF Postdoctoral Fellow Jason Curtis (Columbia University) in an analysis of *K2* and chromospheric data, analogous to that of M67, but for the 3 Gyr open cluster, Ruprecht 147. Finally, Giampapa initiated a novel program of high-resolution, time-resolved observations of the He I 1083 nm line during exoplanet transits in order to learn more about the intrinsic properties of stellar active regions. This effort is in collaboration with Vincenzo Andretta (INAF) and other European collaborators.

### <u>Service</u>

After 15 years as the Deputy Director for the National Solar Observatory, M. Giampapa now serves as the NSO Tucson Site Leader with the implementation of the new Cooperative Agreement. As Site Leader, he will continue to carry out his oversight of the NSO Tucson/Kitt Peak and Tucson program. Giampapa is a point of contact between the NSO, the NOAO and LSST, respectively. In addition, Giampapa is active in community engagement. He recently served as Chair of the NOAO Galactic TAC I peer review panel for NOAO, Gemini, CHARA, and Las Cumbres community proposals for observing time. He is a member of two International Science Development Teams for the TMT project with a recent focus on the completion of the detailed Science Requirements Flowdown to the TMT Observatory Technical Requirements. Giampapa now serves as a member of the PhD thesis committee for NSF Graduate Fellow, Mr. Benjamin Rackham (U. Arizona); he is an SOC member for a Focus Meeting on solar and stellar irradiance variations, proposed for the 2018 IAU GA meeting in Vienna; and, he participates in public outreach, e.g., Giampapa and his research was the focus of an article for *Scientia*, which is now in press. Giampapa is an adjunct astronomer at the University of Arizona.

### Sanjay Gosain, Associate Scientist

### <u>Areas of Interest</u>

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

### Recent Research Results:

Dr. Gosain's main research activities include:

Search for a signature of twist removal in magnetic field of sunspots in relation with major flares (ApJ, in press): We investigate the restructuring of magnetic field in sunspots associated with two flares. The observed changes were evaluated in respect to so-called twist removal model, in which helicity (twist) is removed from the corona as the result of an eruption. We applied the azimuthal symmetry approach to line-of-sight magnetograms to reconstruct pseudo-vector magnetic field when vector data were not available. For both flares the data show changes consistent with twist-removal scenario.

High resolution observations of H $\alpha$  spectra with a subtractive double pass. (Solar Physics, in press): We modified the NSO Sac Peak spectrograph to a subtractive double pass (SDP) configuration and demonstrate that it can reach a similar performance as FPI-based systems with a high spatial and moderate spectral resolution across a FOV of 100"×100" with a spectral coverage of 1 nm. We use H $\alpha$  spectra taken with our SDP system to infer the properties of small-scale super-penumbral filaments. We find that the majority of all filaments end in patches of opposite-polarity fields.

### Instrumentation / Service:

Dr. Gosain is involved in the following instrumentation projects:

1. GONG refurbishment project. He is leading the design and development of the optical design for the GONG H-alpha Doppler imaging setup. Other activities include optical design of the replacement lenses to match the distortion free solar image to the new cameras.

2. SPRING, an international collaborative project between NSO and KIS, Freiburg, Germany. As a part of this project Dr. Gosain has traveled for extended periods to Germany during last year and has completed the conceptual design study to build the next generation of synoptic instruments for solar research. The report for that project has been submitted to European Research Council.

3. Citizen CATE Total Solar Eclipse experiment at Casper, WY. This involved training a team of citizen scientists to carry out measurements of the solar corona during total solar eclipse of 2017.

4. Optical design of a compact solar magnetograph, CMAG. As a part of collaborative project with LASP, CU, Boulder, Dr. Gosain is carrying out the design of CMAG. The instrument concept involves compacting the existing GONG instrument for a space deployment.

5. Gosain has been involved in NSF panel reviews and publication reviews for *ApJ* and *Adv. Space Res.* 

### **Future Research Plans & Service**

S. Gosain plans to complete the upgrade of the GONG H-alpha tunable Doppler imaging system and new camera for the GONG helioseismology instrument. He is involved with the relocation of GONG and SOLIS instruments out of Tucson which includes disassembly and realignment of optics at the new locations. Using GONG engineering setup at Boulder, Dr. Gosain will perform a proof-of-concept experiment for CMAG.

### David M. Harrington, Associate Scientist

### <u>Areas of Interest</u>

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.

#### <u>Service</u>

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

### <u>Areas of Interest</u>

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 others, Hill continues to track the progress of an east-west zonal flow in the solar interior known as the torsional oscillation as it slowly migrates from the solar poles to the equator. Recent data through 2017 still indicates that the poleward 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 subsurface flows of two very large active regions, with very high and very low CME production rates. We found several differences in the subsurface flows below the regions, reinforcing the idea that space weather is driven at least in part by the details of subsurface velocity fields. Hill continues to participate in a NASA Grand Challenge (P. Martens, PI, Georgia State U.) project to constrain dynamo models with realistic flows inferred from helioseismology. He 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 on applying power map movies to GONG and SDO data to study the dynamics of the chromosphere in flaring regions.

### <u>Service</u>

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 Tucson GONG engineering systems and 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.

### Sarah A. Jaeggli, Assistant Astronomer

### <u>Areas of Interest</u>

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**

Dr. Jaeggli is very close to publishing new ultraviolet identifications of molecular hydrogen based on radiative transfer and observations from the Interface Region Imaging Spectrograph (IRIS), research conducted with P. Judge and A. Daw. She has investigated the removal of instrumental polarization in high spatial resolution spectropolarimetry observations of sunspots from the *Hinode*/SOT-SP using ad-hoc techniques to characterize the level of polarimetric accuracy that will be possible using these techniques with DKIST.

### <u>Future Research Plans</u>

Dr. Jaeggli is working with D. Harrington to produce a realistic synthetic dataset by combining MHD models of the Sun, advanced radiative transfer techniques, and a detailed polarimetric model of the telescope and instrument systems to intuitively understand the problem of polarization calibration and provide the inputs needed to develop and test calibration codes. She is also collaborating with A. Kobelski, L. Tarr, and S. Savage on a multi-observatory dataset obtained recently 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.

### <u>Service</u>

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.

### Kiran Jain, Associate Scientist

### Areas of Interest

Helioseismology – solar cycle variation, multi-wavelength helioseismology, sub-surface dynamics, active regions; Sun-Earth connection.

### **Recent Research Results**

Jain studied sub-surface flows in AR 12192, the biggest active region observed in solar cycle 24 so far, and investigated how different was the plasma flow in AR 12192 from that in the biggest active region (AR 10486) of the previous solar cycle. We applied the technique of ring diagrams to high cadence and high-spatial resolution continuous Doppler images from NISP/GONG. Although better spatialresolution observations from two space-borne instruments are available for this work, the GONG observations provided a unique advantage in this work in order to minimize the instrument--related bias on results. It should be noted that both regions produced several high M- and X-class flares, but had different CME productivity. Our analysis suggests that these ARs had unusually large horizontal flow amplitude with distinctly different directions. While meridional flow in AR 12192 was poleward that supports the flux transport to poles, it was equatorward in AR 10486. Furthermore, there was a sudden increase in the magnitude of estimated zonal flow in shallow layers in AR 12192 during the X3.1 flare; however, it reversed direction in AR 10486 with X17.2 flare. These flow patterns produced strong twists in horizontal velocity with depth in AR 10486 that persisted throughout the disk passage, as opposed to AR 12192, which produced a twist only after the eruption of the X3.1 flare that disappeared soon after. Our study indicates that the sunspot rotation combined with the reorganization of magnetic field in AR 10486 was not sufficient to decrease the flow energy even after several large flares that might have triggered CMEs. Furthermore, in the absence of sunspot rotation in AR 12192, this reorganization of magnetic field contributed significantly to the substantial release of flow energy after the X3.1 flare.

Jain and co-worker also used simultaneous velocity and intensity observations from SDO/HMI to obtain better estimates of solar acoustic mode parameters. This was achieved by fitting four spectra simultaneously viz. velocity, intensity, the phase difference and the coherence between the intensity and velocity spectra. We further studied the differences/similarities between the oscillation mode parameters obtained from the single-observable fitting and those from the cross-spectral fitting method. The mode frequencies derived from the cross-spectral procedure were lower than those derived from the velocity spectrum fitted with an asymmetrical profile. We further noted a clear solar cycle dependence in the mode frequencies while other mode parameters e.g. amplitudes and line widths did not show significant variation with solar activity. This corroborates earlier findings that the interpretation of model fit parameters based on measurements of a single spectra should be examined critically.

### Future Research Plans

Jain will 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.

Jain will also 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 study the fundamental modes of oscillations in order to understand the implications of their variability on solar acoustic radius and the total solar irradiance. She further 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.

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

#### <u>Service</u>

Jain continues to serve as a member of the Scientific Personnel Committee (SPC) of NSO. She has also served as the reviewer for the research papers submitted to *Solar Physics*.

### \*Shukirjon S. Kholikov, Associate Scientist

#### <u>Areas of Interest</u>

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 measure-ments 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 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 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, a detailed meridional flow profile 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 a new inversions based on spherical Born kernels with 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. At present he is working on comparative analysis of the deep meridional flow between HMI and GONG projects.

### **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.

#### <u>Service</u>

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

### <u>Areas of Interest</u>

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 started producing daily full-disk maps of the normalized helicity parameter in collaboration with A. Reinard (NOAA/SWPC). 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 divergence of horizontal flows and has derived (a) the relationship between the flow divergence patterns and magnetic activity, (b) the poleward branch of the divergence patterns, and (c) the divergence patterns during the extended minimum.

### <u>Future Research Plans</u>

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. He will focus on the daily variations of subsurface flows of active regions and search for a signature of helicity flow from the solar interior to the photosphere. He will also continue to explore the long-term variation of subsurface flows.

### <u>Service</u>

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 supervises undergraduate and graduate students who participate in NSO's summer REU and SRA programs.

### 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.

### Recent Research Results

Adam Kowalski has recently updated the RH code to include an accurate prescription for hydrogen line broadening in solar flares and the quiet Sun. He published his results in Kowalski et al. 2017. *ApJ* **837**, 125. Dr. Kowalski has submitted an article to *ApJ* describing a new modeling algorithm for solar and M dwarf flares which will be useful for understanding the observed spectra while foregoing the very long computational times (months) required to probe the interesting regime of high heating rates. Dr. Kowalski is working on a submission to Nature where he has detected the NUV continuum in a secondary flare event with IRIS and has used new models to localize the depths where the white-

light is formed in these enigmatic events, which also can result in double-CMEs and are observed in very energetic flares on other stars.

### Future Research Plans

Dr. Kowalski is working on a follow up study of the formation of the red-wing asymmetry in Fe II lines and NUV continuum radiation (Kowalski et al. 2017 ApJ 836 12) in data from IRIS of one of the

best observed solar flares. Motivated by these models, he is working on new predictions for the H alpha line broadening which will be extended for predictions for the DKIST/ViSP. Dr. Kowalski is writing a paper on NUV flare spectra of flares from the M dwarf GJ 1243 that was observed with the Hubble Space Telescope/COS. These results provide robust evidence for a new type of flare with unexplained heating properties and will provide direct comparison to IRIS data of solar flares. *Service* 

Kowalski is 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), he has been on several CU/APS graduate student Comps-II committees, he is teaching an over-load astrophysics seminar (ASTR 6000) on "State-of-the-Art Stellar Atmosphere Modeling", he is a Co-I on the FOXSI SMEX which is currently in Phase-A; as part of this team he is helping plan for the DKIST flare observations if this is accepted.

### John W. Leibacher, Astronomer

#### <u>Areas of Interest</u>

Helioseismology; atmospheric dynamics; asteroseismology.

#### **Recent Research Results**

J. Leibacher's recent work has focused on the search for flare-related changes in the solar interior as manifested in helioseismic "ring-diagrams", and various artifacts of ring-diagram analysis.

#### **Future Research Plans**

Leibacher and colleagues will undertake the first stereoscopic helioseismology using the Kepler observations of Neptune and simultaneous observations from the Earth's neighborhood. In addition, a study of the physics of individual helioseismic modes' temporal variability (energy, phase) as a probe of their excitation and to fill gaps in the global-mode time series is getting renewed attention. These are based on a parametric analysis of the helioseismic time series, in contrast to the typical non-parametric analysis (Fourier transformation) followed by model fitting. A novel, horizontal phase-velocity and horizontal eigenfunction analysis of low-degree spherical harmonic mode frequencies to better probe the deep solar interior is being pursued.

#### <u>Service</u>

Leibacher has been a mentor to several undergraduate (REU and IINSPIRE) students and graduate students. He maintains the American Astronomical Society/Solar Physics Division *SolarNews* distribution and WWW site. He is a member of the Fachbeirat (scientific advisory committee) of the Max-Planck Society's Institute for Solar System Research (Göttingen), co-investigator/advisor to several external projects. He is editor-in-chief of the journal *Solar Physics*.

### 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 in a NSF proposal to continue the joint project between NSO and the Big Bear Solar Observatory to test and commission a path-finder solar multi-

conjugate adaptive optics system for the Goode Solar Telescope (GST), in Big Bear, CA. Marino continues the development and improvement of Blur, a fast and accurate adaptive optics simulation package. At this time, Blur is capable of handling any AO and MCAO simulations and is currently being used to study the performance and aid in the design of the DKIST AO system, the path-finder MCAO system at BBSO, and the future DKIST MCAO system. The latest results produced by Blur were presented at the AO4ELT meeting in Tenerife, Spain in June 2017.

### <u>Future Research Plans</u>

Dr. Marino will continue the development of Blur, a solar AO and MCAO simulation package. Blur simulations will contribute to further our understanding of solar MCAO systems and conventional AO systems in the next generation of large aperture solar telescopes, such as the DKIST. Marino will continue his involvement in the development of the path-finder MCAO system and the solar atmospheric profiler currently being developed at the Big Bear Solar Observatory.

### <u>Service</u>

During 2016 and 2017, Marino served as adviser to graduate student Elizabeth Carlisle. Marino represented the DKIST project as an invited speaker at the AO4ELT meeting where he presented a status update of the DKIST AO system project.

### Matthew J. Penn, Astronomer

### Areas of Interest

Spectropolarimetry; near-IR instrumentation; solar atmosphere; oscillations and magnetic fields.

### **Recent Research Results**

Penn has published the preliminary results for the CATE 2016 experiment in *PASP*, and is a coauthor on a mid-IR flare observation paper in *A&A*, and the mid-IR spectropolarimetry observations at 4135 nm in *Solar Physics*. Penn and the CATE team are developing papers for the 2017 CATE results, including an instrument and a science paper. Penn will be speaking at the AGU and AAS meetings in late 2017 and early 2018, and several poster papers from CATE students will also be presented at these meetings. With data in-hand, Penn is collaborating with NASA/GSFC concerning solar eclipse observations at 5, 10 and 13 microns; he is also collaborating with MIT/Lincoln Labs and NASA/JPL teams on rapid eclipse observations at 5 microns. In collaboration with NJIT/BBSO, Penn is continuing to work with graduate student Yang Xu on Ti I abundances, velocities and magnetic field measurements in a variety of sunspots, and with new CO 4666 nm data taken with the CYRA instrument, including the first polarimetric observations taken with CYRA.

### Future Research Plans:

Penn will work with Citizen CATE Experiment collaborators to produce scientific results from the highly successful CATE 2017 observations, and will help collaborators with future projects for the CATE volunteer team. Penn will work with NASA/GSFC and NJIT/BBSO collaborators to install the mid-IR flare observation bench at BBSO as the McMP facility is closed. Penn is Co-I with Lin (U. Hawai'i) and will be helping to develop the Mees Massively-multiplexed Coronal Spectro-polarimetric Magnetometer, emphasizing the DKIST applications of the device.

### <u>Service</u>

Following work from Lin & Penn (2004), Penn is finishing the design a modern version of a daily sky brightness monitor for DKIST. Application of the recent mid-IR flare, coronal loop and disk observations will be used to develop mid-IR science goals for the DKIST telescope, and to outline a potential new second-generation DKIST instrument. Penn's work with students included being a

research advisor to NJIT student Yang Xu, a research and summer mentor for groups of undergrads at University of Arizona, Wyoming, Illinois, Kentucky and South Carolina, and the development of 22 high school and 27 university academic partners for the recent 2017 CATE experiment. Penn is involved with advising several CATE high school students on their science fair projects in preparation for the upcoming SARSEF 2018. Penn was on the 2017 AAS Eclipse Planning committee, and is worked with NASA Heliophysics, NASA Edge TV, Science Friday, Discovery Channel, CBS News and many other groups for eclipse public outreach. Finally, Penn joined J. Ulvestad (NSF), T. Zurbuchin (NASA), H. Hammel (AURA) and others in Washington DC Experiment on 28 September 2017 to testify to the House Science joint subcommittees about the outcomes from the Citizen CATE project.

### Gordon J. D. Petrie, Associate Scientist

<u>Areas of Interest</u>

Solar magnetic fields.

### <u>Recent Research Results</u>

Petrie investigated the possible use of high-resolution vector magnetic field measurements for the Sun's polar fields in synoptic magnetograms and global coronal and heliospheric modeling. Global coronal field models are particularly sensitive to polar field data, but existing full-disk vector magnetograms from SOLIS/VSM and SDO/HMI lack the spatial resolution and sensitivity to resolve the facular-scale magnetic structure that dominates the polar fields. The NSO's DKIST vector magnetographs will likely provide the most sensitive, highest-resolution polar scans but, until DKIST begins operating, Petrie used *Hinode*/SOT-SP polar vector magnetograms in combination with SOLIS/VSM data for the remainder of the solar surface, to explore improvements to synoptic maps and global field models. A paper has been published in *SoPh* **292**, 13.

Petrie organized the hiring of a new postdoc, Joseph Plowman, to investigate inconsistencies between the GONG and SOLIS/VSM magnetic field measurements, and leads the effort to define and manage his project. Plowman has developed a model for GONG magnetogram measurements based on known MHD magnetic field data, and Petrie and Plowman are working on calibrating real GONG data and studying the effect on global coronal field models. Petrie worked with Axel Brandenburg on a two-scale analysis of magnetic helicity in the solar photosphere using SDO/HMI vector synoptic magnetograms. An article is published in *ApJ* **836**, 21.

Petrie also contributed to the ISSI team lead by Anthony Yeates (U. Durham, UK) investigating global non-potential models for the solar coronal magnetic field by preparing a bespoke vector synoptic magnetogram formed by merging vector data for strong fields and line-of-sight data for weak fields. A paper is submitted to *Space Science Reviews*. Petrie then prepared a time-latitude data set for the photospheric field based on magnetograms from KPVT and SOLIS/VSM spanning the years 1974-2016 for Yeates' Ph.D. student Tim Whitbread, who used it in a parameter optimization for photospheric flux-transport models. A paper has been accepted by *A&A*.

Petrie wrote an article with his 2016 REU student Tyler McMaken (Case Western Reserve U.) on a study of the giant solar active region NOAA 12192. They focused on the evolution of magnetic helicity patterns in the region using vector magnetograms and synoptic map data from SDO/HMI and EUV data from SDO/AIA to track the magnetic and electric current helicity parameters and their relationship to the EUV emission patterns of the region over time, from the early coronal loops all the way to a very long, sheared filament about six months later. They then tracked the decay and dispersal of the magnetic flux and found that, owing to the region's unusual flux distribution, the

two polarities' effect on the polar field approximately cancelled so that the effect on the polar field was small, contrary to received opinion. This article appears in *ApJ*, **840**, 100.

### <u>Service</u>

Petrie analyzed the zero-point error in the GONG magnetograms, which are heavily used by space weather scientists at NASA, NOAA, AFRL and elsewhere. A new software fix was implemented at the GONG sites, eliminating errors associated with frames taken during the change of mudulation. Petrie helped to assess the effects of this change. Petrie has also communicated with users regarding the effects of the improved data on their models.

Petrie has provided NSO data user support on accessing and applying NSO magnetogram data 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*, *Natur* and the *JGR*. Petrie mentored REU student Drew Schwarz (Bethel University) during summer 2017, studying the benefits of a possible magnetograph on a satellite at the Lagrange point L<sub>5</sub> (and another at L<sub>4</sub>). This work is being extended and a publication is expected next year.

### Alexei A. Pevtsov, Astronomer

### Areas of Interest

Solar magnetic fields: topology, evolution, helicity, vector polarimetry; corona: coronal heating, xray bright points, coronal holes; sunspots: topology, evolution, Evershed flow, penumbral fine structure; space weather: solar drivers; chromosphere: filaments and prominences, Moreton waves; solar-stellar research, space climate.

### **Recent Research Results**

A. Pevtsov spent most of the year on sabbatical leave at the University of Oulu, Finland. His projects were aimed at (1) representing the solar magnetic activity over the last century using historical data; (2) establishing the relationship between image properties of plages and their magnetic properties; (3) interpreting properties of solar vector magnetic fields; (4) solar-stellar research; and (5) long-term variations in sunspot properties and Maunder Minimum.

Pevtsov and his colleagues used historical data to establish the presence of two populations of sunspots with smaller and larger areas. The statistical properties of areas of "large" spots were found to be nearly constant over the entire period of observations, while "small" spots showed significant long-term variations. It was suggested that "small" and "large" sunspots may be formed by dynamos operating at different depths in the convection zone. In a separate paper, Pevtsov and his collaborators used <sup>14</sup>C isotope data to establish a pattern of occurrence of past grand minima of solar activity. Extending this pattern to modern times, they predicted that next Maunder-type minima could occur in the year 2090  $\pm$  20.

Pevtsov and his colleagues continued exploiting the surface flux-transport model in modeling past solar activity cycles. As part of this work, the team conducted several modeling tests, which brought a better understanding of the effects related to shape of active regions, their diffusion rate and the orientation on the outcome of flux-transport model. It was found that there is a need for additional decay term (diffusion) of polar field, which, in the absence of sufficient activity in a given hemisphere still allows polar field reversals. As part of this project, a proposal to the International Space Sciences Institute (ISSI) was submitted and selected, and an ISSI international team was formed to work on a project of reconstructing polar magnetic fields over the last century.

### **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.

### <u>Service</u>

A. Pevtsov chaired the NSO's Scientific Personnel Committee (SPC). He reviewed proposals for NASA and NSF, served as a reviewer for several professional publications, and supervised one PhD student at the University of Oulu, Finland. 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).

### 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 116 refereed papers, 226 NASA/ADS entries, 4023 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 Artic 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 second IMaX/SUNRISE flight. This flight received ground support from several of the NSO facilities including the SOLIS VSM instrument. With an REU student, Dr. Pillet is developing alternative ways to calibrate the instrumental polarization of DKIST with an approach that is complementary to the one that would be regularly done at the facility.

# 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.

# Joseph Plowman

# Areas of Interest

Coronal and photospheric magnetic field measurements; spectropolarimetry; Coronal heating and temperature diagnostics; Data analysis; inverse problems, and their application to reconstructing the sources of solar data.

### Recent Research Results

Plowman has developed a simulator for the GONG instrument, applied radiative transfer to 3D MHD simulations, and combined these to create synthetic GONG data. He has also created synthetic magnetograms from these data and used them to create calibration curves for the GONG magnetograms. Other recent work include development of a new algorithm for coronal differential emission measure inversions, and application of these inverse techniques to other solar inverse problems.

#### Future Research Plans

Dr. Plowman will continue to develop the GONG instrument simulator, with a publication and finalized calibration curves coming shortly. Also underway is a similar simulation of the SOLIS/VSM instrument, and the results of the two instrument simulators will be compared to see if they produce relatively similar results to those seen in comparing the real data from those instruments. Application to SDO/HMI will also be investigated, conditional on support. A second line of work, just recently commenced, will look for nanoflares in SDO/AIA data; this is supported by a NASA grant for which Dr. Plowman is PI. Inquiries into other areas of research listed above contingent on support availability.

# Service

Plowman is an active member of the NSO NISP team.

# Kevin Reardon, Associate Scientist

#### Areas of Interest

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.

### **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 scientific requirements.

Reardon was awarded time on the Atacama Large Millimeter/submillimeter Array (ALMA) for his proposal "Turbulence and wave propagation in the solar internetwork," which was one of only our solar proposals receiving a "Grade A" ranking.

Reardon helped organize joint observations between ALMA and the DST in December 2016 and April 2017. Together with a 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. 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 carrying out observations at the 1.6-meter Goode Solar Telescope (GST) at Big Bear. These observations will be 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 image reconstruction and data mosaicking as additional tools needed for efficient usage of the DKIST data.

# **Future Research Plans**

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 tools will help form a bridge to allow solar scientists make the best use and carry out rapid analysis of the calibrated DKIST data.

Reardon will continue to work with graduate students Momchil Molnar (CU) and Yi Chai (of NJIT), as well as Dale Gary, Steve Cranmer, Phil Judge, 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.

Reardon also plans to obtain additional coordinated observations with ALMA during the next observing campaign from the DST and the GST.

# <u>Service</u>

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.

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.

He 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. He is supervising and mentoring DKIST Postdoctoral Fellow Dirk Schmidt (recently promoted to Assistant Scientist) and NSO Assistant Scientist Jose Marino. Both are working on developing multi-conjugate adaptive optics for the Sun in collaboration with BBSO and Kiepenheuer Institute in Gemany.

#### **Future Research Plans**

T. Rimmele hopes to continue his efforts to perform observations at the highest spatial resolution adaptive optics in order to study the properties and the dynamics of small-scale magnetic elements. 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.

### <u>Service</u>

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. Rimmele participates in the European Association for Solar Telescopes (EAST) council meetings as DKIST representative with the goal of identifying potential collaborative efforts between DKIST and the European Solar Telescope (EST); he also is the NSO contact for SOLARNET. He guides the NSO multi-conjugate adaptive optics development effort, which is in collaboration with BBSO and KIS, Freiburg. 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 focused on techniques useful for understanding the magnetic field structure of the upper solar atmosphere including the chromosphere and cool corona. In a recent publication (*SoPh* **292**, 132), he introduced a new machine learning approach based on the Rolling Hough Transform for the automated quantification of coronal rain flows observed off-limb. In a subsequent publication (*SoPh* **292**, 158), he and his collaborators demonstrated the use of a 17-slit massively multiplexed slit spectrograph at the Dunn Solar Telescope that provides unique capabilities for measuring dynamic phenomena in the upper solar atmosphere including coronal

rain. These works together represent necessary steps for developing fine scaled coronal field diagnostics using cooled material in the corona.

# **Future Research Plans**

Making use of the unique observations made by the 17-slit spectrograph, Dr. Schad and collaborators intend to provide initial observational constraints on neutral helium spectral radiance in rapidly evolving coronal rain with data already acquired. This will help bolster science use cases already in development for DKIST. In addition, this unique data provides the ability to understand He I formation as related to other transition region phenomena on disk, e.g. penumbral bright dots. Dr. Schad intends to analyze coordinate He I and IRIS near-UV spectral observations. In addition to these studies, Dr. Schad will continue to formulate use cases for DKIST coronal science using hot lines, especially in his role as a science leader for the DKIST Critical Science Plan (CSP) Workshop focused on the solar corona.

### <u>Service</u>

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. He is also a team leader for the CSP workshop focused on the corona, jointly hosted by the Institute for Astronomy. Schad also participates in educational outreach for the local Maui community. In 2017, he provided public lectures at the Institute for Astronomy, in Pukalani, HI, and helped conduct student activities at a local conference. In addition, Dr. Schad was the site leader for the Citizen CATE eclipse observing team in John Day, Oregon for this year's total solar eclipse.

# 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. The persistence of the MCAO control loop was greatly improved in 2017, and continuous lock was obtained for up to 53 minutes. Schmidt is also working on the concept for the future MCAO implementation at DKIST as well as on a prototype wavefront sensor for solar prominences for DKIST that to be installed at the GST.

# Sushanta C. Tripathy, Associate Scientist

# Areas of Interest

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

#### **Recent Research Results**

S. Tripathy has investigated the spatio-temporal power distribution of acoustic halos in an active region using multi-height observations from the Solar Dynamics Observatory. It is found that the halos occur above the acoustic cutoff frequency and extends up to 10 mHz in Doppler as well as

intensity observations at 170 nm. Halos are found to be strong functions of magnetic field strength and the field inclination angle. Dr. Tripathy further examined the spatially averaged relative phases and cross-coherence spectra and find different characteristics at different heights. The investigation also provided evidence that wave reflection or refraction occurs at certain height and, as a result, the wave propagates downward.

Dr. Tripathy has investigated variations of the intermediate degree mode frequencies with the progression of solar cycle. Analyzing the frequency shifts obtained from Global Oscillation Network Group, it was found that the mode frequencies track the solar activity equally well between the cycles 23 and 24; however, the conditions below the sub-surface layers were found to be different.

Dr. Tripathy participated in an investigation which probed the subsurface flows beneath the active region NOAA 12192, which was the biggest active region of solar cycle 24. The results were compared with the subsurface flows beneath the active region NOAA 10486, which was one of the biggest active regions of solar cycle 23. The study suggests that these active regions had unusually large horizontal flows with distinctly different directions. While meridional flow in 12192 was poleward that supports the flux transport to poles, it was equator ward in 10486. The investigation further indicates that the sunspot rotation plays a crucial role in the flare productivity.

# **Future Research Plans**

Using data from the Solar Dynamics Observatory, Tripathy will further study the wave interaction between the active region and magnetic field and compare the observational results with those from numerical simulations. Dr. Tripathy intends to 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. Tripathy also proposes to compare the high-degree oscillation frequencies between cycles 23 and 24 to comprehend the changes near the sub-surface shear layer.

# <u>Service</u>

S. Tripathy serves as the science lead for the interior group and also organizes the weekly interior science meeting at NSO. Dr. Tripathy participated in the vetting procedure of the GONG data as the data processing pipelines moved to Boulder, CO from Tucson, AZ. Dr. Tripathy has also been a reviewer for scientific journals as well as research proposals from NASA.

# Alexandra Tritschler, Scientist

# <u>Areas of Interest</u>

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.

# <u>Service</u>

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, 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 of international as well as DKIST workshops (as a SOC member). 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. The RH code has been used to calculate Mg II spectra from Rad-MHD simulations of solar chromospheric dynamics in preparation for the launch of the IRIS mission. The results have been published in three *ApJ* papers that have are now widely cited in IRIS-based papers. The code has also been used by Adam Kowalski (NASA GSFC) to model flare spectra in M-dwarfs, by Holtzeuter (MPS Lindau) et al. to model non-LTE iron line spectra in 3D. The RH code was also used to investigate the role of uncertainty in atmospheric models for inferring magnetic fields in the chromosphere with the Hanle effect in the Lyman-alpha line in support of the CLASP sounding rocket flight. 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, and serves as the main ingredient in a massively parallel 3-D transfer code created by Perreira.

# **Future Research Plans**

Development and maintenance of the RH code will continue. Concentration will be on the contribution to irradiance at different wavelengths from small-scale magnetic elements, forward modeling of polarized Sunspot spectra, and forward modeling of polarized radiation from chromospheric structures, both from state-of-the-art 3D Rad-MHD simulations. Uitenbroek will also undertake analysis of IRIS spectra and comparison of its spectra with forward modeling of the Mg II lines.

#### <u>Service</u>

Uitenbroek is the program scientist for the Dunn Solar Telescope at Sac Peak. In this capacity he also helps plan for the transition of the telescope and its instruments to New Mexico State University. He serves as chair of the Sac Peak Telescope Allocation Committee and is part of the NSO Scientific Personnel Committee (SPC). He actively supports users of the RH code with updates and helps with running the code. His RH code is provided on the IRIS data distribution Web page for downloading. Uitenbroek is also member of the planning working group for the next Japanese solar satellite Solar C. He regularly serves as referee for papers and on review panels for proposals, and serves on the Science Team for DKIST.

# Friedrich Wöger, Scientist

# <u>Areas of Interest</u>

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

### **Recent Research Results**

F. Wöger is studying 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 will provide 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 is planning to 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 acquisition of data at diffraction-limited 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.

### <u>Service</u>

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, and is 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. In his function as the DKIST Wavefront Correction Scientist, Wöger is guiding 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 co-supervising a CU graduate student in the modeling of optical transfer functions of Earth's turbulent atmosphere. Woeger has been giving several invited talks on DKIST instrumentation over the course of 2017 to further community interest in the DKIST project.

# APPENDIX I. ACRONYM GLOSSARY

	Astronomy and Astronomics Advisory Committee (NEE)
AAAC	Astronomy and Astrophysics Advisory Committee (NSF)
A&E	Architecture and Engineering
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
aO	Active Optics
AO	Adaptive Optics
APRPP	Annual Progress Report and Program Plan (NSF)
APS	Astrophysics and Planetary Sciences (CU-Boulder)
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 (Hawaiʻi)
BABO	Baboquivari Instrument (NSO McMath-Pierce Solar Telescope)
BLNR	Bureau of Land and Natural Resources
BBSO	Big Bear Solar Observatory
BOD	Basis of Design
BOE	Basis of Estimate
BSA	Boulder Solar Alliance
BVSD	Boulder Valley School District
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
CGEP	Collaborative Graduate Education Program (University of Colorado, Boulder)
CHU	Critical Hardware Upgrade
CISM	Center for Integrated Space Weather Modeling
CJS	Commerce, Justice, Science (Subcommittee of the House Appropriations Committee)
CLASP	Chromospheric Lyman-Alpha Spectro-Polarimeter
CLEA	Contemporary Laboratory Exercises in Astronomy
CLV	Center-to-Limb Variation
CMEs	Coronal Mass Ejections
CMOS	
CNC	Computer Numerical Controlled
CNSF	Coalition for National Science Funding
CoDR	Conceptual Design Review
COLLAGE	COLLAborative Graduate Education (University of Colorado, Boulder)
COS	College of Optical Sciences (University of Arizona)
CoRoT	COnvection ROtation and planetary Transits (French Space Agency CNES)
CoSEC	Collaborative Sun-Earth Connection
CR	Carrington Rotation
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
CU Boulder	University of Colorado, Boulder
CV	Context Viewer
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
DST	Dunn Solar Telescope
EA	Environmental Assessment
EAST	European Association for Solar Telescopes
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
FIDO	Facility Instrument Distribution Optics
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
FUV	Far-ultraviolet
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
GSFC	Goddard Space Flight Center (NASA)
GST	Goode Solar Telescope (Big Bear Solar Observatory)
GUI	Graphical User Interface
HAO	High Altitude Observatory
HIDEE	Heliophysics Infrastructure and Data Environment Enhancements (NASA)
HLS	High-Level Software
HMI	Helioseismic and Magnetic Imager
НО	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
ICD	
ICM	Inversion by Central Moments
IDL	Instrument Control System
	Interactive Data Language
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 (now O-SPAN)
ISP	Integrated Synoptic Program (NSO)
ISS	Integrated Sunlight Spectrometer (SOLIS)
ISSI	Internation Space Sciences Institute
IT	Information Technology
ITAR	International Traffic in Arms Regulations
IT&C	Integration, Testing, & Commissioning
JPL	Jet Propulsion Laboratory (NASA)
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
MBP	Magnetic Bright Point
McMP	McMath-Pierce
MCAO	Multi-Conjugate Adaptive Optics
MCC	Maui Community College
MDI	Michelson Doppler Imager (SOHO)
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ME	Milne-Eddington
MEDB	Maui Economic Development Board
MHD	Magnetohydrodynamic
MKIR	Mauna Kea Infrared
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
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatory
NPDES	National Pollutant Discharge Elimination System
NPFC	Non-Potential Field Calculation
NPR	National Public Radio
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
NUV	Near-ultraviolet
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)
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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
O-SPAN	Optical Solar Patrol Network (formerly ISOON)
PAARE	Partnerships in Astronomy & Astrophysics Research & Education (NSF)
PA&C	Polarization Analysis & Calibration
PAEO	Public Affairs and Educational Outreach (NOAO)
PB	Petabyte
PCA	Principal Component Analysis
PDR	Preliminary Design Review
PI	Principal Investigator
PM	Project (or Program) Manager (NSO)
PMCS	Project Management Control System
PRD	Partial Frequency Redistribution
PRI	Public Radio International
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)
RIF	Reduction in Force
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	Systems Acceptance Testing
SBM	Sky Brightness Monitor
SCB	Sequential Chromospheric Brightening
SCOPE	Southwest Consortium of Observatories for Public Education
SDO	Solar Dynamic Observatory
SDR	Solar Differential Rotation
JUK	Julai Dinerentiai Rotation

SFC	Space Flight Center (NASA)
SH	Spherical Harmonic
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
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
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
STEREO	Solar TErrestrial RElations Observatory (NASA Mission)
STScI	Space Telescope Science Institute
SW	Solar Wind
SSWG	Site Survey Working Group (DKIST)
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
STARA	Sunspot Tracking and Recognition Algorithm
STEM	Science, Technology, Engineering and Mathematics
STEP	Summer Teacher Enrichment Program
STScI	Space Telescope Science Institute
SUMI	Solar Ultraviolet Magnetograph Investigation (NASA, MSFC)
SUP	Special Use Permit
SUVI	Solar Ultraviolet Imager (GOES)
SWPC	Space Weather Prediction Center (NOAA)
TAC	Telescope Time Allocation Committee
ТВ	Tera Bytes
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 Hawaiʻi
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
WSA	Wang-Sheeley-Arge (Solar Wind Model)
WSDL	Web Service Description Language
WWW	World Wide Web