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PROJECT DESCRIPTION

Section 1: Proposal Goal, Objectives, and Significance

The goal of this proposal is to reinvent and reinvigorate the Dunn Solar Telescope in order to promote the formation of a new operating consortium at Sunspot.

For more than half a century the Sunspot site, situated at 9200ft high above White Sands in New Mexico has been known for its excellent daytime sky quality, both in terms of transparency and seeing. The Dunn Solar Telescope (DST) in Sunspot remains one of the finest instrument of its kind, providing data to reveal the many intricacies of the surface features on the Sun imposed by the complex magnetic fields that permeate throughout the photosphere and chromosphere. Currently operated in a PI-proposal mode by the National Solar Observatory (NSO), the DST is equipped with a wide range of excellent instrumentation, including a high-order adaptive optics system, broad band imaging, rapid-scan spectroscopy, and spectropolarimetry.

As part of the restructuring connected to the building of the Daniel K. Inouye Solar Telescope (DKIST), the NSO will leave the Sunspot site by the end of 2017. The New Mexico State University (NMSU) proposes to form and lead a Sunspot Solar Observatory Consortium (SSOC) to operate the DST for a minimum 5 year span after this. The SSOC proposes to reinvent and reinvigorate the DST, in a scientific and financial partnership with NSF, NSO, and other institutions, for the benefit of solar physics research in USA. In particular, the solar community has a need for specific synoptic data that can only be delivered by the DST telescope and instrument suite, there is a 2-year data gap between the NSO departing DST in 2017 and DKIST first light in 2019, NSO wishes to retain the option to use the DST as an instrumentation test bed, and NSF is interested in providing student training and enhanced community participation in preparation for DKIST.

This proposal describes 4 fundamental Science Opportunities (Section 2) as the basis for a critical synoptic science plan to be performed by the SSOC. In order to deliver these science data, specific knowledge-transfer and telescope tasks (Section 3) must be completed during a transition period overlapping the final year of NSO at Sunspot (Oct.'16 - Sept.'17) and the first year of SSOC operations (Oct.'17 - Sept.'18). The three transition-period objectives are:

- **Objective 1: Complete a critical synoptic science plan for the DST**
- **Objective 2: Hire consortium personnel for telescope and site knowledge transfer**
- **Objective 3: Update and upgrade the telescope**

In preparing the community for the DKIST, this proposal plays a vital role in the mission of the NSF to *"promote the progress of science, advance national health, prosperity and welfare and to secure national defense"*. It fosters innovative developments in the progress of astrophysics by studying magnetic features, common to all stars, that determines the habitability of exoplanets. It uses an existing NSF facility (DST) to maximize future science exploitation of the new DKIST. It provides postgraduate and postdoctoral research opportunities aligned to future NSF aspirations. It assists NSF to remove the immediate closing costs of the Dunn Solar Telescope. Aligned to both the NRC Decadal Challenges and NASA's strategic plan, it enhances cross-disciplinary connections of national research goals, and promotes solar physics and space weather to the public.

Section 2: Intellectual Merit - Opportunities of the DST.

The instrument suite, high order adaptive optics, and mid-sized primary mirror at the DST, provides a unique opportunity for the community to initiate critical synoptic science. Simplified operations of the DST under a consortium provides for freedom in planing synoptic observations, while retaining PI-proposal observing for consortium members. Depending on consortium size, up to half the telescope time can be dedicated to simplified observing designed for critical synoptic science. All data will be distributed to the entire solar community. NSO has reduction software, including speckle reconstruction, available.

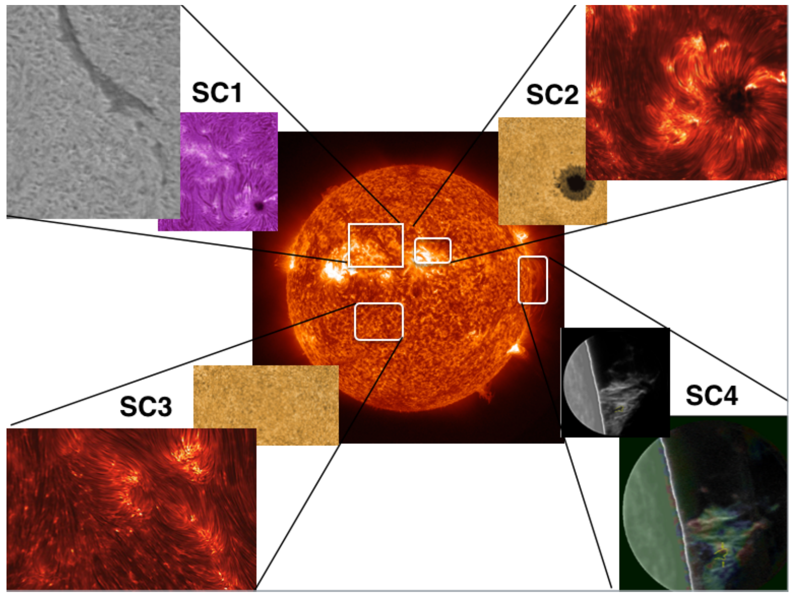

Figure 1: The topics of the Science Opportunities are: SO1 - active filaments, SO2 - flare kernels, SO3 - magnetic canopy, SO4 - quiescent prominences. DST-type field of views of imaging, spectroscopic, and spectropolarimetric data are overlaid on a full disc image provided by NASA SDO.

2.1 Science Opportunities

Synoptic Science Opportunities for the DST

- **SO1: What is the magnetic field configuration in solar filaments?**
- **SO2: What is the energy budget of solar flares?**
- **SO3: What is the role of the magnetic canopy in chromospheric heating?**
- **SO4: What is the nature of instabilities in quiescent prominences?**

These four opportunities form a synoptic observing program at the DST (objective 1). During a 2Yr transition from NSO to SSOC, we will provide the optimized observing set ups, knowledge-transfer, and telescope upgrades required to address these four Science Opportunities in the longer term. Research in filament magnetic fields, solar flare energy budget, quiet-Sun canopy, and prominence instabilities is of vital importance in understanding the structure and dynamics of the chromosphere. However, the instrumental and programmatic difficulties in providing appropriate synoptic data has severely limited research progress in these areas. After 2019, the DKIST will provide the spatial, temporal and spectral capabilities needed to study individual features and events by a large variety of regular PI-proposal requests. Our scientific goal is to establish the DST using more homogeneous telescope observations to compliment DKIST by providing lower resolution, but longer term, regular, synoptic, data of a large number of events.

2.1.1 What is the magnetic field configuration in solar filaments?

The formation, stability, and explosive instability of solar filaments remains a controversial research topic. Models of these structures usually invoke some large-scale photospheric motions (including shear flows, convergence towards a neutral line, and ongoing reconnection) to form dips in the field structure, where plasma can then flow and become gravitationally constrained (e.g., Devore and Antiochos 2000). However current small sets of observations of both quiescent (Aulanier and Schmeider, 2002) and activated filaments (Lites et al., 2010) do not find the systematic flows expected. Other models work on the assumption that twist in the field lines is already present in the subsurface, prior to emergence (e.g., Low 1994, Lites 2005). Observational evidence (Kuckein, Pillet, & Centeno, 2012a, 2012b) shows that such flux rope topology may be present, albeit in small datasets as observed long after the filament is formed. The identification of the process responsible for the formation of filaments plays a key role in determining how they are structured. It is vital to determine if a twisted magnetic field is present prior to the formation and how such twist evolves over these early stages.

Observations, Tasks, and Outcomes for SO1

The best observational solution for SO1 is a dedicated mapping of filament structures on the solar disk using a high-sensitivity, infrared spectropolarimeter (the Facility Infrared Spectropolarimeter, FIRS) at the DST. Achieving the sensitivity required for a complete magnetic field inversion in the chromosphere remains a technical challenge. However, novel post-facto calibration methods have been used to complete successful measurements of atomic-level polarization signatures within the He I triplet at 10830Å at the DST by SSOC instrument partners at University of Hawaii. We propose dedicated observations of filament vector magnetic fields via polarized spectroscopy of this He I triplet using FIRS. As a permanent facility instrument of the DST, FIRS can routinely map full Stokes vectors for both visible and infrared spectral lines. It boasts an efficiency advantage over comparable instruments, by using multiple parallel slits and advanced multi-cavity filters to place multiple slit spectra on the same detector simultaneously. High-spatial resolution is achieved by the high-order adaptive optics system. The FIRS spectrograph can sample the He I line at a spectral resolution of 1.6 pm/pixel, adequate to cover the Doppler shifted spectrum, while extending far enough into the blue to include continuum spectrum from the broad damping wing of the Si I 10827Å line. A demonstration of high sensitivity polarimetry in He I beyond single-slit mode is a key undertaking for NSO.

The outcomes for SO are to define a specific observing sequence for the future synoptic program through test observations, including an analysis of these data, as feasible. All data will be made openly available to the entire solar physics community. Initially we will select recently-formed filaments, as they are most abundant from an observational perspective (where they often form in the place of recent eruptions or decaying active regions) and can have the simplest structure. We expand on this to then observe all filaments on a synoptic basis.

2.1.2 What is the energy budget in solar flares?

Solar flares result in a restructuring of the coronal magnetic field, and a bombardment of accelerated coronal particles into the chromosphere. The energy content of these particles can be studied by observing the response of the chromospheric plasma, including Doppler shifts both towards and away from an observer. The vast majority of the radiative flare energy is released in Hydrogen lines and continua. The visible part of the electromagnetic spectrum that can be studied at the DST is well suited for this research as it covers some of the most important radiative cooling agents (e.g., Balmer continuum, Paschen continuum) as well as the Balmer/ Paschen lines and the Ca II h and k. However, complete coverage of all these lines requires a long duration observing sequence, and it has long been recognized that conditions in a solar flare result in very fast spectral fluctuations (e.g., Wulser 1987). Typically these fast fluctuations have been detected in hard X-ray data, (e.g., Kilplinger et al, 1983), in microwave data, and decimetric data (e.g., Kliem et al. 2000). The common source of these fast fluctuations is probably the beam of high-energy electrons accelerated in the corona, with Bremsstrahlung radiation creating the hard X-rays and gyro-synchrotron radiation responsible for the microwave emission. However recently Wang et al. (2000) discovered sub second fluctuations in Hα and Trottet et al. (2000) suggest Hα blue wing emission consists of a slowly varying component (analogous to soft X-ray emission) and a rapidly varying component.

Observations, Tasks, and Outcomes for SO2

Clearly there is some optimum simplified observing sequence that can retain sufficient spectral information without sacrificing too much cadence. Kirk et al. (2013), using data from Sunspot as part of a PhD thesis at NMSU, showed one potential solution - that red/blue wing Hα data can be combined to extract the Doppler shift and energy content in elementary flare bursts. The DST can deliver such data at ~5s cadence, and cover a field of view large enough to encompass an entire active region. These data can also be used to study sunquakes (usually observed with low-spatial resolution instruments, and usually only with the largest flares). The large field-of-view and higher spatial resolution of the DST will improve upon these measurement by probing the temporal and spatial fine structure of the active regions.

We propose a flare-patrol sequence to observe all large solar flares. This will be possible by carrying out observations if, and only if, the Max Millennium Chief Observers (MMCOs) call a MM003 Major Flare Watch. A daily email is sent out by the MMCO stating which region is likely to produce a flare, and if the likelihood is high for a major flare. Usually a major flare watch lasts for 4-5 days so we have the option of waiting until a major flare watch (Op 003) is called before acting. This is part of a long term synoptic plan to coordinate ground- and space-based observatories for Major Flare watches, and the community is keen to see how this sort of coordination works in practice, in preparation for the DKIST. In particular we would like to know if a daily email is sufficient or if we need to provide more updates, and what sort of fidelity to expect from coordinated observations. We will deliberately pick a simple observing plan to minimize set up time at the DST. The overall observing strategy is a simple, high-cadence, sit and stare campaign. As such, we propose imaging spectroscopy with IBIS in sparse sampling, spectroscopic mode, in a single spectral line. We select Hα core, blue wing (-1.0A) and red wing (+1.0A) at a repetition of 50 images per position to facilitate speckle reconstruction. The blue wing will show the precipitating electron beam as enhanced intensity kernels during a flare. The red wing will be used together with the core to provide contextual data on Doppler shifts. We combine this with ROSA images in the blue continuum, at highest cadence, which will only show intensity changes for the most energetic electron beams (i.e., largest flares and brightest kernels). If more spectral information is required, we will have to sacrifice temporal resolution or speckle reconstruction. The fidelity of a solar flare patrol is only possible by creating an observing sequence that can be ran at minimum (poor-seeing) conditions in the DST afternoons. Note, even in poor-seeing conditions the changes in intensity caused by an electron beam are much larger than those in the nearby vicinity on the Sun. The science goal here is that any result will be confirmed beyond statistical anomaly by repeated observations over many flares.

The outcomes for SO2 are to define a specific observing sequence for the future synoptic program through test observations, including an analysis of these data, as feasible, with all data openly available to the entire solar physics community. Initially we will design, run and optimize an observing sequence for regions which have shown a propensity to produce large solar flares. We then expand on this to observe all regions called during a major flare watch by the Max Millennium program. At this stage in the cycle, we expect only 3-4 such regions each year, sufficient to provide for a reasonable statistical analysis of a large number of flare kernels.

2.1.3 What is the role of the magnetic canopy in chromospheric heating?

The variation in the position and geometry of the magnetic canopy in the solar chromosphere influences the upward propagation of magneto-acoustic waves, and thus promotes an opportunity to perform a synoptic mapping of the magnetic canopy. The ubiquitous magnetic field of the chromosphere acts as a wave guide in this low-β plasma. The propagation of any oscillatory signal is greatly influenced by this magnetic field (De Pontieu et al 2004; Shelyag et al ,2009). Finsterle et al (2004) performed such a mapping for near active regions; we propose to endeavor the similar mapping of the quiet-Sun over repeated observations. Khomenko et al (2008) found that deep horizontal motions of flux tubes can generate oscillations; a finding observationally confirmed for a single case by Andic et al. (2010). Steiner et al. (2007) demonstrated the feasibility of using high frequency oscillations for probing magnetic fields in the photosphere and chromosphere, a finding observationally confirmed for a single case by Jess et al. (2013). More recently, Stangalini et al. (2014, 2015) found evidence for non-linear wave excitation as a result of flux tube buffeting, and since non-linear waves can be leaky, observations of their ability to ‘shed’ wave energy is a vital component to a study of chromospheric heating.

Observations, Tasks, and Outcomes for SO3

It is clear that there are many individual studies of (magneto)acoustic waves in isolated, diverse, and short-duration datasets. PI-proposals to perform more observations will undoubtedly be a large and important part of DKIST. Such single-use observing runs are normally acceptable in this work, since the lifetimes of the structures that support the waves (e.g., magnetic bright points, spicules) are typically short (a few hours). However, a complimentary, statistical analysis of the wave power energy densities as a function of (a) atmospheric height, (b) magnetic field strength, inclination and latitude, (c) wave mode (sausage, kink, Alfvén, etc.), and (d) various supporting structure (pores, sunspot complexity, etc.) can be best performed at the DST.

In particular, the new HARDcam at DST, when combined with high order AO, can obtain diffraction-limited observations with a field-of-view sufficient to capture an entire supergranular cell and at a spatial resolution of ~250km. These data will be combined with FIRS, using He I 10830Å observations to provide full spectropolarimetric values (to directly address point (b) above) in the chromosphere. A direct measurement of the field strength will also help reduce the errors in calculating phase speeds, and therefore the calculation of wave energy flux. Out SSOC instrument partners at QUB have already experiment with FIRS in an observation set-up alongside ROSA and IBIS. Models and observations indicate velocities of 7km/s, (Jess et al., 2012) thus a wave train would cover a range of heights from the photosphere to chromosphere in about 200s. The proposed experimental set up would include the IBIS instrument scanning through sufficient lines to cover this height range (Fe, Na, and Ca lines) but with each line scanned in only 7 positions so as to provide an overall cadence of about 10s.

The outcomes for SO3 are to define a specific observing sequences for the future synoptic program through test observations, including an analysis of these data, as feasible. All data will be made openly available to the entire solar physics community. By initially observing disc center for a few hours every month, we will build up statistics to study these small scale magnetic features at the footpoints of the canopy.

2.1.4 What is the nature of instabilities in quiescent prominences?

The formation of bubbles and plumes in quiescent prominences has recently attracted a lot of controversy. Bubbles seem to form beneath quiescent prominences and are dark in visible light images. Plumes form at the top boundary between a prominence and a bubble. Taken together, these two features provide evidence for turbulent flows within a prominence (Berger 2014). Initial rare ground-based observations (e.g., Stellmacher & Wiehr, 1973), merely resulted in a deduction that some sort of instability was responsible. The phenomenon of rising plumes was re-evaluated more quantitively after the launch of the Hinode Satellite. About that time, deToma et al. (2008) noted these plumes in Hα images. Ryutova et al. (2010) were the first to suggest that these plumes were consistent with a Rayleigh-Taylor (RT) buoyancy instability. In general, an RT instability occurs when a dense fluid is suspended above a less-dense one, in this case, against the force of gravity (Chandrasekhar 1981).

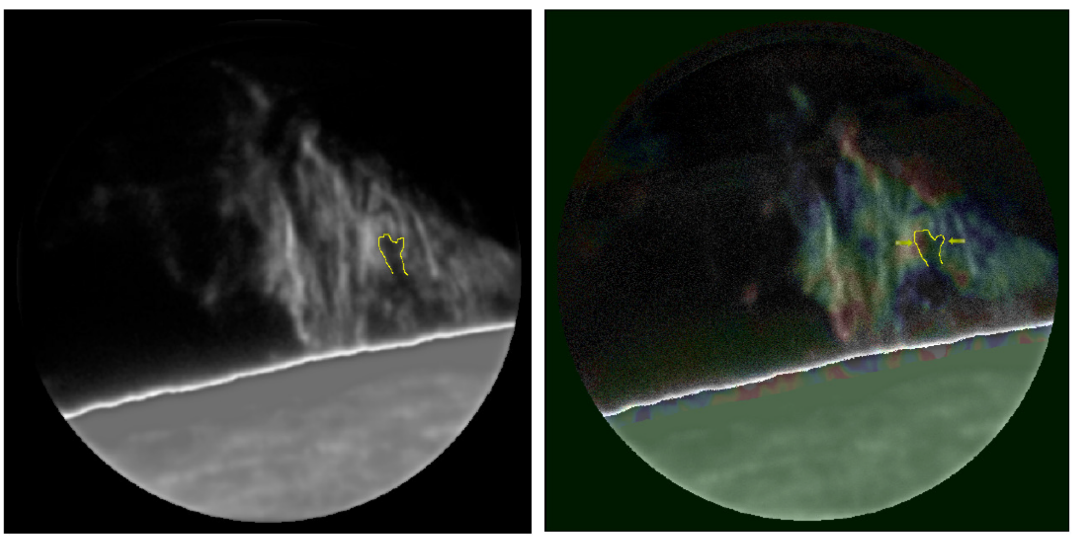

Figure 2: Left - white light image showing the data quality using an off-limb AO. Right- doppler shifts towards (blue) and away (red) are used to probe bubbles and plumes. from NMSU thesis by Greg Taylor.

When a plume rises through a prominence, it pushes the prominence plasma out of its way, both to the sides as well as toward and away from the observer. Between 2012 and 2016, an off-limb AO system was designed by a Phd student, supervised at both NSO and NMSU, to study this specific feature. Data from this research (figure 2 above) shows a dark plume (designated by the arrows), with plasma on the left of the plume pushed away from the observer (red shifted) while plasma on the right is pushed toward the observer (blue shifted). A sequence of these images shows that the plasma seems to be oscillating toward and away from the viewer such that a wave probably propagates from the right to the left, during the time series. The period, wavelength, and phase shift can be used to determine the magnetic nature of off-limb solar prominences.

Observations, Tasks, and Outcomes for SO4

The observational plan is to perform a large-scale study of rising plumes in quiescent prominences and determine if their motions are consistent with those arising from RT instabilities. The study of transient phenomena in solar prominences requires measurement of doppler shift and plane-of-sky velocities of these features. This will be performed using IBIS tuned across the 8542Å spectral line, and using the off-limb AO system developed by Taylor et al. (2012). A 2-hour time series allows for the observation of any plume motion at each of 17 wavelength positions. Once the full spectrum has been extracted at each pixel, the line-of-sight and doppler velocities of the plasma can be determined relative to the observer. The resulting velocity maps show the bulk motion of the plasma either away from, or toward observer, and plane of sky velocities are determine by cross correlation measures of small scale features.

The outcomes for SO4 are to define a specific observing sequence for the future synoptic program through test observations, including an analysis of these data, as feasible. All data will be made openly available to the entire solar physics community. In Yr1, a small sample of limb prominences will be studied for 2-hours each. In yr2 we expand on this to observe all prominences on a synoptic basis.

2.2 Instrumentation Opportunities

The DKIST will provide unparalleled imaging, spectroscopy, and polarimetry to probe the solar atmosphere. In the more immediate future, the DST provides an opportunity for the solar community to experiment with instruments and optical setups that will be similar to the planned 1st generation DKIST instrument suite. Every instrument at the DKIST has a parallel instrument at the DST. Three of the DKIST instrument partners designed and built current instruments at the DST and have expressed interest to join the SSOC as instrument partners - University of Hawaii, High Altitude Observatory, and Queen's University Belfast (leading the UK involvement). The provision of an upgraded AO, and addition of an identical system on a second port, strengthens future instrument opportunities at the DST. It is expected that the initial instrument suite for the DKIST will be expanded after 3 years of service. The DST provides an unique platform for the design and testing of these 2nd generation DKIST instruments, personnel training in operating them, and student involvement in this design.

2.3 Education and Public Outreach Opportunities

The NSO and CU Boulder have led the design of a successful online PhD student education program - the Hale Collaborative Graduate Education Program - consisting of five universities (CU, NJIT, U. Hawaii, NMSU, MSU) and two national labs (NSO, HAO). We have proposed Sunspot as a location for these students to meet up, discuss, design, and implement observing programs on the DST. Sunspot has sufficient housing and facilities to host an inexpensive workshop, and the hands-on DST observing platform provides added value to this remote, online program. We also envision the DST as a platform for REU students for partners and NSO.

The visitors center in Sunspot attracts over 10,000 visitors each year, mostly local families from Texas and NM, and tourists. The SSOC will expand on this by employing a full time Education and Public Outreach specialist to seek close connections with, and provide guided tours to, local school groups, museum parties, and interested groups from the local area. We have already started discussions with the Alamogordo Space Museum and the Southern Rockies Education Center to build these links.

Section 3: Operations Proposal

Given the science, instrumentation, and educational opportunities afforded by continued operation of the DST, we propose to form the Sunspot Solar Observatory Consortium (SSOC), between several academic institutions and the NSF, to operate the DST over a period of five or more years. However, while the idea of such a consortium has generated considerable vocal support from the community, and several expressions of interest from a few potential partners, no firm financial commitments have been made to date. To even keep the possibility open, however, requires immediate investment so that personnel can be hired to allow knowledge transfer from the existing NSO staff before they leave near the end of 2017. Funding for such personnel is the primary function of this proposal. In order to attract sufficiently skilled personnel, we must provide a guarantee of a minimum of two years of funding, hence this proposal covers a two-year transition period, with the first proposal year overlapping with the final year of NSO operations.

At the end of this proposal, operations should be streamlined and optimized so as to minimize annual costs and with reduced risk of catastrophic failure. As a result, we propose that the highest priority for the second year of this proposal, after knowledge transfer and documentation of existing systems has been completed, is to modify systems to allow for lower operating costs. We propose to do this by a strategic consideration of modifications to hardware and software systems to allow operation of the DST by a single observer, and to consolidate the computing infrastructure so that it can be supported and maintained by a single IT person.

Exploratory observations for the science opportunities will be made in Yr1. If at all possible, we will continue these into the second year, but such science operations will be contingent on availability of the telescope for observations given the upgrade plans. In addition, extra observing in Yr2 will be contingent on the availability of some additional funds (beyond those proposed here) from the SSOC. A key goal of the first year will be to establish an official entity (the SSOC) and to obtain additional funding from its members.

3.1 Simplification of DST Operations

The current telescope and site operations is operated on 14.25 FTE, at a budget of ~$1.5M. This is greatly reduced from the historical value of ~$3.5M. The current NSO operations includes a 5-day week of observations, with 2 observers and 1 science support staff. The long term vision of the SSOC is to move to a streamlined and simplified operations model encompassing only 9 FTE of personnel, at a budget of ~$1.1M, but moving to a 7-day week by only requiring one observer at most times by upgrading the telescope control system and AO, and building a larger synoptic program element. By operating on these reduced personnel requirements, and efficient cost of operations, we increase the likelihood of obtaining a successful consortium to operate the site.

Table 1 outlines the current and proposed personnel breakdown. The bare minimum to keep the possibility of continued operation alive is described in the 'Transition Yr' columns; these FTE are the positions we request funding for in this proposal. The minimum plan involves the hire and training of one observer, a telescope engineer, an IT specialist, an adaptive optics (AO) engineer, and a site engineer. In discussions with NSO, it is clear that the both site and AO engineers could be trained in 6 months, so we propose only 50% funding for these personnel.

Personnel	NSO FTE (current)	Transition FTE Yr1 (Fy17)	Transition FTE Yr2 (Fy18)	SSOC FTE (Fy18)	Total FTE (Fy18)	Total FTE (Fy19+)
Science / Admin	3.75	-	-	1	*1*	*1*
Observers	2	*1*	*1*	1	*2*	*2*
Telescope Engineer	2	*1.5*	*1.5*	0.5	*2*	*2*
IT	1	*1*	*1*	-	*1*	*1*
Facilities (Site Engineer)	4.50	*0.50*	*0.5*	1.5	*2*	*2*
Visitors Center	1	-	-	1	*1*	*1*
Total	**14.25**	**4**	**4**	**5**	**9**	**9**

Table 1: Summary of FTEs for current and proposed operations model of the DST and Sunspot site (both during the 2 years of this transition and in the following years). The current NSO operating model is 14.25FTE. The proposed SSOC-model is 9FTE. In order to reach this reduced operations model, the transition period tasks include 4FTE for 2 years. In Yr1 of the transition, 4FTE will work with NSO staff at Sunspot. In Yr2 the SSOC will assume operations and these 4 FTE will continue at Sunspot. If the SSOC is to retain full operations, it will have to acquire sufficient financial arrangements additional FTEs beyond this proposal. After the 2 year transition, SSOC operations will consist of a total of 9 FTE.

The SSOC, through funds supplied by NMSU, in conjunction with the Astrophysical Research Corporation that uses Sunspot infrastructure for its Apache Point Observatory, will fund the other half of these two personnel in Yr2. Table 1 also includes additional SSOC personnel to be hired in Yr2 if consortium funding is available. All 9FTE (4 from this proposal, 5 from the SSOC) will be required to actually fully operate the site and telescope during the Yr2. In addition to the extra 1/2 year for the AO and site engineer, the SSOC should first aim to employ a second observer, a second site engineer, and, pending funding a scientist administrator on-site and an education and public outreach officer to run the visitor’s center.

3.2 Specific DST Tasks

The transition to SSOC operations to a low level of 9 FTE requires the completion of the three proposal objectives during the transition period encompassing the final year of NSO operations and first year of SSOC operations. First, the observational sequences for the synoptic science plan should be optimized (Section 2.1 above). Second, personnel should be hired and trained alongside existing NSO personnel in observing. Third, in order to significantly reduce costs and risks, the telescope should be updated and upgraded. There are five specific tasks to be accomplished in order to complete objectives 2 and 3.

Task 1: Train one telescope observer, and document telescope observations.

There are currently three fully-trained NSO observers at Sunspot and most observations carried out 5 days per week at the DST are PI-driven, with two observers on site. For this proposal we will hire a new observer. During the first year, this person will learn and document all of the observation procedures. During year two, this person will work with the telescope and AO engineers to determine how the telescope can be run by a single observer at any time. This person will be the main observer for carrying out the synoptic observing sequences.

Task 2: Train one telescope IT engineer, and document and upgrade telescope IT.
Maintenance of the IT at the telescope is currently covered by 1 NSO IT specialist in Sunspot. The DST contains over 50 computers, of different ages, hardware, operating systems, and software versions. This diversity poses a significant IT maintenance and failure risk, which we will mitigate by consolidating and updating these systems. For this proposal we will hire a new IT specialist. During the first year, this person will learn and document the existing computing systems. During the second year, this person will work to consolidate these systems. The IT engineer will also work with the telescope engineer on a modified telescope control system. This task will also incur some hardware and software costs.

Task 3: Train one telescope control engineer, and simplify and document the telescope control system.
The current telescope control system (TCS) necessitates a requirement for 2 observers at the DST at most times - one on the light table with the adaptive optics system, and one on the bridge. The design and implementation of a simplified TCS (and AO, see task 4) is the key to allow for the telescope to be operated by one single observer at most times. It also ensures the longevity of the TCS. For this proposal we will hire a new telescope control engineer. During the first year this person will learn and document the existing TCS, while designing a new simplified TCS under the supervision of NSO personnel in Sunspot. The new TCS will be initiated in Yr1, and then fully implemented in Yr2. This task will also incur some hardware and software costs.

Task 4 Simplification, and duplication, of the DST Adaptive Optics system.
The current Adaptive Optics (AO) system at the DST is a unique design, based on spare parts that were previously on a back-up port. Many of these parts are no longer available, and as such the AO is a high-risk point of catastrophic failure. If the current AO fails, the DST loses its unique capabilities required for a world-class observing site. In order to mitigate this high risk, the current AO should be replaced with modern, simple, readily-available components. In addition, an identical back up system should be built and placed on the back-up port. This will provide a new second light path, which will help attract new SSOC membership from instrumentation partners and for student training. For this proposal we will hire a new AO specialist to design and build a new telescope AO. Based on conversations with NSO scientists, this design and implementation can be completed in one year (6 months in Yr1, 6 months in Yr2). This person will then transition to an instrument engineer position in the consortium.

Task 5: Train one site engineer, and document site maintenance.
The Sunspot site currently provides for housing, a visitor's center, a small dining facility, community buildings, water, sewage, and electricity. These tasks are covered by 4.5 facilities personnel in Sunspot. For this proposal we will hire a new site engineer to assume full control of a much reduced, scaled-back, site. Based on conversations with current site engineers at NSO, the site operations can be documented and new site engineer trained in 6 months in Yr1, ready to oversee the site in Yr2. During this time, this new site engineer will also be responsible for completing a written site operations document. This person will then transition to a site engineer position in the consortium.

3.3 Consortium Tasks

The most critical community task is to establish a formal, legal, Sunspot Solar Observatory Consortium. This must consist of sufficient and appropriate membership to use the new upgraded facility at the end of the 2 years covered by this proposal. The SSOC must establish, and provide the budget, for an operations model to include both PI-science proposal and the synoptic program discussed in Section 2. We expect to draw heavily on the success and experience of the Astrophysical Research Corporation to establish this entity. The goal is to have an independent consortium entity that establishes a budget and management system, collects funding from member institutions and NSF, and distributes it as needed. We expect that the bulk of the SSOC personnel will be hired through a contract with NMSU. The formation of the SSOC, and the viability of this proposal, rests on the assumption that NSF will retain the overall responsibility for the operations permit for the site and all liability for any future decommissioning of the site, while maintaining a funding level at around 50% in the years following the transition.

3.4 The Sunspot Solar Observing Consortium

3.4.1 Long term vision of the SSOC:

The long term vision of the SSOC is to reinvent and reinvigorate the DST and Sunspot by focusing on science, education, instrumentation and public outreach. In science, up to 50% of the observing time will be dedicated to synoptic observations of the Sun, complementing and enhancing current NSO synoptic data. The DST is large enough to allow for detailed synoptic studies of solar filament magnetic fields and flows, active region magnetic fields, quiet Sun features, and off limb prominences. It also has the potential to study coronal holes and polar fields, potentially attracting new consortium partners. These type of measurements are not possible with smaller telescopes, and will be too time-consuming for the DKIST. The location of the DST is also ideal for joint contextual observations in support of the DKIST, ALMA, and rocket flights from White Sands. PI-driven science time will be allocated to partners in commensuration with their financial input. We estimate that partner investment of $50,000 per year will provide for a 2-week observing block.

In education, we propose to retain sufficient redwood houses (including appliances and furnishings), apartment block, community center, and dining facilities in order to host partner observations, and to host students as part of the Hale graduate education program. In instrumentation, we propose to retain electrical and machine shops (with the understanding that NSO can take any equipment to their new HQ), the aluminizing chamber, and optics. The addition of a simple AO on the back-up port opens up a brand new light feed for instrumentation design. In public outreach, we propose to retain and improve upon the current visitor's center in Sunspot. The SSOC will employ a full-time education and public outreach person in their operations budget. We envisage that existing displays and stock would be transferred to the SSOC when NSO departs Sunspot. With a fully functional telescope observing the Sun daily, and education specialist creating a close connection with local schools, museum, and interest groups, it is likely that the current number of visitors to the site will increase.

3.4.2 Status and prospects of the SSOC:

The vision of the SSOC is to operate the DST in Fy19+ with 9FTE at an annual estimate of ~ $1.1M, with continued NSF participation at the ~50% level. Efforts at community outreach to deliver on the 50% funding for SSOC operations are ongoing. Current interested parties in USA are NMSU, Cal State University Northridge (CSUN), University of Colorado Boulder (CUB), University of Hawaii, High Altitude Observatory, and the Astrophysics Research Corporation (ARC; which includes partners with an interest in solar physics in Georgia State University and University of Washington). The University of Hawaii and High Altitude Observatory are interested in both leaving and developing their DST instruments. We have international instrumentation interest from UK and Italy, and potential financial interest from the Chinese Academy of Sciences. Two items of special note here are (i) that we recognize potential ITAR conflicts with a partnership with the Chinese Academy of Sciences therefore we accept that NSF may have to veto this membership and (ii) ARC have expressed interest to join the SSOC in return for continued access to site facilities.

The 2-year transition plan provides time and motivation for SSOC partners to obtain their funding to ensure the longevity of the project. If funding for the additional 5 FTE (see Table 1) cannot be found by Yr2 of this proposal then we cannot fully operate the telescope. If funding for 50% of the budget in Fy19+ cannot be obtained, then we cannot operate the telescope past the 2 years of this proposal. We note, however, that there are further opportunities for operations at reduced cost by implementing partial year observing (closing over the summer months), or sharing personnel with ARC. An NMSU request for state-funding beginning July 2016 was stymied by a severely deflated state budget. NMSU will push to submit a similar proposal to the state for funding beginning July 2017. However, current estimates of the state budget are such that it appears funding may not be available until July 2018. As such, this proposal consists of the 2 Yr transition costs to overlap through until this date.

Section 4: Broader Impacts of the Proposed Work

This proposal will play a key role in securing the future of solar physics research nationwide. With NSF as a key partner, and including other international, national, and state funding, NMSU has led the effort to reinvent and reinvigorate the operations of the DST and its facilities into the future. This proposal plays a key role in this effort by providing opportunities for training in solar physics instrumentation for PhD students and engineers. The SSOC contains 6 solar physics graduate programs, and we continue in our efforts to attract new university partners. Three partners are in states that serve underrepresented minorities.

NMSU will approach the Space Weather Prediction Center and the Air Force Research Lab to use synoptic measurements (e.g., including filament magnetic field measurements into CME propagation models to study the impact on the accuracy of CME strength and arrival predictions). These two space weather research institutes are potential future financial backers of the DST, (e.g., if, as strongly suspected, it can be shown that these magnetic field measurements play a key role in CME propagation). In order to strengthen this relationship, Dr Arge from AFRL, and Dr Biesecker from SWPC, will be asked to serve on the SSOC executive board.

This proposal assists NSF in divesting this facility (hence removing the immediate closing costs), provides student training and public outreach, and assists the community to maximize the science from the upcoming DKIST. As part of this consortium, the proposal will assist to operate a telescope, support research program and graduate training programs, a STEM-skills training program, and an education and outreach center in Sunspot, New Mexico. This provides a national research base for graduate studies in training for the DKIST and a vital opportunity for undergraduate research incorporating local hispanic URM students. This provides key STEM training in optical and electronic engineering. It will consolidate an on-site visitor center that attracts over 10,000 visitors each year.

Section 5: General plan of work

5.1 Timeline, risks, and outcomes

Proposal Objective	Task		Yr1		Yr2	
			10/16 -3/17	4/17 -9/17	10/17 -3/18	4/18 - 9/18
Objective 1: **Complete a critical synoptic science plan for the DST**	1	Hire and train observer	■	■		
	1	Plan synoptic obs.		■	■	■
Objective 2: **Hire consortium personnel for telescope and site knowledge transfer**	2	Hire and train IT specialist	■	■		
	3	Hire and train TCS specialist	■	■		
	4	Hire AO specialist		■		
	5	Hire and train site engineer		■		
Objective 3: **Update and upgrade the telescope**	1,4	Design AO system		■		
	1,4	Implement AO system		■	■	■
	2	Design IT upgrades		■		
	2	Implement IT upgrades		■	■	■
	3	Design TCS upgrades		■		
	3	Implement TCS upgrades			■	■

Table 2:Gantt chart detailing objectives, tasks, and a timeline for completion. Three hires are performed at the start of the project. Two hires are performed after 6 months. All training and designing is performed in Yr1, while NSO is operating the telescope and present on-site. Upgrades are mostly performed in Yr2.

The timeline for this proposal, assuming a start date of Oct 1st 2016, is provided as a Gantt chart in Table 2. **In year 1** of this proposal we hire key personnel, initiate observing sequences, and start on the design of required telescope upgrades. The risk in obtaining observing time at the telescope is mitigated by the close collaboration with NSO, the availability of engineering / maintenance time, NSO knowledge of the telescope and instruments, an early all-hands physical team meeting in Sunspot and provision of some university funds for NSMU personnel. The key outcomes for Yr1 are to initiate the synoptic plan to deliver the data to address the 4 science opportunities (objective 1) and complete the hire for knowledge transfer (objective 2). **In Year 2** of this proposal the consolidated SSOC starts operations, implements upgrades, and optimizes observation sequences. The largest risks with this phase is the timing with NSO moving out of

Sunspot and consortium personnel taking on all operational management. To mtitgate, we note that NMSU, CSUN, CUB, and ARC have already made substantial progress in obtaining funds. NMSU will lead the consortium effort to obtain more partners. The key outcomes for Yr2 are to finalize the synoptic plan to deliver the data to address the 4 science opportunities (objective 1) and complete the telescope upgrades and updates (objective 3).

5.2 Roles and responsibilities

As PI of this proposal, Dr. McAteer assumes responsibility for all scientific and financial management. He will act as the single point-of-contact with NSF regarding scientific reporting. He will also assume the responsibilities of ensuring the key outcomes are delivered in a timely fashion. Dr. McAteer will host meetings in New Mexico, and lead the efforts to build the SSOC.

As Co-PI of this proposal, Dr. Holtzman will play a key role in communications with both the NMSU administration and the Astrophysics Research Corporation. He will assist on formation of the SSOC. He will assist on hiring the new personnel.

As Co-PI of this proposal, Dr. Jackiewicz will guide science outcomes of the synoptic program, ensuring community involvement and data availability. He will act as the connection between the SSOC and the Hale Collage online PhD program, and assist on hiring new personnel.

As Collaborator on this proposal, NSO will assist with training for the new hires and the design of the new upgrades for the telescope. NSO will provide key scientific and instrumentation insight into the SSOC.

As Collaborators on this proposal, all partners in the SSOC will continue to finalize their scientific and financial commitment to the project. They will ensure the synoptic program meets the needs of the community.

5.3 Outcomes Assessment

Dr McAteer will form an executive board that includes one person from each partner, Dr Nick Arge from AFRL, Dr Biesecker from SWPC, and one designated person from NSO. This board will meet twice a year to evaluate the progress of the project against the projected outcomes. An assessment committee document will then be provided to NSF as part of the annual report.

Section 6: Results from prior NSF Support

Title: Career: an Integrated Solar Physics Program in Research and Education (INSPIRE); **Principle Investigator:** McAteer R.T.J.; **Award Number:** NSF GEO#125024; **Amount:** $756,746; **Project Period:** Sept. 1, 2013 – Aug 30, 2018

Project Summary: The INSPIRE project to create a long-lasting integrated research and education program in solar physics at New Mexico State University has three objectives: to provide opportunities, methods, and tools for scientific research; to increase the number of URM students in interdisciplinary research; to identify key components of complexity and dynamics relevant to energy release processes. In 2 years the project has 8 direct publications. **Intellectual Merit:** The project aims to answer two specific research questions. How is the corona structured? How and why does the corona vary? These fundamental areas of research apply interdisciplinary tools to solar physics. **Broader Impact:** Team-based active-learning projects, based on recognizing key elements in scientific discoveries, are incorporated and assessed for effectiveness. These elements of modular and interdisciplinary research are used to attract and retain the students in research, with an emphasis on hispanic students.

Title: CAREER: New Constraints on the Solar Dynamo Using Helioseismology; **Principle Investigator:** Jackiewicz, J.; **Award Number:** NSF GEO#1351311; **Amount:** $593,521; **Project Period:** Mar. 1, 2014 – Feb. 28, 2019

Project Summary: The research objective of this proposal is to provide tight constraints on interior dynamo models so that a better understanding of the Sun and solar-cycle dynamics becomes possible. Project goals are: (1) measuring the meridional and zonal flows at the surface and in the solar convection zone; (2) quantifying the time variations of these flows; and (3) understanding and correcting systematics in helioseismic data. **Intellectual Merit:** This project will make substantial progress in studying the origin of the Sun's magnetic field. This will provide the most accurate measurements of large-scale flows in the convection zone. **Broader Impact:** Two PhD students will be trained in helioseismology, and ten underrepresented minorities from interdisciplinary fields will be mentored and supported in research projects. This will impact 15,000 6th-grade students through educators in professional training.

Title: Collaborative Research: Chemical Cartography in the Milky Way with Apogee; **Principle Investigator:** Holtzmann J.; **Award Number:** NSF AST#1109178; **Amount:** $156,120; **Project Period:** Aug. 1, 2011 – July 31, 2016

Project Summary: This project has supported analysis of SDSS/APOGEE data. Briefly, APOGEE is providing abundances with good precision across the Milky Way disk. **Intellectual Merit:** There is clear evidence for variations in the distribution of abundances, the pattern of abundance ratios with position in the disk, and the metallicity distribution function, and these will be invaluable in constraining models of Milky Way disk formation. Three published papers (Holtzman et al, 2015, AJ 150, 148; Hayden et al, 2015, ApJ 808,132; Hayden et al. 2014, AJ 147, 116) led by NMSU have been directly enabled by this NSF support; a fourth (Feuillet et al. 2015) is in the review process. **Broader Impact:** The NSF support has also led to the educational development of several graduate students at NMSU. There has also been considerable software development, in particular, on the implementation of a full analysis pipeline for stellar parameters and abundances. The NSF support has helped to enable the public dissemination of the entire APOGEE data set. The broad availability of these data to the entire community will lead to a broad suite of scientific investigations.

Section 7: Summary

This proposal details the transition tasks necessary for the SSOC to provide for the eventual operations of a world-class science, instrumentation, education, and public outreach facility at the DST, Sunspot. This transition plan facilitates the formation of a synoptic plan to provide for the data required to address 4 key science opportunities in research areas of filaments, solar flares, quiet Sun canopy, and prominence instabilities. In operating the DST, this proposal provides an increased user-base for the new DKIST in USA. It postpones the immediate necessity of decommissioning the DST site and allows for any such decommissioning to then be carried out piece-meal and selectively over the next few years. By fulfilling our three objectives to complete a critical synoptic science plan for the DST, hire consortium personnel for telescope and site knowledge transfer, and update and upgrade the telescope over a 2-year transition from the NSO to the SSOC, we will **reinvent and reinvigorate the Dunn Solar Telescope in order to promote the formation of a consortium to operate the Sunspot site.**