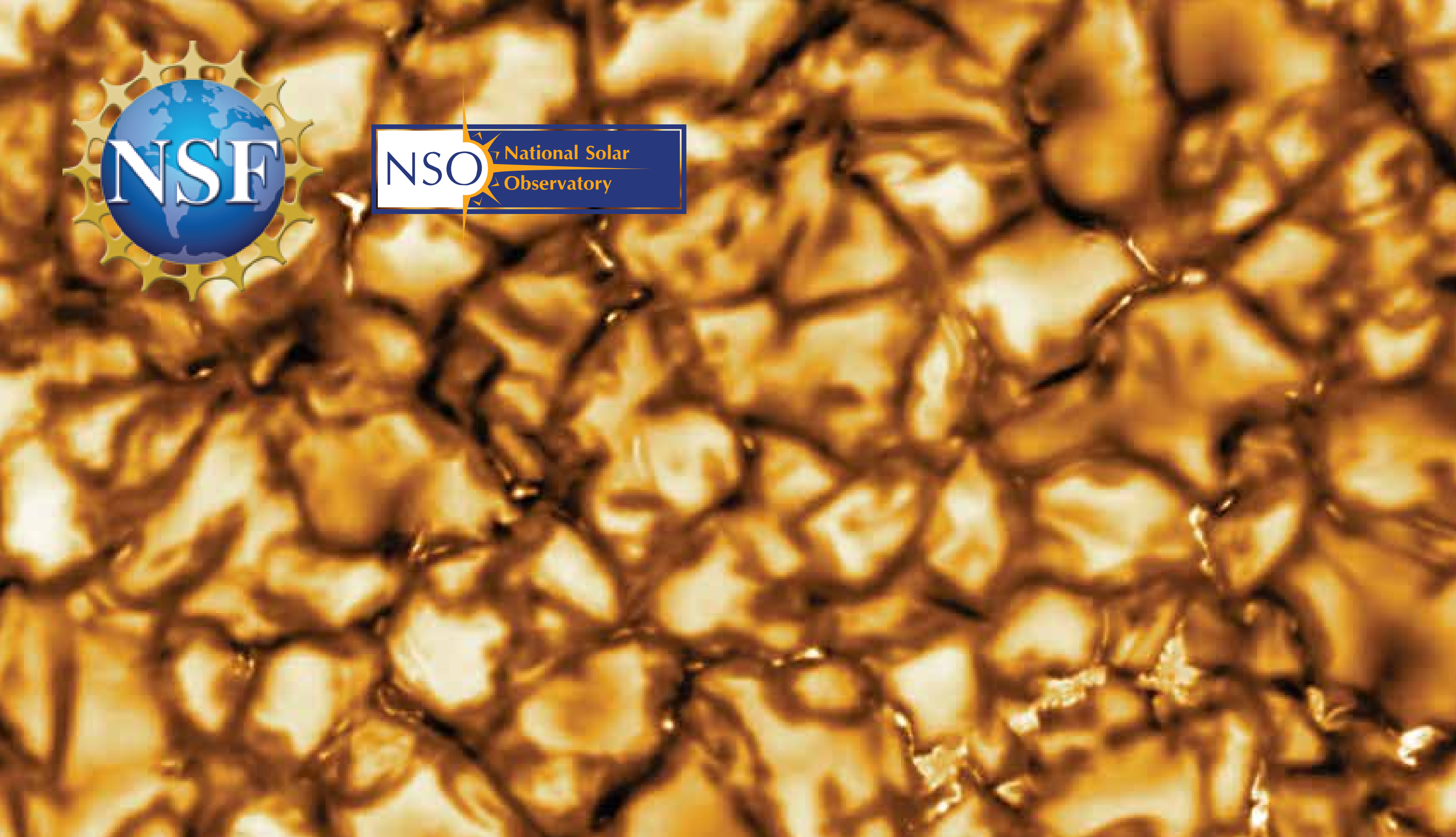
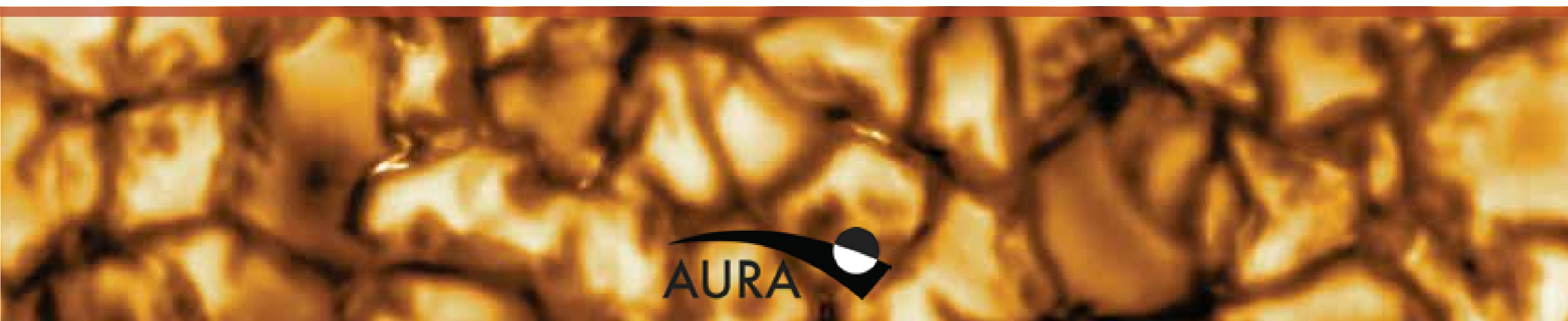


NSF
NSO National Solar Observatory

DANIEL K. INOUYE SOLAR TELESCOPE

CRITICAL SCIENCE PLAN



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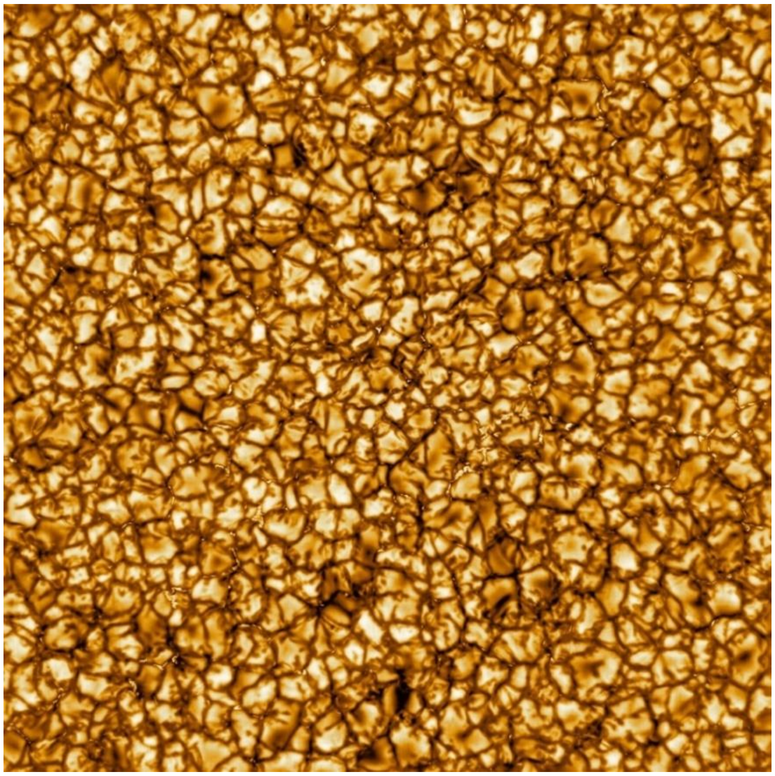

Figure 1. First-light DKIST image released publicly on 29 January 2020. The image was taken with the Visible Broadband Imager (VBI) using its longest wavelength filter (789.2 nm; FWHM 0.356 nm) and resolves granulation down to tens of kilometers in scale.

This DKIST Critical Science Plan (CSP) is a snapshot of some of the scientific pursuits that the Daniel K. Inouye Solar Telescope hopes to enable as start-of-operations nears. The first-light DKIST images (Figure 1), released publicly on 29 January 2020, only hint at the extraordinary capabilities which will accompany full commissioning of the five facility instruments. This document is an attempt to anticipate some of what those capabilities will enable. The document relies on the combined contributions of the DKIST Science Working Group (SWG) and CSP community members, who generously shared their experiences, plans, knowledge and dreams. Discussion is primarily focused on those cutting-edge issues to which DKIST will uniquely contribute. References are necessarily incomplete; they are exempli gratia only, even where not explicitly so noted. All errors in content and exposition are the responsibility of the editing author of this final version.

Mark Rast
11 May 2020

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1 Overview

The Daniel K. Inouye Solar Telescope (DKIST) will revolutionize our ability to measure, understand and model the basic physical processes that control the structure and dynamics of the Sun and its atmosphere (Rimmele et al. 2020, Woeger et al. 2020, DeWijn et al. 2020, Jaeggli et al. 2020, Fehlmann et al. 2020, von der Lühe et al. 2020, Tritschler et al. 2020, Harrington et al. 2020, Davey et al. 2020, Rast et al. 2020). The four-meter, clear-aperture telescope will be the world's largest solar telescope. Its first-light suite of instruments will make diffraction-limited observations, both on and off the solar disk, at wavelengths ranging from 380 to 5000 nm. It will be able to measure the polarization properties of solar photons from across this spectral range with unprecedented precision, and these will enable deductions about the strength and direction of the solar magnetic field at many heights in the solar atmosphere.

The DKIST has been designed to combine a large light-collecting area with: 1) the ability to observe faint optical and infrared signals in the presence of a much brighter background (a true telescope-coronagraph); 2) an integrated, high-order adaptive optics system to achieve diffraction-limited angular resolution over a wide range of wavelengths; 3) extreme sensitivity to the polarization state of light (an unsurpassed telescope-magnetometer); and 4) a diverse post-focus instrument suite that can simultaneously observe a target over a range of wavelengths, from the near-UV to the mid-IR, and thus simultaneously sample a broad range of heights in the solar atmosphere, from the deep photosphere to the low corona.

The primary goal of the DKIST is to address long-standing problems in solar physics, such as the operation of the solar dynamo and the heating and acceleration of the solar chromospheric and coronal plasma, but its scientific impact will extend well beyond the Sun. DKIST data will contribute to our understanding of fundamental physical processes, such as the generation and annihilation of magnetic field in plasmas of very high electrical conductivity, the role of turbulence under extreme conditions not achievable in terrestrial laboratories and the quantum mechanical underpinnings of polarization spectroscopy essential to the interpretation of a broad range of astrophysical observations. The anticipated high spatial and temporal resolution spectropolarimetric observations of the continuously reorganizing and reconfiguring solar magnetic field will allow detailed study of the underlying impulsive energy release and particle acceleration mechanisms responsible for the formation of particle beams and plasma ejecta. These processes are ubiquitous in astrophysics, critical to the stability of laboratory plasmas and directly impact our ability to robustly extend human technology into the Earth's space environment.

The start of DKIST operations coincides with two space encounter missions which aim to understand the physical conditions of the solar wind plasma near the Sun, the Parker Solar Probe (PSP) (e.g., Fox et al. 2016, first papers summarized by Verscharen 2019), launched in August 2018, which is already making measurements at record setting close approaches to the Sun, and Solar Orbiter (e.g., Müller et al. 2013), launched in February 2020, which will combine in-situ and remote-sensing measurements from a vantage point that lies out of the ecliptic plane. Together, DKIST, PSP and Solar Orbiter will provide unprecedented opportunities to advance our understanding of the inner heliosphere and by extension the origin and properties of the magnetized plasma surrounding other stars. DKIST will make essential contributions to these collaborative investigations (Martinez Pillet et al. 2020). It will be able to measure the off-limb coronal magnetic field directly out to 1.5 solar radii, close to the inner field-of-view of the Wide-Field Imager (WISPR) (Vourlidas, et al. 2016) on PSP during closest solar approach (in 2024). More broadly, it will measure the solar magnetic field at multiple heights in the solar atmosphere, from the deep photosphere to the corona. Those measurements will contribute to a dramatic increase in the reliability of the magnetic field extrapolations, which are essential to understanding the origin of the solar wind plasma whose properties are measured at the in-situ locations of the spacecraft. Knowing the plasma origin is in turn a key ingredient in deciphering which properties of the solar wind are determined at the Sun and which develop through subsequent instabilities as the plasma flows outward.

With a post-focus suite of five instruments, the DKIST's novel capabilities come with extreme flexibility and consequent complexity. Significant effort is required to understand how to best leverage that flexibility to achieve the rich scientific goals uniquely accessible by DKIST soon after the start of operations. The strategy of the National Solar Observatory (NSO) has been to actively engage a large cross-section of the US and international solar and space physics community in defining these goals and how to achieve them. This was done not only to expand the range of science to be pursued, but also to ensure that the early critical science can indeed be addressed using the DKIST telescope and the anticipated post-focus instrument suite.

At the heart of the DKIST Critical Science Plan, described in this document, is a set of scientific goals formulated by the DKIST Science Working Group after considering the Science Use Cases contributed by the community via an Atlassian® Jira® development interface. Science Use Case development was partially facilitated by a series of Critical Science Plan Workshops hosted jointly by the NSO and community partners (https://www.nso.edu/telescopes/dki-solar-telescope/csp/dkist-csp-workshops/). Though participation in those workshops was not mandatory for Science Use Case development, they served as an efficient way to acquaint the community with the telescope and instrument capabilities, the range of operational possibilities, and some of the challenges unique to ground-based observing. In turn, the DKIST project acquired a sense of the range and popularity of different observing configurations to expect in meeting the critical early scientific objectives.

Abstracts of the Science Use Cases developed as part of the Critical Science Plan development can be found in the Appendix A. Their full content goes well beyond those abstracts. Each Science Use Case was developed as a first draft of an Observing Proposal. Many include observing strategies as well as instrument performance estimates obtained using Instrument Performance Calculators provided by the DKIST instrument teams. At the time of this writing, over one-third of the Science Use Cases listed in the Appendix are developed to a degree that they can be considered nearly observation ready. It is anticipated that the first year of telescope operations will occur in a shared-risk shared-opportunity mode, called the Operations Commissioning Phase (OCP). During this period, instruments will come on line successively and community members will collaborate with telescope, instrument and operations scientists to commission the instruments over a wide range of operation modes, refine the complex data reduction pipelines, and exercise the full system from the proposal writing tools to the data storage algorithms. Since, through the development of this Critical Science Plan, members of the community have become acquainted with the telescope and instrument capabilities, they will be able to effectively adapt their science goals to the available instrument configurations both during the OCP phase and beyond when all instruments are fully operational. It is therefore anticipated that DKIST will "hit the ground running," with clearly defined scientific objectives and well developed strategies to meet them.

In this Critical Science Plan document, we first briefly describe the unique capabilities of the DKIST instrument suite. We then elaborate on the DKIST science goals, first in terms of the broad Research Areas to be addressed and then in more detail as specific Research Topics. While not limited by the scientific content of the current set of Science Use Cases, each Research Topic references specific relevant Use Cases as available.

1.1 Unique DKIST Instrument Capabilities

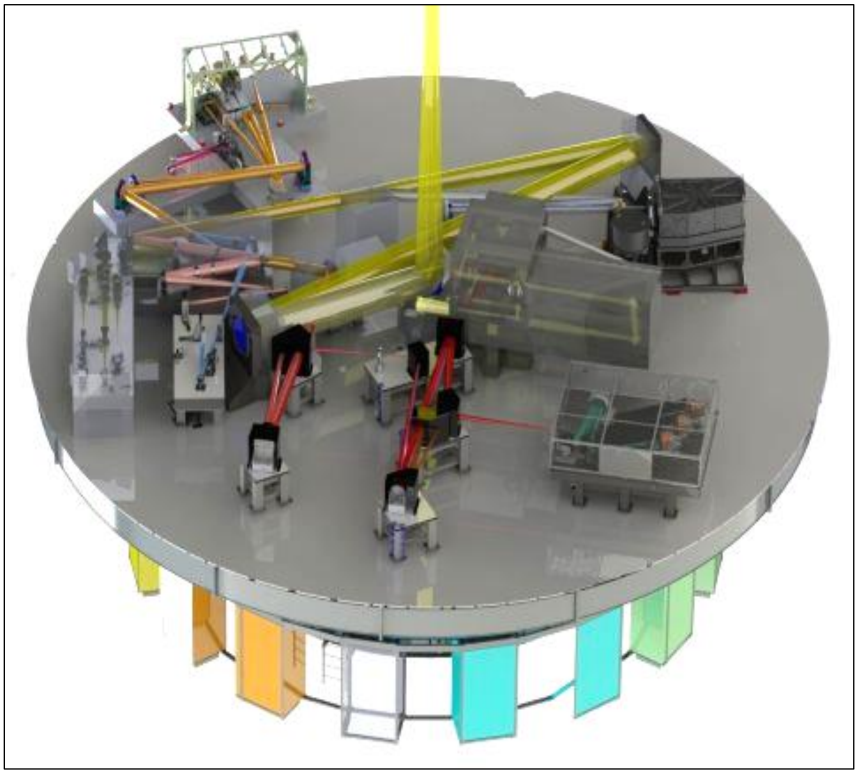


Figure 2. Rendering of the five first-light instruments on the rotating Coude' lab table with individual light paths indicated by colored beams. Simultaneous use of four of the five instruments will be possible using the Facility Instrument Distribution Optics (FIDO, Tritschler et al. 2020).

The DKIST primary mirror has a diameter of 4m, a size chosen so that small-scale plasma dynamics in the solar photosphere can be resolved while simultaneously making polarization measurements of weak magnetic fields. Moreover, the all-reflective clear-aperture off-axis optical configuration of the telescope allows broad wavelength access and minimizes scattered light, yielding the dynamic range sensitivity necessary for studies of the full solar atmosphere from the deep photosphere to 1.5 solar radii (0.5 solar radii above the photosphere).

DKIST's first-light instrument suite was selected to take advantage of these capabilities. The five instruments cover wavelengths between 380 and 5000 nm. With the exception of the Cryogenic Near-Infrared Spectro-Polarimeter (CryoNIRSP), the instruments can be used individually or in combination, and employ a common integrated high-order adaptive optics system which enables diffraction-limited observations with resolution ranging from 0.02 arcseconds at the shortest wavelengths to 0.09 arcseconds at 1800 nm. The cryogenically cooled CryoNIRSP, on the other hand, makes seeing-limited observations with 0.15 arcsecond critical spatial sampling along the spectrograph slit over the spectral range 1000 to 5000 nm. Scattering by the Earth's atmosphere, and thus the background sky brightness, is greatly reduced at longer wavelengths making regularly observations of the dim corona possible with the CryoNIRSP.

All instruments, with the exception of the Visible Broadband Imager (VBI) are highly sensitive spectropolarimeters. Careful calibration of the instrument and telescope polarimetric contributions (Harrington et al. 2019, Harrington et al. 2020, and references therein) will allow measurement of solar magnetic flux densities of less than 1G both on and off the disk. That level of sensitivity is needed to understand many processes which control the small-scale dynamics of the solar magnetized plasma such as, for example, the operation of a possible small-scale surface dynamo and the mass and energy loading of the upper atmosphere. All DKIST instruments employ specially developed large-format cameras capable of frame rates up to 30 Hz. For coronal observations in particular, the cameras have the ability to make non-destructive detector reads in order to improve signal to noise with longer exposures.

1.2 The Cryogenic Near-Infrared Spectro-Polarimeter (CryoNIRSP)

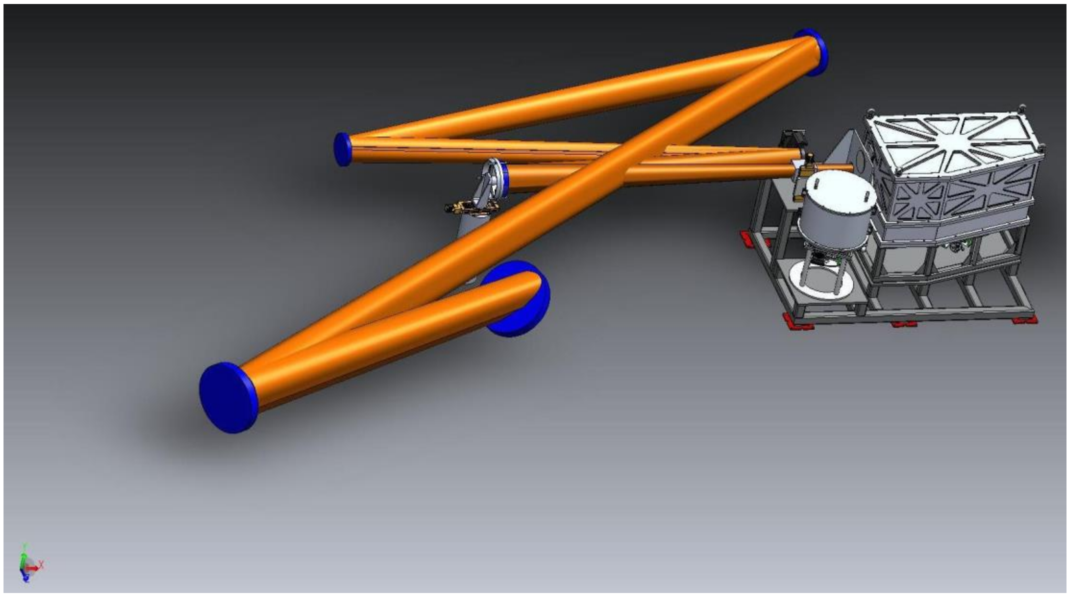


Figure 6. CryoNIRSP Coudé Light Path with imager and spectrograph.

Regular near-infrared (up to 5000 nm) spectropolarimetry of the solar corona will become possible with the Cryogenic Near-Infrared Spectro-Polarimeter (Fehlmann et al. 2020). The instrument will observe a 5 arcmin field-of-view and cover wavelengths from 1000 - 5000 nm. It combines cryogenically cooled single-slit scanning spectropolarimeter with an IR imager. The cryogenic grating spectrograph achieves a spectral resolving power of R=40000 along with angular resolution of about 0.3 arcsec (seeing limited). Warm optics in front of the IR spectrograph and imager allow the full field-of-view of the telescope to be sequentially sampled across the 4-arcmin-long spectrograph slit while simultaneously imaging the central (100 x 100 arcsecond) portion of the 2 x 2 arcminute on-disk and 4 x 3 arcminute off-disk field-of-view with

the IR imager. Observable wavelengths are determined by an interference filter set for the context imager and a set of order-sorting filters for the spectrograph. The benchmark coronal magnetic field sensitivity is about 1 G with 1 arcsec pixel sampling and a 5-minute exposure. Science supported by CryoNIRSP leverages the low IR sky brightness, the discovery potential of the heretofore little examined IR coronal line diagnostics, and the unprecedented resolution and regularity with which the coronal magnetic field measurements will be made.
https://www.nso.edu/downloads/cryonirsp_inst_summary.pdf

1.3 The Diffraction-Limited Near-Infrared Spectropolarimeter (DL-NIRSP)

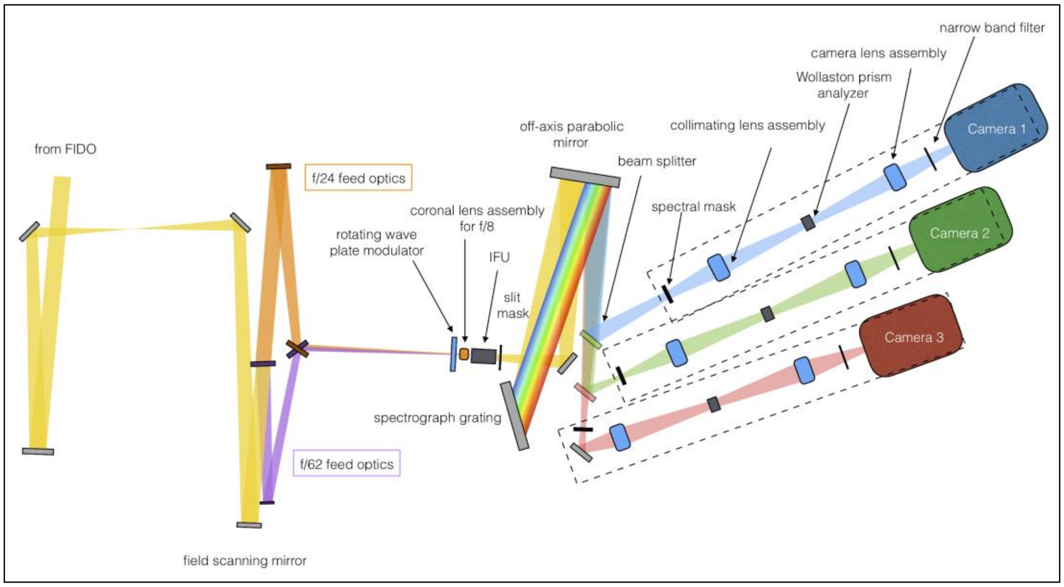


Figure 5. Optical layout of DL-NIRSP. Note that the feed optics and spectrograph are not shown to scale.

The Diffraction-Limited Near-Infrared Spectropolarimeter (Jaeggli et al. 2020) fulfills the need for multi-wavelength high cadence spectropolarimetric observations of the upper and lower solar atmosphere concurrently over a continuous field of view. A birefringent fiber optic integral field unit (IFU) is used to reformat a small contiguous solar image into multiple slits that feed a high dispersion spectrograph. Three reconfigurable spectrometer arms are available for simultaneous targeted coverage of selected visible (500 - 900 nm), K-band (900 - 1350 nm), and H-band (1350 - 1800 nm) diagnostics of the solar magnetic field. A rotating wave-plate polarization modulator is located immediately before the IFU and Wollaston prisms specific to each spectral arm are located in an optical relay which reimages each spectrum onto the focal plane at the detectors. Narrow-band filters specific to the wavelength being observed are necessary to restrict the spectral bandpass from each slit illuminated by the IFU. The first-light filter set includes bandpasses centered on Fe XIV (530.3 nm), He I D3 (587.6 nm), Fe I (630.2 nm), Fe XI (789.2 nm) and Ca II (854.2 nm) on the visible arm; Fe XIII (1074.7 nm), Fe XIII (1079.8 nm) and He I (1083.0 nm) on the K-band arm; and Si X (1430.0 nm) and Fe I (1565.0 nm) on the H-band arm. Three configurations of the feed optics allow for different spatial sampling and field-of-view coverage. These address different science requirement trade-offs between high spatial resolution, high cadence and high signal-to-noise measurements. The fields of views available are 1.9” x 1.8” with 0.03” sampling (high-res mode), 5.0” x 4.6” with 0.08” sampling (mid-res

mode), and 14.9” x 27.8” with 0.46” sampling (coronal wide-field mode). Because these fields are rather small, DL-NIRSP is equipped with a scanning mirror capable of producing mosaics up to the 2.8’ field provided by the DKIST light distribution optics. The DL-NIRSP is particularly important to those science goals for which simultaneous spectra at all spatial positions are necessary, as well as those cases for which long wavelength observations are needed in combination with other instruments.
https://www.nso.edu/downloads/dlnirsp_inst_summary.pdf

1.4 The Visible Broadband Imager (VBI)

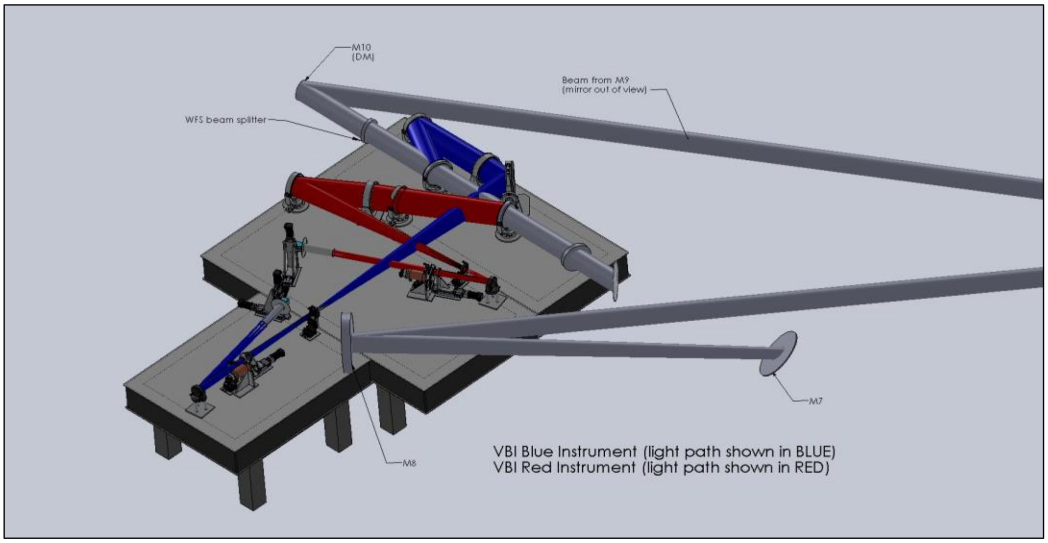


Figure 3. A schematic of the VBI optical path. The VBI is two instruments in one: one filter-graph for blue (390 - 500 nm) and another for red (550 - 860 nm) wavelengths.

The Visible Broadband Imager (Woeger 2014, Ferayorni et al. 2016, Woeger et al. 2020) is a diffraction-limited filtergraph, with four passband interference filters available in each of two channels spanning blue (390 - 500 nm) and red (550 - 860 nm) wavelengths. The VBI provides filtergram images at the highest possible spatial resolution (0.011 arcsecond/pixel spatial sampling) and temporal cadence (0.033 s cadence) available with DKIST. Its eight first- light filters probe a range of temperatures from the photosphere (e.g., G-band at 430 nm) to the chromosphere (Ca II K, H-beta, H-alpha) and into the corona (Fe XI 789 nm), and therefore support a large majority of the DKIST critical science both as a key measurement component and by providing context images when the fields of view of the other instruments are more constrained. VBI typically operates its two 16 megapixel (4096 x 4096) detectors at rates up to 30 frames per second in order to “freeze” the atmospheric turbulence contributions unavoidable in ground-based observing. Real-time speckle-interferometric deconvolution image-reconstruction techniques are applied to the data at the telescope to reach the highest possible spatial resolution over the largest possible field-of-view. The maximum instantaneous field of view of the VBI is 45 x 45 arc seconds in the blue channel and 69 x 69 arcseconds in the red. Since deconvolution is done at the telescope, the data volume is significantly reduced before transport and archiving. It is expected that VBI filtergram images will reveal hitherto unobserved fine-scale solar phenomena.
https://www.nso.edu/downloads/vbi_inst_summary.pdf

1.5 The Visible Spectro-Polarimeter (ViSP)

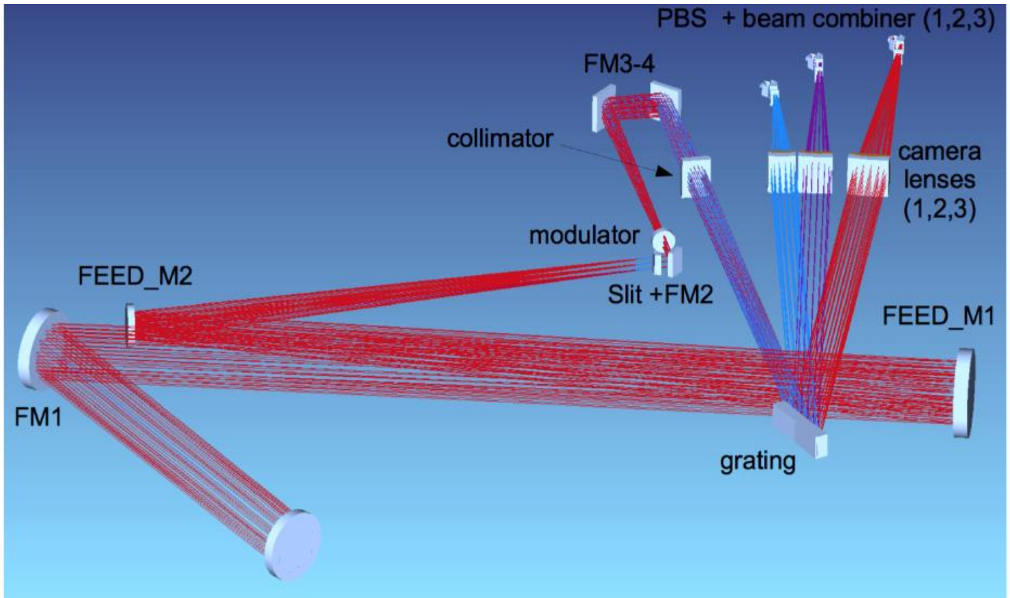


Figure 4. Optical layout of the Visible Spectro-Polarimeter showing its slit and modulator unit followed by its diffraction-grating based spectrograph feeding three simultaneously operating spectral arms.

The Visible SpectroPolarimeter (Nelson et al. 2010; de Wijn et al. 2012, de Wijn et al. 2020) addresses the need for diverse access to spectral lines over a wide range of wavelengths in order to enable sensitivity to critical physical parameters throughout the volume of the solar atmosphere. To meet this need, ViSP was built with spectral flexibility in mind. It is a reconfigurable diffraction-grating based spectrograph capable of precision spectroscopy and spectropolarimetry. Up to three spectral bands (about 1 nm wide at 630 nm) located between 380 and 900 nm can be simultaneously observed using three 2560 x 2160 pixel visible detectors. Each of the three channels simultaneously obtains a full Stokes spectrum using a single polarimetric modulator for all channels and separate dual-beam polarimetric analyzers for each individual channel. Large spectropolarimetric data cubes are accumulated by scanning the single slit across the field of view. Almost any combination of three spectral bands is possible, but example photospheric and chromospheric lines accessible include the often observed lines of Fe I 630.2, Fe I 617.3 and H-alpha 656.3 nm, alongside a host of other useful lines such as Ca II H and K, Sr I 460 nm, Mg I b1/b2, Na I D1/D2, and the Ca II infrared triplet. ViSP promises unprecedented precision for mapping the solar magnetic field throughout the solar atmosphere, and thus supports a very wide range of early critical science.
https://www.nso.edu/downloads/visp_inst_summary.pdf

1.6 The Visible Tunable Filter (VTF)

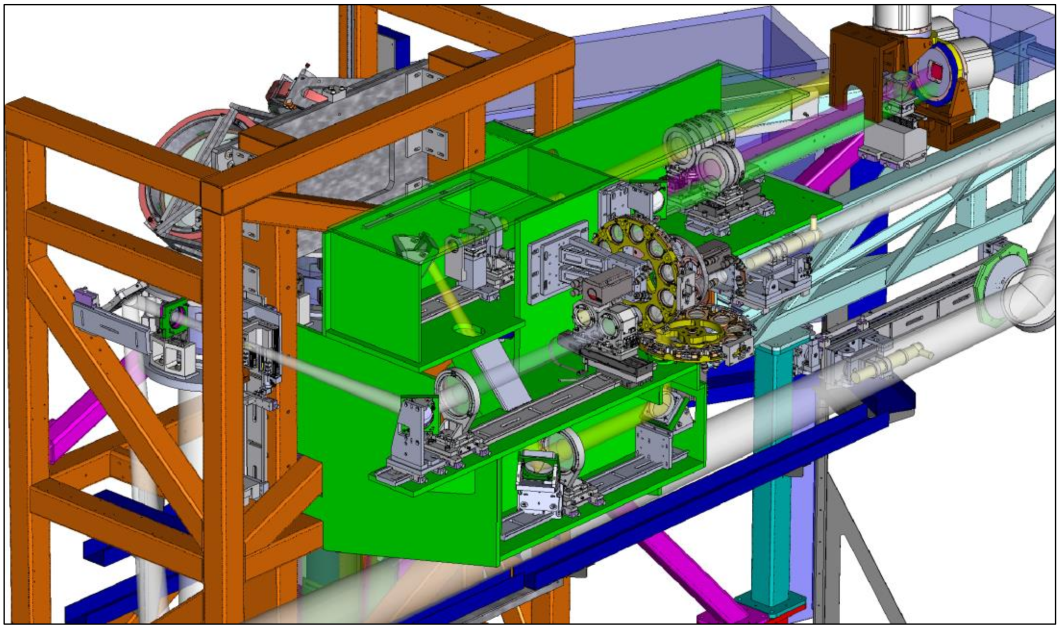


Figure 7. Design and light path of the focal plane area of the VTF. In the center of the drawing the prefilter wheels for the spectroscopic and the broadband channel are seen, as well as the polarization modulator. The polarizing beam splitter and the corresponding focal plane detectors are in the upper right corner.

The Visible Tunable Filter (Schmidt et al. 2014, von der Lühe et al. 2020) is a diffraction-limited narrowband tunable Fabry-Perot interferometer. It will be used for two-dimensional Stokes spectropolarimetry in the wavelength range between 520 and 860 nm. The instrument has a fixed field of view of one arcminute squared. At the shortest wavelengths, each detector pixel corresponds to an area of ~10 x 10 km on the Sun (0.014 arcsec square). The spectral resolution is 6 pm at a wavelength of 600 nm (R=100,000). The large-format Fabry-Perot interferometer is a tunable monochromator, and is combined with narrowband interference filters to isolate individual spectral regions (0.1 - 0.2 nm wide, depending on wavelength), with up to 10 pre-filters simultaneously accommodated. The instrument can record one diffraction-limited 2D-spectrum for the full field of view via measurements at 11 positions in a photospheric line with a polarimetric sensitivity better than 5 x 10^{-3} in less than 15 seconds. A faster cadence is possible at the cost of spectral coverage and/or polarimetric sensitivity, or the sensitivity of the instrument can be further improved by increasing the effective integration time at each wavelength point, without sacrificing field of view. Doppler-only measurements, without polarimetry, over the full field of view can be made in a photospheric line in less than four seconds. VTF is also equipped with a broad-band channel. It uses a 1 - 2 nm prefilter to simultaneously image the same field of view as the polarimetric channel at a nearby continuum wavelength. These images can be used for context and for subsequent post-facto image reconstruction. VTF's unique capabilities make it a key instrument for early science goals ranging from sunspot dynamics to rapid tracking of the horizontal motion of structures to multiheight measurement of flows and magnetic fields in the photosphere and the chromosphere.
https://www.nso.edu/downloads/vtf_inst_summary.pdf

2 Research Areas

2.1 Magnetoconvection and Dynamo Processes

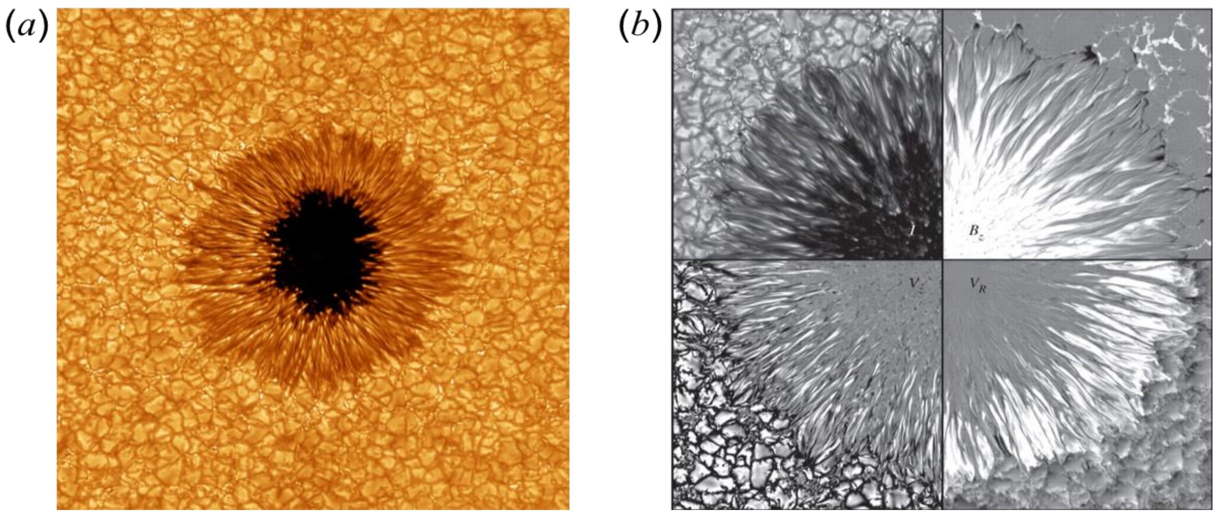


Figure 8. (a) Image of AR NOAA 1084 taken on July 2, 2010 in TiO (706 nm) filter from Big Bear Solar Observatory from http://www.bbso.njit.edu/nst_gallery.html . (b) simulated sunspot from Rempel 2012b, Phil. Trans. R. Soc. A (reproduced with permission; copyright 2012 Royal Society).

Magnetic fields on the Sun are highly structured and multiscale. Field is found not only on the scale of active regions and sunspots, but down to the smallest spatial scales observed. The small-scale fields may have their origin with larger-scales as the endpoint of a turbulent cascade acting on field produced by a global-scale dynamo, or they may originate with small-scale motions perhaps in the photosphere itself as the result of a turbulent fluctuation dynamo (a small-scale or local dynamo). Many questions remain about the field distributions observed, about how and why the field is organized as it is in the solar photosphere.

On the largest scale, the global solar magnetic activity cycle reflects dynamo processes that operate with remarkable regularity. The most conspicuous aspect of the global-scale dynamo is the cyclic appearance and disappearance of large regions of strong magnetic field organized into sunspots and active regions. These come and go with the solar cycle on spatial and temporal scales that suggests an origin in the deep convection zone or in the overshoot region just below it. But the solar convection zone is in a highly turbulent state and spans many pressure scale heights, with the density changing by a factor of over a million between the bottom and the top. If formed near the bottom of the convection zone, how do the magnetic structures we see manifest as sunspots and active regions in the photosphere survive transit across the highly stratified and vigorously turbulent convection zone? Some aspects of solar active region evolution in the photosphere are very dynamic, with a complex interplay between the field and magnetoconvective motions observed during active region formation, evolution and ultimate dissolution. The vertical scale height in the photosphere is much smaller than the characteristic size of an active region, sunspot or even a pore. Could these structure form in the photosphere or upper convection zone itself? Both the lower and upper boundaries of the convection zone, the tachocline and photosphere respectively, seem to play important roles in the buildup of magnetic flux and its loss into the solar atmosphere, but interplay between them and their respective roles in the production of the observed multiscale highly structured photospheric field is unknown.

Sunspot umbrae are the most strongly magnetized regions of the Sun accessible to spectropolarimetric observations. They are cool and dark, characterized by magnetic fields that are close to vertical with respect to the photosphere, and exhibit constrained columnar convective motions that are only poorly understood. The surrounding penumbral field is highly inclined, with multiple interleaved magnetic components permeated by strong plasma flows. It is unknown how the multicomponent sunspot structure arises. For example, reproduction of the observed penumbral properties by state-of-the-art radiative magnetohydrodynamic simulations requires upper boundary conditions on the magnetic field whose counterparts on the Sun have yet to be identified. DKIST's large photon flux and high spatial and temporal resolution are critical to advancing our understanding of sunspot dynamics.

The quiet (non-active region) Sun is magnetized almost everywhere. In the quietest regions (internetwork) the fields appear to be weak and highly inclined. Determining the origin of these small-scale fields is difficult and DKIST will make critical contributions to this problem as well. It will allow simultaneous observations in Zeeman-sensitive and Hanle-sensitive lines, to determine if the Hanle polarization signals measured in the internetwork regions of the Sun are consistent with the field deduced from the Zeeman diagnostics, and thus assess the amount of unresolved flux present as function of resolution. This will allow careful exploitation of these techniques to precisely measure the internetwork field coverage and its spatial distribution as a function of global solar magnetic activity. The statistics and evolution of the smallest scale fields on the Sun can then be compared to those seen in dynamo simulations to untangle the signatures of its origin.

Beyond its origin, knowledge of the small-scale magnetic field distribution on the Sun is key to assessing the role of photospherically generated waves in atmospheric heating. Waves propagate from the photosphere upward into the atmosphere, guided by local magnetic structures. They undergo mode conversion, and steepen, shock and dissipate in the chromosphere. The underlying magnetic field distribution is critical to these processes and thus to the heat and momentum budget of the atmosphere with height. The small-scale fields also play an important role in modulating the solar radiative output. Small concentrations of magnetic field are sites of reduced gas pressure, density, and thus opacity. An amalgam of small-scale field elements reduces the average temperature gradient of a region, locally changing the radiative output and thus contributing to variations in global solar spectral irradiance. Many small-scale magnetic structures remain unresolved by current instruments, and changes in their size and contrast distributions with the solar cycle are unknown. Since weakly magnetized internetwork regions cover the bulk of the solar surface, currently unresolved field elements may play a significant role in global spectral irradiance trends. DKIST will play a critical role in unraveling their contributions.

Several critical science topics in this Research Area are discussed in detail in Section 3.1, including 1) the formation, structure and dynamics of small-scale photospheric magnetic fields; 2) wave generation and propagation; 3) magneto-convective modulation of the solar luminosity; and 4) active region evolution and sunspot fine structure.

2.2 Flares and Eruptive Activity

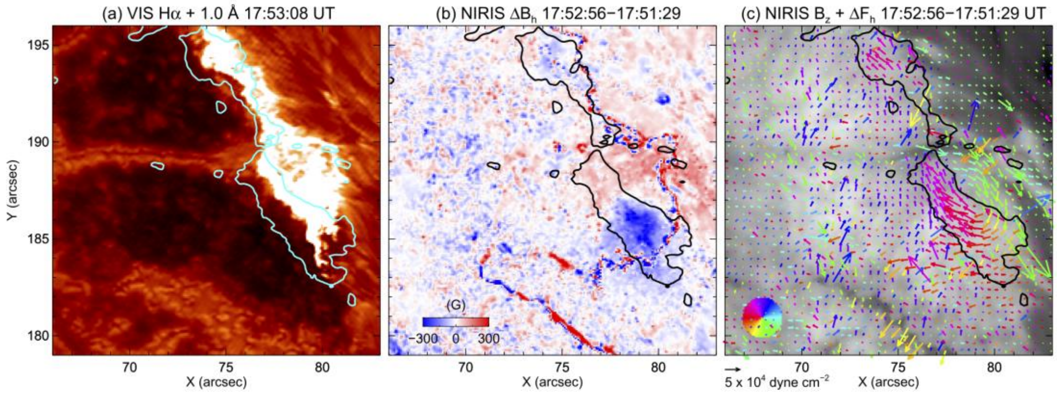


Figure 9: Observations taken during an M6.5-class flare using the Goode Solar Telescope. The bright flare ribbon seen in the Hα image (a) is the site of changes in the horizontal (b) and vertical (c) components of the photospheric magnetic field measured from the 1565 nm Fe I line pair. Contours in all three panels are from a running-difference image of Hα ribbons. From Liu et al. 2018, ApJ (reproduced with permission; copyright 2018 American Astronomical Society).

Solar flares and coronal mass ejections are spectacular phenomena that are not only critical to the space weather environment of Earth, but reflect processes ubiquitous in astrophysical plasmas. The Sun, by its proximity, allows the unique possibility of high-resolution studies of the physics of magnetic reconnection, the related acceleration of particles to relativistic energies, the heating of the plasma to more than 10 million Kelvin, and the excitation of plasma waves. Flares and mass ejection events are a template for magnetic activity on a variety of stars, some much more active than the Sun, with implications for the habitability of exoplanets. Moreover, the underlying physical processes are common to even more energetic astrophysical events that produce relativistic jets, beams, and shocks.

The solar atmosphere is a dynamic magnetized plasma of very high electrical conductivity that can form and sustain complex current systems. When these currents abruptly reconfigure during magnetic field reconnection events, particle acceleration and bulk plasma ejection can result. Intense electromagnetic radiation occurs when the energy of accelerated non-thermal particles or accompanying plasma waves is deposited and thermalized. Observationally, solar flares are transient bursts of electromagnetic radiation over a wide range of wavelengths, from radio to X-ray (or even shorter in some cases). Coronal mass ejections (CMEs) occur when a magnetic flux system with substantial magnetic free energy, initially confined by overlying field, evolves so that the outward magnetic pressure forces on the trapped plasma overcome the inward magnetic tension force of the overlying fields. The energetic flux system can then escape into interplanetary space, with the consequent expulsion of magnetized coronal plasma into the heliosphere. Subsequent flaring often occurs as the magnetic field in the wake of the coronal mass ejection relaxes back to a lower energy state. Many flares occur without CMEs, and some CMEs occur without substantial enhancement of radiative emission, but it is common for both phenomena to occur as part of such a solar eruptive event.

Much of the research on solar flares and CMEs over the last decades has focused on the evolution of temperature and density structures within the corona. DKIST's ability to regularly and systematically measure coronal magnetic fields will enable more direct connection of the local plasma properties and the radiative signatures of flares and CMEs with the field evolution. Additionally, the ability of DKIST to readily probe the lower solar atmosphere at very high spatial resolution, in combination with ongoing developments in radiation magnetohydro-dynamic modeling, will allow more direct deductions of the evolution of the physical conditions deeper in the atmosphere during flaring and eruptive events. Further, DKIST measurements of subtle changes in the intensity and topology of the photospheric magnetic fields underlying flaring regions will help in assessing the amount of magnetic energy released during these events and the mechanisms that drive the rapid conversion of the energy stored in stressed coronal magnetic fields into other forms. Spatially-resolved rapid imaging and spectroscopy of the chromospheric footpoints of flares will allow determination of the actual extent of the sites of flare energy deposition, providing strong constraints on particle acceleration mechanisms. Measurements of the penetration depth of the flare disturbance into the lower atmosphere, facilitated by DKIST's multi-wavelength capabilities, will help determine the role of various proposed energy transport mechanisms, for example, the relative importance of waves and particle beams.

Several critical science topics in this Research Area section are discussed in detail in Section 3.2, including 1) flare and CME precursors; 2) changes in the magnetic field associated with flares and CMEs; 3) energy deposition during flares; and 4) the fundamental structure and evolution of flare ribbons.

2.3 Magnetic Connectivity through the Non-Eruptive Solar Atmosphere

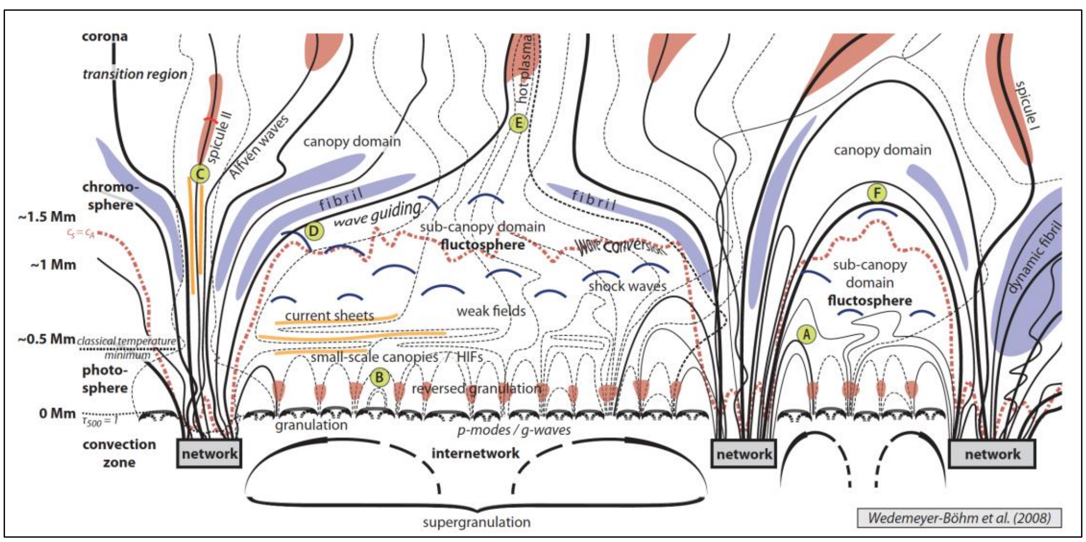


Figure 10. A schematic representation of the rich phenomena and processes at play within a magnetically structured stellar atmosphere as summarized by Wedemeyer-Bohm et al. 2009, Space Sci. Rev. The solid black lines denote magnetic field lines. (Reproduced with permission. Copyright 2009 SpringerOpen.)

The solar magnetic field extends from the solar interior, across the photosphere, through the chromosphere and transition region, and into the corona. It permeates the entire volume of the solar atmosphere and beyond into the heliosphere. Plasma motions in the solar convective envelope yield a highly structured magnetic field distribution in the photosphere which in-turn sets the boundary condition for the magnetic field above. As the photospheric boundary field evolves, that above it must reconfigure, and because the atmosphere extends over many scale heights, the energetics and dynamics of the response are diverse and multi-scaled. Central to the DKIST science mission is understanding the complex interplay between flows, radiation, conduction, wave propagation, dissipation and reconnection in both the ionized and partially ionized plasma regimes of the solar atmosphere. This understanding is critical to the resolution of long-standing problems in solar and stellar astrophysics such as chromospheric and coronal heating, the origin and acceleration of the solar wind, and the propagation of magnetic disturbances into the heliosphere.

Addressing this complex, connected system requires diverse, flexible, and multi-spectral line polarimetric instrumentation capable of probing the many heights of the solar atmosphere simultaneously, at high temporal cadence and over small spatial length scales. DKIST is at the forefront of these observational challenges and will provide manyfold advancement over current capabilities. New capabilities in high precision spectropolarimetry will allow inference of magnetic field properties in previously poorly-measured regimes, at spatial and temporal resolutions never before achievable. For example, while the distribution of solar photospheric magnetic fields has been routinely measured since the invention of the magnetograph based on the Zeeman effect, understanding the connections to the upper solar atmosphere requires the measurement and interpretation of chromospheric spectral lines formed under non-local thermodynamic equilibrium (NLTE) conditions in which both Zeeman and atomic-level polarization processes are important. DKIST will facilitate measurements of these with unprecedented precision.

DKIST is also at the forefront of coronal spectropolarimetry, providing new opportunities to understand the magnetic connectivity and energetics of the solar corona. Extrapolation of the photospheric magnetic field into the solar corona is inherently limited by assumptions made regarding the distribution of currents and forces in the magnetized volume. To advance our understanding of, for example, the available free magnetic energy driving solar flares and eruptions, remote sensing of the magnetic field in the corona itself is necessary. DKIST, as the world’s largest coronagraphic polarimeter, will allow the measurement of the full Stokes spectrum of forbidden magnetic-dipole emission lines formed by highly ionized metals. These can be used to determine the topology and evolution of the coronal field and, along with DKIST chromosphric diagnostics, its connectivity to the lower atmosphere.

Several critical science topics in this Research Area section are discussed in detail in Section 3.3, including 1) the mass and energy cycle in the low solar atmosphere; 2) the origin and acceleration of the solar wind; 3) magnetic reconnection throughout the solar atmosphere; 4) waves in the solar atmosphere; 5) impact of flux emergence on the non-eruptive solar atmosphere; 6) multilayer magnetometry; and 7) large-scale magnetic topology, helicity, and structures.

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

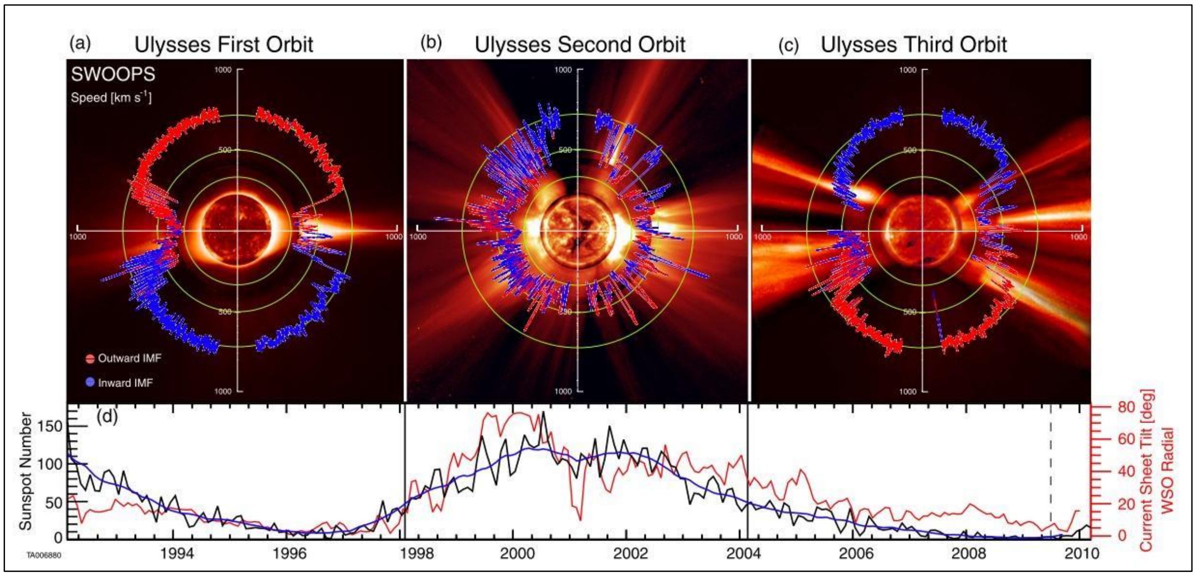


Figure 11. Solar wind speed in polar plots from Ulysses' three polar orbits (a)–(c). IMF sector is color-coded: outward (red) and inward (blue). For each polar plot, time progresses counterclockwise from the nine o'clock position. Matching time ranges in the bottom panel (d) are indicated by the vertical lines; this panel provides the sunspot number (black), smoothed sunspot number (blue), and Wilcox Solar Observatory (WSO) calculated heliospheric current sheet tilt angle (red; http://wso.stanford.edu/Tilts.html). Figure and caption (partial) from McComas et al. 2008, GRL (American Geophysical Union FreeAccess).

The Sun exhibits remarkable changes over decadal time scales, with the spatial distribution of active regions, sunspots, coronal holes, and prominences continuously changing along with the roughly 11-year polarity reversal. The frequency and severity of solar events, such as flares and CMEs, are strongly dependent on the phase of the solar cycle, and the amplitude of the basal high-energy radiative output of the Sun (in the X-ray and EUV) is modulated by orders of magnitude over the course of a solar cycle. These cycle-dependent changes and others hold clues about the underlying operation of the global solar dynamo.

Interestingly, cycle-related changes have been observed on the Sun at scales as small as supergranulation; supergranules get larger when the Sun is more active. It is possible that careful synoptic observations at higher resolution will reveal cycle-dependent dynamics at even smaller scales. Assessing these variations may provide fundamental insights into the multi-scale turbulent dynamics of highly stratified convection. Moreover, global modulation of solar activity occurs on time scales longer than the solar cycle as well, with variation in the strength of solar maxima and the duration and depth of solar minima leading to a cascade of consequences from total and spectral irradiance variations to changes in the solar-wind ionization state and mass flux. These, in turn, impact the near-Earth and interplanetary space environments, the Earth's upper atmosphere and to some degree the Earth's climate. Understanding, modeling and potentially forcasting these impacts requires long-term consistent monitoring of the Sun's magnetic and plasma properties. This is most readily achieved by a ground-based facility, which can maintain the required spatial and temporal resolution and spectropolarimetric sensitivity over decadal time scales since it can be fine-tuned, repaired and upgraded as needed.

Although DKIST is a dedicated solar telescope, its unique capabilities allow for a broad range of investigations beyond the core solar physics areas which form the bulk of this document. For example, as with previous space solar observatories such as SOHO, SDO and STEREO, DKIST will likely make contributions to cometary studies and the use of comets as probes for otherwise inaccessible coronal regions, regions for which both remote sensing observations (too faint to be detected) and in-situ direct measurements (closer than Parker Solar Probe's closest approach to the Sun) are not otherwise achievable. Similarly, atomic physics has benefited from the high resolution spectrometers on board SOHO (CDS and SUMER) and *Hinode* (EIS). These have provided the critical line intensity measurements necessary to benchmark theoretical predictions based on atomic parameters and electron-ion collision rates, and have led to major advances in atomic calculations and spectral synthesis codes, such as CHIANTI. This in turn has allowed far more accurate predictions of solar X-ray, EUV and UV spectral irradiance and improved plasma diagnostics. DKIST will significantly advance spectropolarimetric instrumentation and measurement, making fundementsl contributions to these broader efforts.

Several critical science topics in this Research Area section are discussed in detail in Section 3.4, including 1) long-term studies of the Sun; 2) Sun-grazing comets; 3) Mercury transit science; 4) turbulence and reconnection processes; and 5) synergies with in-situ measurements.

3 Research Topics

3.1 Magnetoconvection and Dynamo Processes

3.1.1 Small-Scale Photospheric Magnetic Fields: Formation, Structure, Dynamics

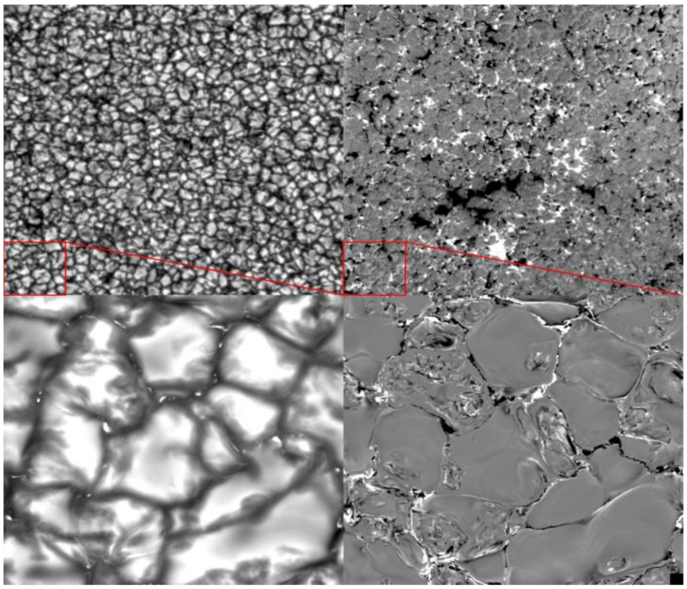


Figure 12. Top: SST CRISP observation of quiet sun with 0.15" resolution (~100 km), displaying Stokes I and Stokes V; bottom: quiet Sun simulation with 4-km grid spacing (DKIST comparable effective resolution of ~20 km) displaying bolometric intensity and vertical magnetic field (+/- 200 G) at optical depth 0.1. Simulation from Rempel 2014, ApJ (with permission; copyright 2014 American Astronomical Society.)

Is there a small scale dynamo operating in the solar photosphere? What is the relative importance of local amplification, flux emergence, flux cancelation and non-local transport in small scale field evolution? How turbulent are granular flows? How dependent is quiet-sun magnetism on the solar cycle?

Convection in the solar photosphere is driven by rapid radiative losses from a thin layer that is less than a pressure scale height in vertical extent. In this layer, the internal, kinetic, and magnetic energy of the plasma are all comparable (within a factor of a few). This leads to vigorous dynamics with strong coupling between these three energy reservoirs. While the solar convection zone is generally believed to be a highly turbulent medium, this is less than obvious in observations of the solar photosphere (Nordlund et al. 1997). Plasma that is transported upward into the photosphere, and is observed as bright hot granules, has undergone significant horizontal expansion and is expected to show nearly laminar flow structure even at DKIST resolution. A higher degree of turbulence may be found in the intergranular downflow lanes, but in these regions it likely develops as an advected instability at the interface between upflows and downflows as the fluid moves downward out of the boundary layer. Turbulence may thus only be apparent in high spatial resolution measurements of the deep photosphere. For these the anticipated high contrast achievable by DKIST is essential.

Small-scale magnetic field is ubiquitous on the solar surface and, in terms of unsigned flux density, exceeds the total active region magnetic field at all phases of the solar cycle (e.g., Lites et al. 2008, de Wijn et al. 2009, Lites 2011, Bellot Rubio and Orozco Suárez 2019). The quiet Sun magnetic field strength in the solar photosphere has an average value of about one third equipartition with the kinetic energy of the flows, about 600 G. Since most of the field is concentrated in downflow lanes, the field strength reaches much higher local values and strong feedback on the convection is expected, but a detailed understanding of the interaction between the flow and small-scale turbulent magnetic field and the consequent potential suppression of turbulence within intergranular downflows is still elusive due to the lack of resolution in current observations. This has broader significance, as the development of turbulence in the shear layers of intergranular downflow lanes may contribute to spectral line broadening (§3.4.2). Furthermore, even in the quiet-Sun, a small fraction of the magnetic field is locally amplified to a strength of a few kilogauss. These flux concentrations are typically rather small and only the larger ones are resolved with current instrumentation. DKIST will allow both dynamical studies of the formation and evolution of individual kilogauss elements and detailed statistical studies of the quiet-Sun flux concentration size and strength distributions and their solar cycle dependencies. Since modulation of the solar radiative output by magnetic flux elements is the primary cause of solar irradiance variations, these studies will be critically important in that context (see §3.1.3 below).

The small-scale magnetic field in the solar photosphere is maintained by a combination of several processes: (1) dispersal of active region flux; (2) turbulent amplification by photospheric flows; and (3) small-scale flux emergence from deeper regions. While process (1) reflects contributions from the large-scale global dynamo, processes (2) and (3) are linked to a turbulent fluctuation dynamo (also called a "small-scale" or "local" dynamo") that relies on the chaotic nature of flows in the uppermost layers of the convection zone. Some numerical simulations of turbulent fluctuation dynamos in the solar context have been successful in producing small-scale magnetic field with flux densities similar to that suggested by current observations, but these and all numerical fluctuation dynamo models operate at magnetic Prandtl numbers (ratio of viscosity and magnetic diffusivity) close to unity (e.g., Cattaneo 1999, Vögler and Schüssler 2007, Rempel 2014, Khomenko et al 2017). By contrast, the magnetic Prandtl number in the solar photosphere, if based on molecular values of the diffusivities, may be as low as 10^{-5}. Producing a fluctuation dynamo at small magnetic Prandtl number and large Reynolds number, the parameter regime most relevant to the Sun, is an unmet challenge for both numerical simulations and laboratory experiments. This makes the solar photosphere a unique plasma laboratory.

Moreover, Prandtl number unity models of the solar fluctuation dynamo can generate total unsigned magnetic flux densities close to those observed only when flux advection from deeper layers is allowed (Rempel 2014), not if the dynamo is strictly local, operating only in the photosphere. The observed level of quiet-Sun magnetism implies a significant amount of recirculation within in the convection zone, with convective motions bringing substantial amounts of field up into the photosphere from below (Stein et al. 2003, Rempel 2014, Rempel 2018). Simulations thus suggest that a more complete understanding of the solar fluctuation dynamo requires a quantitative assessment of the relative importance of local field amplification and non-local field transport (see e.g., Gošić et al. 2016 and references therein for recent observational studies).

Finally, the motions of small-scale magnetic field elements in the photosphere may be critical in the operation of the global solar dynamo. Global scale transport of small-scale field is a central ingredient of many global dynamo models (see reviews by Charbonneau 2014, Cameron et al 2017), with the accumulation of a dominant polarity field in the polar regions of the Sun, as a result of supergranular diffusion and meridional flow advection of small-scale field elements, critical to the reversal of the global dipolar field. For this reason, the measured solar polar field strength is often cited as the most reliable indicator for solar cycle predictions (e.g., Bhowmik and Nandy 2018). The behavior of small scale fields in the solar polar regions can be directly assessed via synotic DKIST observations (§3.4.1), and the value of the transport coefficients used in dynamo models can be dramatically improved by separating advective and diffusive contributions to magnetic displacement statistics in high-resolution DKIST observations (Agrawal et al. 2018). In these ways, DKIST will enable quantitative assessment of the small-scale field behaviors which may underlie the global dynamo.

Critical science to address:

1. What is the structure of the internetwork field, how does it vary with solar cycle, and is there evidence for small-scale dynamo action?
   Relevant Science Use Cases: 25, 62, 113, 121, 127, 191, 208, 232, 243

2. How important are the processes of local amplification, flux emergence and cancelation and non-local transport in producing the observed intergranular magnetic fields?
   Relevant Science Use Cases: 63, 65, 83, 134, 136, 224, 229

3. How turbulent are granular flows? What determines the convective scales observed?
   Relevant Science Use Cases: 13, 21, 39, 55, 117, 230

4. How are the turbulent properties of granular flows affected by the presence of magnetic field? How do the field and plasma properties evolve over the course of flux element interaction?
   Relevant Science Use Cases: 41, 93, 188, 229, 274

5. What is the structure of kilo Gauss magnetic field concentrations in the solar photosphere? How do they arise and evolve?
   Relevant Science Use Cases: 52, 119, 120, 125, 228

6. What is the origin and of the polar magnetic fields, how do they evolve and what can we learn about their contribution to the solar dynamo in coordination with IRIS, *Hinode*, SDO and Solar Orbiter?
   Relevant Science Use Cases: 135, 151, 152, 153, 161

3.1.2 Acoustic Gravity Wave Excitation

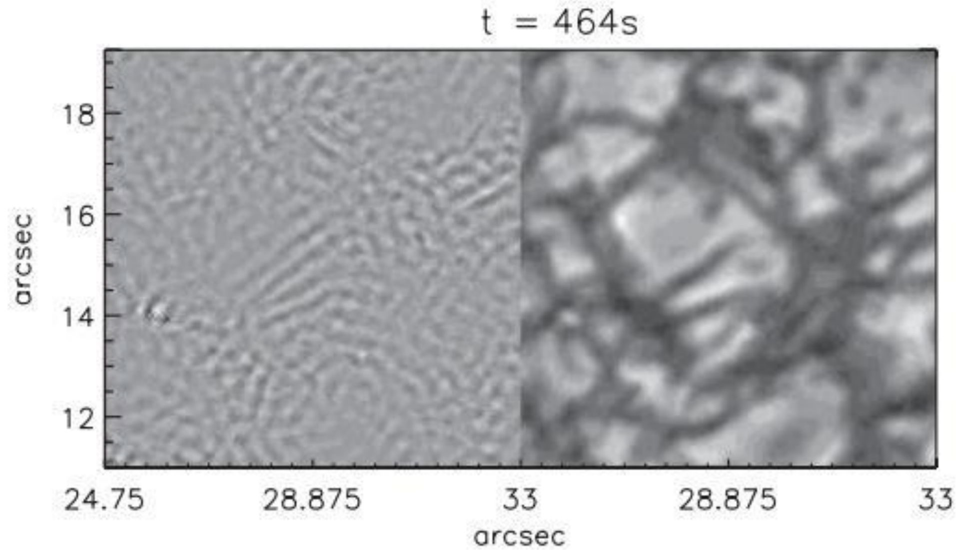


Figure 13. Filtered Doppler velocity (left) and simultaneous continuum images of the same area (right). A time series of these observations suggests the launching of parallel wavefronts by new downflow lane formation during granule fragmentation. From Roth et al. 2010, ApJ (reproduced with permission; copyright 2010 American Astronomical Society.)

What excites the solar acoustic oscillations? How do observed source properties effect helioseismic inferences? What physics underlies flare induced acoustic wave emission?

Magnetohydrodynamic wave generation, propagation, mode conversion, and dissipation are central processes in the energy and momentum budget of the solar atmosphere. Those issues are largely discussed in Section 3.3.4. Here we focus on the role of DKIST in determining the source of the solar p-modes and the potential for gravity wave observations and diagnostics in the lower solar atmosphere.

Acoustic-mode excitation on the Sun and other stochastically excited stars likely results from small-scale dynamical processes associated with convection, but the detailed source properties are not known. Some studies point to excitation occurring within intergranular lanes by Reynolds stress induced pressure fluctuations, the Lighthill mechanism (Goldreich and Keeley 1977), while others suggest that the dominant source is associated with pressure perturbations caused by local radiative cooling (Stein and Nordlund 1991, Rast 1999) and the sudden formation of new downflow plumes as often occurs during the fragmentation of large granules (Rast 1995). Moreover, some flares can be strong acoustic wave sources (e.g., Kosovichev and Zharkova 1998, Ambastha et al. 2003, Donea and Lindsey 2005), though the mechanisms associated with acoustic emission during flaring is only partially understood (Lindsey et al. 2014).

There is observational support for both of the hydrodynamic mechanisms suggested above (Rimmele et al. 1995, Chaplin et al. 1998, Goode et al. 1998, Straus et al. 1999, Skartlien and Rast 2000, Severino et al. 2001, Roth et al. 2010), but it is unclear which process dominates, how much power is radiated by each, and how well that power is coupled to the solar p-modes.

Unambiguous characterization of the p-mode sources requires separating local wave motions from higher amplitude compressible convective flows and p-mode coherence patches. This is theoretically challenging and observationally likely requires high spatial and temporal resolution (on the order of tens of kilometers at 15-second cadence) observations over a range of heights from the deep to the middle photosphere. A statistically significant number of individual events must be studied to assess their physical characteristics, frequency, and acoustic energy contributions, and thus their importance, and it is only with DKIST that these observational capabilities will become regularly available. Moreover, direct measurements of pressure fluctuations along with the temperature and velocity fields are needed to fully characterize the excitation mechanisms, and pressure sensitive spectral diagnostics are only now being developed in preparation for DKIST start of operations.

The precise nature of the p-mode excitation events – the efficiency, phasing and relative importance of the source contributions – is critical to both local and global helioseismic inferences. For global helioseismology, and local methods that employ the mode spectrum such as ring-diagram analysis (Haber et al. 2002, Gizon and Birch 2002 and references therein), precise determination of the modal frequencies and frequency shifts depends on the assumed power-spectral line shape with which the modes are fit. One source of systematic error in the measured solar p-mode frequencies is the unknown non-Lorentzian shape of the spectral lines. Line profiles vary with wavenumber and frequency depending on the source depth and physical properties (e.g., Gabriel 1995, Rast and Bogdan 1998, Nigam et al. 1998, Skartlien and Rast 2000). Similarly, local helioseismological deductions are sensitive to the phase relationship between the waves and their source. For example, travel-time kernels used in time-distance helioseismology depend on the assumptions about the source phasing and characteristics (Gizon and Birch 2002, Birch et al. 2004), and source properties may be particularly critical for multi-height local helioseismology if the source is spatially and temporally extended.

The photosphere also provides the lower boundary of the solar atmosphere which is stably stratified, and convective overshoot into the lower solar atmosphere drives internal acoustic-gravity waves that propagate upward. These waves are probes of the physical properties of that layer and may make a significant contribution to the solar chromosphere energy balance (e.g., Hindman and Zweibel 1994, Straus et al. 2008). The increased spatial resolution and temporal cadence of DKIST will allow higher spatial and temporal frequency waves to be observed and more extended high quality observation periods will enhance the frequency resolution possible, potentially allowing individual atmospheric gravity wave mode identification. Together these capabilities will allow detailed study of the convective driving of gravity waves, a process more broadly important in regions more difficult to observe, such as the base of the solar convection zone and in the interior of other stars. Moreover, since the solar atmosphere is highly magnetized, significant mode coupling likely occurs, and as this coupling depends on the orientation and strength of the local field, such observations have additional diagnostic value (Vigeesh et al. 2017, Vigeesh et 2019, see Section 3.3.4).

Critical science to address:

1. What dynamical events in the solar photosphere are associated with significant acoustic wave emission? What mechanisms are involved? How do acoustic wave sources evolve in time and with height? What are the phase relationships between velocity, temperature and pressure fluctuations as a

function of height and between the heights sampled by multi-height helioseismology?
Relevant Science Use Cases: 103

2. What is the occurrence rate of acoustic events in the solar photosphere? What is the total wave energy emitted by any individual event and how does this depend on the mechanisms underlying the emission?
Relevant Science Use Cases: 221

3. What physics underlies flare induced acoustic wave emission? Why do most solar flares not generate sun-quakes? How does the emitted wave power relate to the flare magnitude?
Relevant Science Use Cases: 100

4. What is the nature of the gravity wave field present in the lower solar atmosphere? Is there evidence for both traveling and standing wave components? How efficient is convective overshoot as a driving mechanism in the presence of differing magnetic field configurations?
Relevant Science Use Cases: 24

3.1.3 Magnetoconvective Modulation of the Solar Luminosity

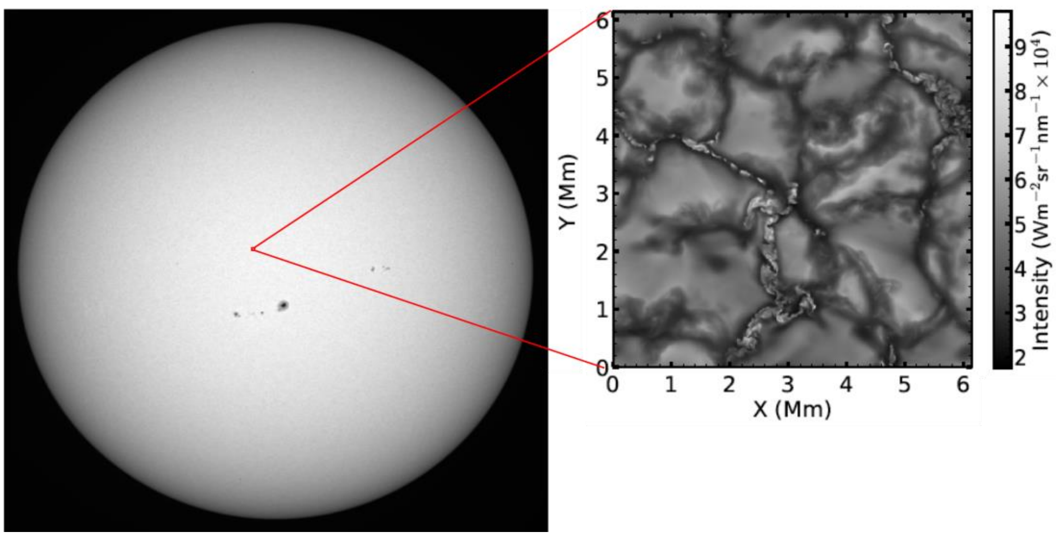


Figure 14. Understanding global solar irradiance variations requires measurements of the full solar disk because of the differing center-to-limb contributions of magnetic structures. However, there are significant differences in the magnetic morphology underlying pixels classified as the same structure at full-disk resolution. These differences influence the solar spectral irradiance and its variability with solar cycle. Image on left from the Precision Solar Photometric Telescope (courtesy M.P. Rast, http://lasp.colorado.edu/pspt_access/). Image on right from Rempel 2014, ApJ (reproduced with permission; copyright 2014 American Astronomical Society).

How do small scale magnetic flux elements contribute to global solar irradiance variations? How well do observed temperature and pressure stratifications within flux elements agree with atmosphere models employed for irradiance reconstruction?

Observational evidence suggests that the solar irradiance is modulated by changes of solar surface magnetism. Based on this, empirical techniques have been developed to reproduce total and spectral solar irradiance variations from observed changes in the coverage of magnetic features over the solar disk. Depending on their size and field strength, different magnetic features show different center-to-limb variation in different spectral regions. Thus both the disk location and disk coverage of the features are needed to model irradiance changes, and full-disk medium resolution (one to two arcsecond) observations are typically employed (e.g., Chapman et al. 1996, Krivova et al. 2003, Yeo et al. 2017).

Observations obtained at high spatial resolution (sub-arcsec) and radiative magnetohydrodynamic simulations, reveal the presence of magnetic structures not detectable in medium resolution data. Spectra modeled on the basis of full-disk pixel average features do not necessarily capture the radiative output of the underlying highly structured atmosphere, nor do they distinguish between differently structure atmospheres with the same low-resolution appearance (Röhrbein et al. 2011, Criscuoli et al. 2017, Peck et al. 2019). The mapping between full-disk imagery, the underlying small-scale structure, and spectral irradiance is only poorly understood. Understanding this mapping is critical for irradiance modeling, particularly spectral irradiance modeling (see Ermolli et al. 2013 and references therein), and there is still some uncertainty about whether full-disk magnetic structure based irradiance models can account for the observed spectral irradiance variations. In particular, both the sign and the magnitude of the spectral irradiance trends with solar cycle are controversial, with some authors reporting out of phase irradiance variation in key wavelength bands (Harder et al. 2009), while others report in phase variation across the spectrum (Wehrli et al. 2013). Out of phase variations have been explained in terms of a change in the mean photospheric temperature gradient with cycle, but which magnetic component contributes most to that change remains unclear, particularly when the contribution is disk integrated. Addressing these uncertainties requires the development of meaningful and reliable measurements of the photospheric temperature gradient (Faurobert et al. 2016, Criscuoli and Foukal 2017).

Unresolved magnetic elements are particularly important to the spectral output of the quiet Sun (Schnerr and Spruit 2011) and its center-to-limb profile (Peck and Rast 2015), against which the contrasts and contributions of magnetic structures is often measured. The quiet Sun covers the majority of the solar photosphere and typically its integrated irradiance contribution is taken to be constant in time, but due to the presence of possibly time varying unresolved magnetic structures this may not be the case. Measuring how the magnetic substructure of the quiet Sun actually changes with the solar cycle is a key DKIST capability. Beyond this, the radiative contributions of magnetic structures such as plage and faculae depend on the fact that they are composite (Okunev and Kneer 2005, Criscuoli and Rast 2009, Uitenbroek and Criscuoli 2011). Some facular pixels show negative continuum contrast in full-disk images even close to the limb, which may reflect their underlying substructure (e.g., Topka et al. 1997, Harder et al. 2019). Measuring the radiative properties of composite features and understanding the physical mechanisms that determine their spectral output is an important next step in the development of irradiance reconstruction techniques. These must be capable of statistically accounting for the contributions from a distribution of small-scale magnetic features unresolved in full-disk images.

Finally, the astrophysical implications of small-scale fields extend beyond the Sun. The spectral energy distribution of stars is a key fundamental input in the modeling of planetary atmospheres (e.g., Hu et al. 2012, Miguel and Kaltenegger 2014). In particular, UV radiation is responsible for the production and destruction of molecular species that are the anticipated biomarkers to be used in future NASA exoplanet atmospheric characterization missions. More critically, UV variability is important in determining the climate and habitability of (e.g., Scalo et al. 2007, France et al. 2013, Linsky et al. 2013, O'Malley-James and Kaltenegger 2019) and biogenic processes on (Buccino et al. 2007) extrasolar planets. While not sensitive to UV radiation directly, DKIST observations can be used to develop and test models of stellar chromospheres and/or proxies that reliably reconstruct stellar UV spectra from measurements obtained at longer wavelengths.

Critical science to address:

1. What is the temperature and pressure stratification within small-size magnetic elements, and how well do they agree with atmosphere models employed for irradiance reconstruction?
   Relevant Science Use Cases: 247

2. Which visible and IR spectral features are best correlated with UV variability?
   Relevant Science Use Cases: 129

3. How does sub-arcsecond magnetic structure evolve with the solar cycle, and what does this imply for irradiance variations?
   Relevant Science Use Cases: 247

4. How do unresolved (in full disk images) magnetic structures impact the spectral irradiance contribution of the quiet Sun?
   Relevant Science Use Cases: 49

5. How does unresolved magnetic substructure impact the spectral irradiance contributions of magnetic regions?
   Relevant Science Use Cases: 49

6. How can DKIST observations of spectra in both quiet and magnetic regions be used to constrain 3D radiative MHD simulations?
   Relevant Science Use Cases:

7. Can meaningful and reliable measurements of the photospheric temperature gradient be made and can these techniques be successfully adapted to full-disk observations?
   Relevant Science Use Cases: 54

3.1.4 Active Region Evolution and Sunspot Fine Structure

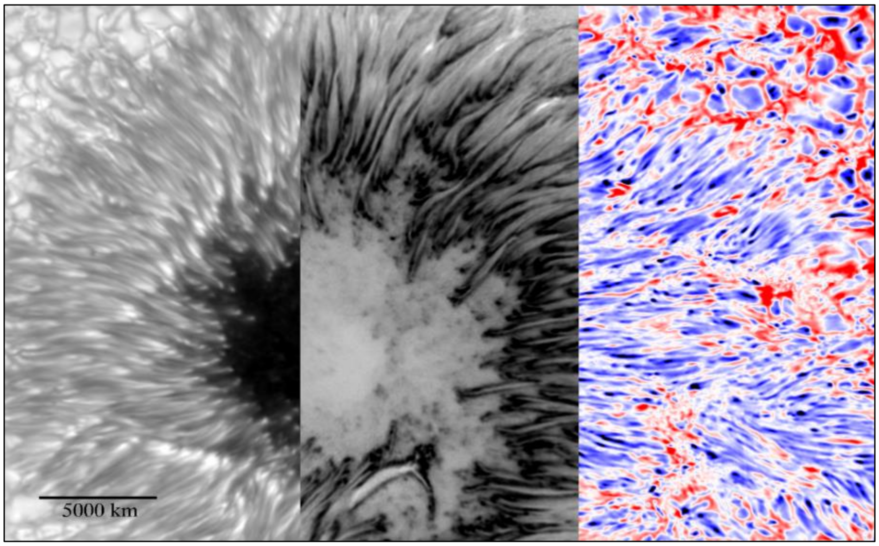


Figure 15. Sunspot in active region 11302, observed in intensity (left), circular polarization (middle), and line-of-sight velocity (right) with the CRISP instrument at the Swedish 1-m Solar Telescope on 28 September 2011. Penumbral fine structure is apparent in all three maps, showing details down to the diffraction limit of the telescope (0.15 arcsec). Lateral edges of penumbral filaments appear to harbor localized short-lived vertical downflows. Adapted from Esteban Pozuelo et al. (2015, 2016) ApJ (reproduced with permission; copyright 2015/2016 American Astronomical Society).

Why is magnetic flux concentrated into sunspots? How do sunspots form? Why do sunspots have penumbrae? How do penumbrae form? What is the dynamical and magnetic substructure of a sunspot umbra and penumbra, and what are the magnetic and dynamical links to the chromosphere, transition region and corona above?

Sunspots are the most prominent manifestation of strong magnetic fields in the solar atmosphere. They consist of a central dark umbra, within which the magnetic field is primarily vertically oriented, and a brighter penumbra, with weaker and more inclined fields. Both regions exhibit small-scale structure, such as umbral dots and penumbral filaments, and rich dynamics with mass flows and wave motions spanning the photosphere and chromosphere. The range of observed behaviors reflects the presence of magnetic fields of varying strengths and inclination angles, making sunspots an ideal laboratory for studying magneto-convective processes in complex magnetic field geometries.

However, despite significant advances over the past decades, observationally characterizing the field geometry and associated flow dynamics in sunspot umbrae and penumbrae presents formidable challenges that result from the small scales present, the low umbral photon counts and the difficulties in interpreting the distorted spectral line profiles observed (Borrero and Ichimoto 2011, Rempel and Schlichenmaier 2011). For example, we do not yet know the magnetic topology or flow structure of the penumbra at the smallest scales, nor how these vary with height in the atmosphere. In state-of-the-art numerical models (e.g., Heinemann et al. 2007, Rempel et al. 2009, Rempel 2011, 2012a,b), penumbral filaments result from overturning convection in highly inclined magnetic field regions, with the Evershed flow being the main flow component oriented in the radial direction. These models predict the existence of vertical downflows at the edges of penumbral filaments where the overturning plasma descends below the solar surface, but systematic study of such downflows on the Sun, for comparison with models, is very difficult due to their intrinsically small sizes (e.g., Esteban Pozuelo et al. 2015, 2016 and references therein). Supersonic vertical velocities at the outer end of penumbral filaments have been reported and associated with penumbral field lines dipping down below the solar surface (van Noort et al. 2013, Esteban Pozuelo et al. 2016), but similar flows have also been detected in the inner penumbra without relation to the Evershed flow (Louis et al. 2011). In both regions, very large field strengths (on the order of 7 kG and 5 kG respectively, compared to typical peak umbral values of 2 - 3 kG) have been associated with the high-speed flows (Siu-Tapia et al. 2017, Okamoto et al. 2018), but because the observed Stokes profiles show anomalous shapes, these determinations are uncertain. Multi-line, very high spatial resolution spectropolarimetric observations by DKIST will allow improved inference of both the field strengths and flow velocities, to determine the origin of the supersonic flows and the processes leading to local field amplification beyond umbral values.

More fundamentally, the formation of the penumbra itself (e.g., Rezaei et al. 2012) remains a mystery. The process lasts only a few hours, making it difficult to capture, and observations have not yet identified the mechanism triggering the process around a naked pore. There are indications that the chromospheric magnetic field may play a prominent role. Current sunspot simulations (Rempel 2012a,b) only form an extended penumbra if the field inclination at the top boundary is artificially enhanced. The nature and origin of a similar field on the Sun, if it exists, is unknown. Penumbrae are a robust feature of sunspots and are present under a wide range of conditions, whereas the presence of penumbrae in sunspot simulations requires this special boundary condition. This critical difference may be related to the fact that the dynamics of a penumbra during formation are observationally very different from those seen once it is mature. Instead of a regular Evershed outflow, 'counter' Evershed inflows, toward the umbra, are observed during formation. These inward directed flows turn into the classical radial outward Evershed flow as the penumbra stabilizes (Schlichenmaier et al. 2010). This important transition and other chromospheric precursors (Shimizu et al. 2012, Murabito et al. 2017) likely hold clues about the penumbral formation process, a process missing from the simulations. High-sensitivity DKIST measurements of the vector magnetic field and flow in both the photosphere and the chromosphere during penumbra formation will allow an assessment of the relative importance of photospheric magneto-convective processes and the evolution of overlying chromospheric magnetic fields.

In umbra, strong magnetic fields severely constrain convective motions, and numerical simulations suggest that umbral dots are the signature of convective plumes (Schüssler and Vögler 2006). Direct observational confirmation is difficult due to the small sizes and low contrast of the structures and the overall low photon counts in umbral regions. These conspire to dramatically reduce the signal-to-noise ratio of the observations, particularly when spectropolarimetric measurements are needed to determine the magnetic field configuration along with the flow. Interestingly, umbral dots may not be uniformly distributed throughout the umbra, with recent measurements suggesting the existence of very dark, fully non-convective umbral regions (Löhner-Böttcher et al. 2018). DKIST's off axis design and consequent low scattered-light properties will allow high-quality high-resolution Doppler and spectropolarimetric measurements of even the darkest regions of the umbra.

More generally, the magnetic topology and dynamics of sunspots in the chromosphere are poorly understood. Few high-spatial resolution observations extending from the photosphere up into the chromosphere with the required sensitivity have been made, so the connectivity with height is uncertain. Intense chromospheric activity is observed on small spatial scales above sunspots. Examples include umbral dynamic fibrils, penumbral microjets, penumbral bright dots, and jets at the edges of light bridges (e.g., Louis et al. 2008, 2014, Shimizu et al. 2009, Robustini et al. 2016, Tian et al. 2018). These phenomena likely involve shocks and/or magnetic reconnection, are expected to be a source of chromospheric heating, and have far reaching effects up into the overlying transition region and corona (e.g., Samanta et al. 2017, Tian et al. 2018 and reference therein). Rapid DKIST multi-line time series along with simultaneous observations with facilities such as IRIS, *Hinode*, Solar Orbiter, and SDO are necessary to untangle these diverse phenomena.

Finally, the disappearance and dissolution of sunspots is not well understood. High-cadence high-resolution magnetogram sequences are required to assess the role of small moving magnetic features which stream out from the penumbral border and merge with the surrounding network magnetic field (e.g., Hagenaar and Shine 2005). While these features seem to play a role in the slow disaggregation of the sunspot magnetic bundle, only limited measurements of their individual magnetic topologies and configurations and of their integrated contributions sunspot decay have been made (e.g., Kubo et al. 2007).

Critical science to address:

1. What is the small-scale magnetic and dynamic structure of the penumbra?
   Relevant Science Use Cases: 28, 32, 37, 56, 93, 142

2. How does a penumbra form? What is the role of chromospheric fields in penumbral formation? How do horizontal flows evolve during penumbra formation? Does the existence or nonexistence of a penumbra (pore to sunspot transition) depend on the global magnetic field configuration or just the local field strength?
   Relevant Science Use Cases: 73, 118

3. How do sunspots decay? What is the role of moving magnetic features?
   Relevant Science Use Cases: 92

4. What is the magnetic, dynamic and thermodynamic structure of the umbra?
   Relevant Science Use Cases: 8, 85, 124, 190, 192, 218, 252

5. What is the magnetic and dynamic structure of sunspot light bridges?
   Relevant Science Use Cases: 43, 288

6. What are the properties of the inverse Evershed flow and how does it arise?
   Relevant Science Use Cases: 56

7. What is the nature and origin of the dynamic phenomena observed in the chromosphere, transition region and corona above sunspots?
   Relevant Science Use Cases: 6, 8, 9, 116, 169

3.2 Flares and Eruptive Activity

3.2.1 Flare and Coronal Mass Ejection (CME) Precursors

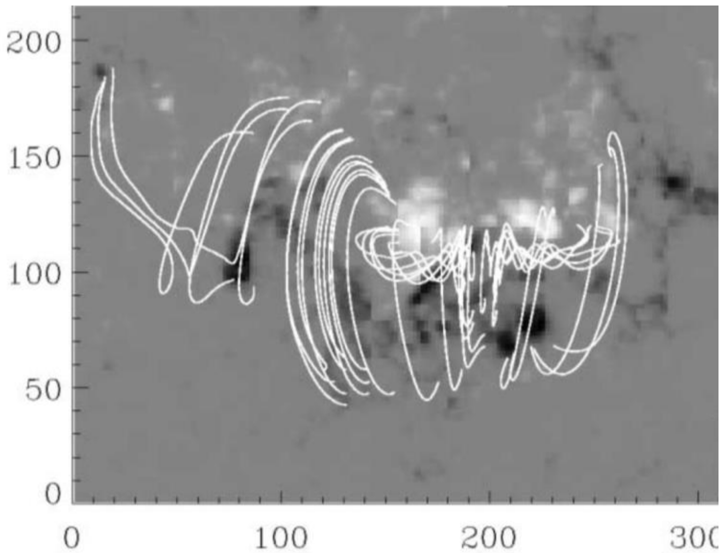


Figure 16. Nonlinear force-free magnetic field reconstruction of NOAA Active Region 9077 before the X5.7/3B (10:24 UT) flare on 2000 July 14. Based on vector magnetograms taken at the Huairou Station of the Beijing Astronomical Observatory. The photospheric longitudinal magnetogram is shown in the background for reference. Field lines trace the magnetic flux rope above the neutral line and the overlying arcade field. From Yan et al. 2001, ApJ (reproduced with permission; copyright 2001 American Astronomical Society).

What triggers coronal mass ejections and solar flares? What are the relative importance of mechanisms proposed, such as flux emergence, current sheet instabilities and small scale flux cancellation? When, where and how do large-scale flux ropes form?

Solar flares and coronal mass ejections result when magnetic energy stored in the solar corona is released. The release is sudden (over a few to tens of minutes) compared to the timescale over which energy is built up and stored (many hours to days, e.g., Schrijver 2009). Despite decades of study, the physical mechanisms that trigger flares and/or CMEs remain elusive. Understanding the conditions that lead up to a CME or flare and identifying the trigger mechanisms which initiate them are central to developing the predictive capabilities necessary for successful forecasting of their space weather impacts.

While no "necessary and sufficient" conditions for flaring or CME initiation have been identified, various precursor phenomena have been reported to occur in chromospheric and coronal observations in the minutes to hours before a flare or CME (for reviews see e.g., Chen 2011, Shibata and Magara 2011, Green et al. 2018). These include multiple small-scale brightenings in Hα (Martres et al. 1977) and/or soft x-ray (e.g., Tappin 1991), plasmoid ejection (e.g., Hudson 1994, Kim et al. 2009), S-shaped or inverse-S (sigmoidal) soft x-ray emission (Canfield et al. 1999), and the slow rise and darkening of chromospheric filaments known as filament "activation" (e.g., Martin 1980, Schuck et al. 2004). There is also some evidence for spectral line broadening before flares (e.g., Harra et al. 2009, Woods et al. 2017) and pre-flare thermal X-ray enhancements without evidence of non-thermal particles (Benz et al. 2017).

The limited spatial resolution, cadence and wavelength coverage of many previous observations have hampered efforts to understand the physical nature of these precursor signals, but recent high-resolution observations with the 1.6-m Goode Solar Telescope (Wang et al. 2017b) suggest that very small-scale polarity inversions, currents and magnetic loops in the low atmosphere are associated with main flare initiation. Magnetohydrodynamic simulations also show that small, opposite-polarity bipoles or reversed-magnetic-shear structures introduced into a highly sheared, larger-scale field can destabilize the field (e.g., Kusano et al. 2012, Muhamad et al. 2017). Reconnection between these small magnetic perturbations and pre-existing sheared loops can result in flux rope eruption and main flare reconnection.

Additionally, it has been known for some time that, at least in some cases, the onset of a coronal mass ejection can precede flaring by several minutes, with the CME coinciding with precursor indicators. This suggests that some precursors may serve as an early signature of erupting fields. Current CME models (Toriumi and Wang 2019) can be grouped into two broad classes: flux rope models (Low 1996, Lin and Forbes 2000, Fan and Gibson 2007) which assume that a flux rope exists before the eruption onset, in which case precursors reflect the flux rope's sudden rise, and sheared magnetic arcade models (van Ballegooijen and Martens 1989, Mikic and Linker 1994, Antiochos et al. 1999, Longcope and Beveridge 2007, Karpen et al. 2012) which postulate that the flux rope is formed during the initial stages of the flare, implying that precursor signatures are the manifestation of the formation process itself. Not all models are consistent with this dichotomy, however. For example, the flux cancellation model (e.g., Amari et al. 2010) involves elements of both. Careful study of flare precursors will thus inform the CME eruption models.

Critical science to address:

1. Do precursors precede all solar flares or only a subset of flares? Which small-scale precursors, if any, are uniquely associated with CMEs?
   Relevant Science Use Cases: 38, 57

2. Are particular thermal or magnetic structures associated with the precursor emission? How do they form? What is their spatial structure and how does it evolve with time?
   Relevant Science Use Cases: 36, 57

3. What is the connection between flare precursors (brightenings and/or flows) and magnetic channel structures?
   Relevant Science Use Cases: 11, 95, 138

4. What is the role of small-scale magnetic reconnection in triggering flares and eruptions?
   Relevant Science Use Cases: 143, 189, 225

5. Do shearing, converging, and rotational flows contribute to the build-up of magnetic free energy and trigger eruptions?
   Relevant Science Use Cases: 99, 106, 133, 200, 251

6. How do observed precursors inform existing flare and eruption models? Are they critical to the flux rope formation or flux rope release processes?
   Relevant Science Use Cases: 38, 57, 226

3.2.2 Changes in Magnetic Field Associated with Flares and CMEs

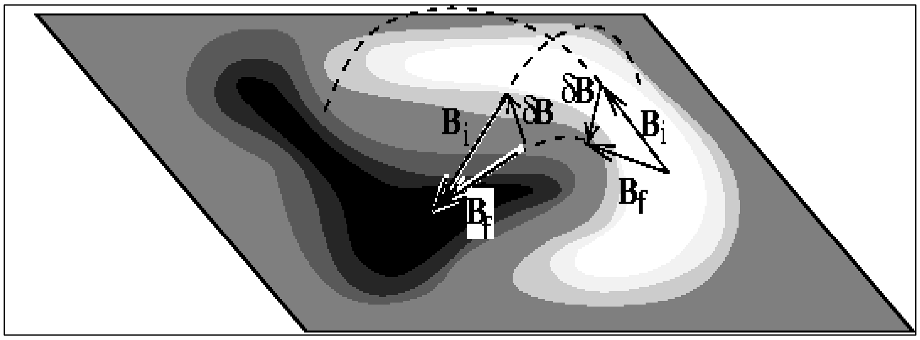


Figure 17. Photospheric magnetic vector field associated with a flare. The initial photospheric field vectors B_i, the change δB as a result of coronal restructuring during the flare/CME, and final state B_f. The associated changes in the connectivity of the coronal field are represented by the dashed lines. The changes agree with the expectation that the photospheric field should become more horizontal. Adapted from Hudson et al. 2008, ASP Conf. Series.

What are the differences between the pre- and post-flare/CME magnetic field configuration? How do the magnetic field changes depend on height and time? What are the theoretical and practical implications of these changes? For example, how are flare emission and CME energy related to the magnetic restructuring?

Flares and coronal mass ejections are one of the most spectacular manifestations of solar activity (e.g., Webb and Howard 2012). Flares occur when stressed magnetic fields in the low corona abruptly reconfigure, accessing a lower energy state. The field reconfiguration propagates downward into the lower and denser atmospheric layers. Resulting changes in the photospheric magnetic field may be either transient or longer lived (Sudol and Harvey 2005, Wang and Liu 2015), and the rapid conversion of magnetic energy into plasma heating and bulk motion causes changes in coronal and chromospheric active region emission over a wide range of wavelengths. Flares are often accompanied by CMEs and the onset of CMEs has been associated with flaring, although flares without CMEs and CMEs without flaring also occur.

Direct measurement of the pre-flare/pre-CME magnetic field and the post-flare/post-CME reconfigured field is scientifically significant and of practical value, contributing to our understanding of the underlying reconnection processes, with possible implications for plasma confinement. CMEs are a key contributor to the interplanetary plasma dynamics that causes transient disturbances at Earth. They drive interplanetary shocks, an important source of solar energetic particles, and are a major contributor to space weather events at Earth, where they interact with the Earth's magnetosphere. While all CMEs are large plasma-containing magnetic structures expelled from the Sun, they exhibit a variety of forms. Some have the classical "three-part" structure: a bright front, interpreted as compressed plasma ahead of a flux rope, along with a dark cavity with a bright compact core (Riley et al. 2008 and references therein). Others display a more complex geometry and can appear as narrow jets (Webb and Howard 2012). The underlying magnetic field morphology plays a critical role in a CME's geoeffectiveness.

Direct measurement of the pre- and post- flare/CME magnetic field morphology is very challenging. The magnetic field changes often occur on very short timescales, and propagate quickly through the layers of the solar atmosphere. Outside of the photosphere (Wang and Liu 2015, Wang et al. 2017b, Petrie 2019), low photon counts make it hard to achieve the needed sensitivity at the required cadence, and multi-wavelength, full-Stokes flare studies are consequently difficult (Kleint 2017). It is such studies that are, however, key to quantitative knowledge of flare and CME magnetism. While existing white-light CME observations provide information on the mass content of the CME, and x-ray and EUV observations provide diagnostics of the flare and CME plasma thermal properties, regular measurement of magnetic field strength and orientation are essential to the further development and validation of eruption models. This requires DKIST capabilities.

Importantly, DKIST on-disk, limb and off-limb capabilities will allow quantitative assessment of the relationship between plasma sheet observations and reconnection current sheet properties. Current sheets are an important component of most solar flare models. In particular, large-scale current sheets are an essential element of post-CME flaring. Thin off-limb high-density high-temperature plasma structures are sometime observed above limb flares (e.g., Savage et al. 2010, Liu 2013, Seaton et al. 2017), and spectroscopic observations have led to detailed understanding of the plasma properties within these structures (Li et al. 2018, Warren et al. 2018) with implications for the underlying reconnection and field reconfiguration processes (Longcope et al. 2018). Direct measurements by DKIST of the magnetic field, along with the thermodynamic properties and dynamic behavior of the plasma, in and around plasma sheets will allow more accurate assessments of the amount of flux opened by an eruption, better understanding of the evolution of the post-eruption field, and clarification of the mechanisms underlying the slow (sub-Alfvénic) outflows observed during flare reconnection events (e.g., Wang et al. 2017a and references therein).

The DKIST instrument suite will allow regular multi-wavelength spectropolarimetric measurements at high temporal cadence and spatial resolution in the solar photosphere, chromosphere and low corona. These will enable the assessment of the local magnetic field properties with good sensitivity and the determination of flare- and CME-related changes in that field simultaneously over several heights in the solar atmosphere. When coupled to x-ray and EUV/UV observations from available and future space observatories, DKIST will, for the first time, allow us to directly connect coronal magnetic field evolution to flare and CME emission and plasma properties. It will enable the measurement of the magnetic field reconfiguration that occurs at the origin of space weather events.

Critical science to address:

1. What are the basic properties of the magnetic field changes during flares and CMEs? Do the changes represent changes in magnetic pressure or tension, or solely inclination? What are the temporal and spatial scales of the field changes?
   Relevant Science Use Cases: 29, 48, 81, 147, 201, 202, 209, 210

2. How do the field changes vary with height during flares/CMEs? Is there a coherent organization, correlation, or causal connection between the changes over the different atmospheric layers? Are changes in the electric current and helicity correlated across the different atmospheric layers? Are the field changes widespread or isolated?
   Relevant Science Use Cases: 29, 36, 20, 81, 147, 204, 209, 210, 273

3. How do magnetic field changes during flaring or eruption relate to the physical structure of an active region as a whole? Is there a link between the structure of an active region as a whole and the likelihood it will erupt?
   Relevant Science Use Cases: 36, 48, 201

4. How is the transfer of energy and momentum between atmospheric layers related to the observed reconfiguration of the magnetic field? How fully can we quantify the energy/momentum transfer in an eruptive flare/CME?
   Relevant Science Use Cases: 48, 77, 81, 202, 212

5. How is flare emission related to magnetic restructuring? Do flare ribbon patterns relate to particular magnetic field changes in the chromosphere? How does the X-ray flux depend on the size, direction and degree of organization of the field changes?
   Relevant Science Use Cases: 48, 77, 98, 204, 212

6. How is flare emission related to seismic waves excitation? How well do magnetic field and Lorentz force changes correlate with the size and locations of seismic events?
   Relevant Science Use Cases: 100, 167

7. What do chromospheric brightening and coronal dimming tell us about the nature of reconnection in the corona during an eruption? How are supra-arcade downflows related to other reconnection-related phenomena?
   Relevant Science Use Cases: 77, 98

8. How do the main components of a CME evolve magnetically, dynamically and thermally? What can we learn about the physics of reconnection in the current sheet trailing a CME using off-limb spectroscopy and polarimetry? How similar is it to reconnection in the Earth's magnetotail?
   Relevant Science Use Cases: 89, 91, 203, 215

3.2.3 Energy Deposition during Flares

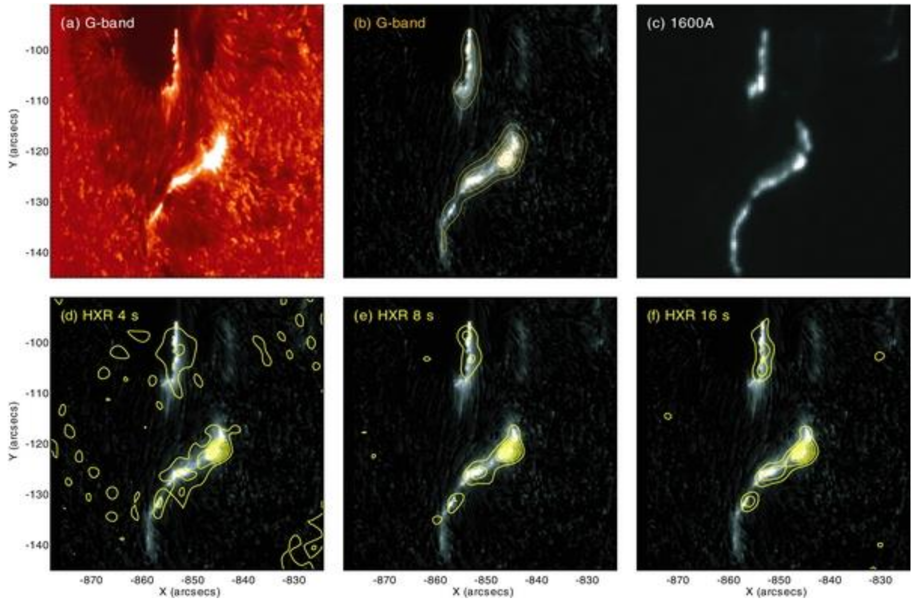


***Figure 18.* Optical flare ribbons at very high spatial resolution during hard x-ray peak. (a) Hinode/SOT G-band, (b) same image with pre-flare subtracted, (c) TRACE 160nm image taken at almost the same time, and (d) through (f) RHESSI contours (levels 15%, 30%, 45%, 60%, 75%, 90% of the peak flux)in the 25 – 100 keV range for 4, 8 and 16s time integrations. From Krucker et al. 2011, ApJ (reproduced with permission; copyright 2011 American Astronomical Society).**

Waves or beams? How is flare energy transported from the corona to the chromosphere? Where are nonthermal particles produced? What is the origin of the flare optical continuum? How compact are flare kernels? What explains the large widths of chromospheric flare emission lines?

Flare energy, liberated in the corona, is transported to and dissipated in the chromosphere and upper photosphere, resulting in localized heating and intense bursts of radiation across the electromagnetic spectrum. This leads to chromospheric expansion and drives mass motions, upward-moving chromospheric 'evaporation' and downward-flowing 'condensation'. In some locations, hard x-ray (HXR) bremsstrahlung emission is observed, revealing the presence of non-thermal electrons containing a significant fraction of the total flare energy. Ultimately, the majority of a flare's radiated energy is emitted in near-UV and optical lines and continua (Woods et al. 2004), and these provide rich diagnostics of the energy transport and deposition processes.

One of the most longstanding and important questions in flare physics is the origin of the optical continuum, which was first observed during the famous Carrington-Hodgson flare of 1859 and generally accounts for a large fraction of the total flare emission (Neidig 1989). There are two primary candidates (e.g., Heinzel et al. 2017): the optical component of an enhanced black body (photospheric H- continuum enhancement) or hydrogen recombination continuum (Paschen and Balmer). It is difficult to disentangle these two mechanisms (Kerr and Fletcher 2014), but doing so would allow height discrimination of the flare energy transport and deposition mechanisms, since the former implies penetration of significant amount of energy down into the photosphere while the latter carries information about the ionization state evolution higher up in the chromosphere. Additionally, since the observed continuum emission carries away a large fraction of the flare energy, making it unavailable to drive a dynamical response, which mechanism is responsible is relevant in determining which flares are important acoustic sources.

High time-cadence high spatial-resolution observations may be able to distinguish these processes (Hudson et al. 2006, Xu et al. 2006, Fletcher et al. 2007, Martínez Oliveros et al. 2011, 2012, Kleint et al. 2016, Yurchyshyn et al. 2017). The standard flare model suggests that flare energy is transported from the corona to the chromosphere by beams of non-thermal electrons. The only way to significantly heat the photosphere is by reprocessing the electron beam energy via backwarming by Balmer and Paschen continuum radiation originating in the mid to high chromosophere (Allred et al. 2005). Radiation-hydrodynamical (RHD) models can predict the light curves of Balmer and Paschen continua consistent with time evolution of the electron-beam energy deposition (Heinzel and Kleint 2014, Kowalski et al. 2015). The Balmer limit is not observable with the DKIST, but as with the Balmer limit and lines (Kowalski et al. 2017b), observations of Paschen line broadening near the Paschen limit (820.5 nm) and the presence or absence of a continuum jump there (Neidig & Wiborg 1984) can help constrain the charge density and optical depth of the flaring solar chromosphere for comparison with predictions of differing transport and heating mechanisms (Kowalski et al. 2015). Achieving high spatial resolution along with spectral resolution is critical. Unequivocal evidence for dense chromospheric condensations during the impulsive phase of solar flares has been established (Kowalski et al. 2017a), and intensive localized heating may be key to the interpretation of flare spectra.

While the standard flare model invokes energy transported from the corona to the chromosphere by beams of non-thermal electrons, the dominant energy transport mechanism is still under debate. Chromospheric heating to megakelvin temperatures can start before observable HXR emission begins (Fletcher et al. 2013), and the apparent low height of HXR and optical sources during limb flares appears inconsistent with the expected penetration depths of accelerated electrons (Hudson et al. 2006, Krucker et al. 2010, Martínez Oliveros et al. 2012). Moreover, the electron beam densities implied by the HXR intensities observed require that a very large fraction of the pre-flare coronal thermal electron population be accelerated (Krucker et al. 2010, Fletcher et al. 2013, Krucker and Battaglia 2014), so it is unclear whether the electron beam requirements can be met at coronal densities. Finally, issues involving the origin, amplitude and stability of the return currents required to support these dense coronal beams are not fully resolved (Alaoui and Holman 2017). Together these imply that additional modes of energy transport may be required.

Possible mechanisms include ion beams (Hurford 2006, Zharkova and Zharkov 2007), heat conduction (Longcope 2014, Graham et al. 2015, Longcope et al. 2016) or Alfvén waves (Russell and Fletcher 2013, Reep and Russell 2016). Each produces a different energy deposition rate as a function of height in the chromosphere, impacting the local atmospheric properties (e.g., Kerr et al. 2016), its temperature, density, bulk and turbulent velocities, ionization fractions and atomic level populations as a function of time, thus producing potentially unique spectral diagnostics. DKIST's unique capabilities, working hand-in-hand with advanced radiation hydrodynamics simulations, will be critical to differentiating between these proposed energy deposition mechanisms.

Critical science to address:

1. To what depth do accelerated electrons penetrate the lower solar atmosphere?
   Relevant Science Use Cases: 44, 195, 270

2. What is the origin of the optical continuum in flare spectra? What do observations near the Paschen limit tell us about the properties of the flaring solar chromosphere? What role do chromospheric condensations play?
   Relevant Science Use Cases: 122, 198, 207, 270

3. How highly localized (spatially and temporally) are the sites of impulsive energy deposition? Do the fundamental scales fall below those resolvable by previous studies?
   Relevant Science Use Cases: 58, 97, 195, 207

4. Can we find an unambiguous impact polarization signature in chromospheric spectral lines resulting from the impact of highly collimated particle beams on the dense chromosphere? Can these measurements be used to learn about magnetic field nonuniformity by assessing pitch angle de-collimation of the beam?
   Relevant Science Use Cases: 29, 58, 123, 207

5. Can we observe the penetration of the "flare disturbance" at various heights / densities within the lower solar atmosphere, and derive from their relative timing a sequence of causal phenomena to relate to the main mechanism of energy transport?
   Relevant Science Use Cases: 58, 165, 202

6. Can we directly observe waves in the chromosphere before the flare's occurrence? Will signatures such as non-thermal widths of spectral lines be useful to identify them?
   Relevant Science Use Cases: 34, 167

7. What is the dynamical response of the lower solar atmosphere to energy deposition and under what circumstances does this result in seismic wave excitation?
   Relevant Science Use Cases: 23, 100, 197

3.2.4 The Fundamental Structure and Evolution of Flare Ribbons

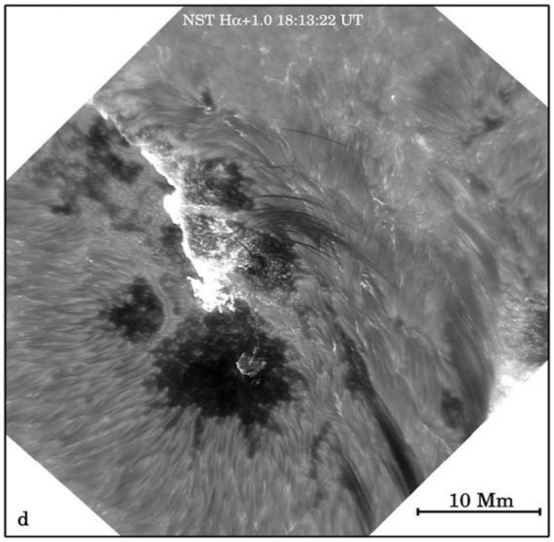


***Figure 19:** Image of a flare ribbon captured in Hα + 1 Å with the 1.6-m Goode Solar Telescope, showing the ribbon crossing the sunspots, coronal rain in the post-flare loops and fine-scale brightenings at the footpoints of the falling plasma in the chromosphere. Courtesy Jing et al. 2016, Nature Sci. Reps.*

What is the mapping between the evolution of the flare ribbon and the reconnection process? What does this tell us about changes in the overlying three-dimensional field geometry and the acceleration and heating processes?

Flare ribbons are localized elongated brightenings in the chromosphere and photosphere. They are the sites of energy deposition at the conjugate foot points of the set of magnetic loops involved in flare reconnection. The brightening, due to the increased temperature of the flaring chromospheric plasma, is believed to be primarily due to collisional heating by flare-accelerated non-thermal electrons, though questions about the viability of this mechanism remain (see §3.2.3 above). The brightest parts of a flare ribbon can be subject to localized heating of 10^{12} ergs cm^{-2} s^{-1} (Krucker et al. 2011), on the order of 100,000 times the energy flux required to heat the quiet chromosphere. The detailed structure and evolution of flare ribbons can provide insight into the fundamental length and timescales of flare energy deposition and the link between particle acceleration and the evolving coronal magnetic field.

Flare ribbons occur in pairs that show a characteristic temporal evolution, reflecting changes in the overlying magnetic field. Conjugate ribbons separate in time, mapping out the progress of coronal magnetic reconnection. When observed simultaneously with the photospheric or chromospheric magnetic, the motions of ribbons as a whole, and of the individual sources composing them, can be used to obtain the coronal magnetic reconnection rate (Qiu et al. 2002, Isobe et al. 2002, Fletcher 2009, Liu et al. 2018). Distinct brightenings are often observed to run along the ribbons, and have been linked to properties of three-dimensional 'slip-running' reconnection (Dudík et al. 2014). Moreover, since the evolution of the flare ribbon reflects changes in the large-scale coronal magnetic field, careful observations can inform our understanding of the dynamics of eruptive (CME) events (e.g., Sun et al. 2017, Hinterreiter et al. 2018).

At small scales, flare ribbons are composed of numerous small sources and show complex structure that appears differently at different wavelengths, reflecting structured energy deposition. In line cores, flare ribbons exhibit a stranded structure, as if a small portion of numerous magnetic loop tops in the chromosphere are illuminated (e.g., Mikula et al. 2017). In the visible and infrared continuum or in the far wings of spectral lines, however, individual sources are very compact, with clear evidence for sub-arcsecond (100 km) structure suggesting very small scales for individual flaring magnetic loops and current dissipation (Sharykin and Kosovichev 2014, Jing et al. 2016). The sizes of the sources vary with wavelength, and this has been interpreted as being due to the narrowing with depth of the chromospheric magnetic flux tube along which energy is being deposited (Xu et al. 2012). Additionally, the individual source sites display a 'core-halo' continuum intensity sub-structure (Neidig et al. 1993, Hudson et al. 2006, Xu et al. 2006, Isobe et al. 2007a). This may be a signature of spatially varying heating across a magnetic structure or of two heating components, direct heating by energetic particles in the core and indirect heating by radiative backwarming (one of the mechanisms proposed to account for near-UV and optical continuum emission in flare kernels) in the halo (Neidig et al. 1993, Xu et al. 2006).

Flare kernels are the very brightest sources in flare ribbons, and are the locations most clearly associated with strong hard X-ray emission generated by non-thermal electrons. In the very earliest stages of a flare, these kernels can expand significantly on timescales less than one second (Xu et al. 2010), possibly as a result of reconnection spreading through a highly-stressed region of the coronal magnetic field. As discussed above, flare ribbons themselves spatially propagate as the site of reconnection changes. At the leading edge of a propagating ribbon, sites of particularly large Doppler line broadening are observed (Jing et al. 2016, Panos et al. 2018), suggesting that the strongest energy input into the lower chromosphere and photosphere occurs at the locations of the most recently reconnected field. Furthermore, on arcsecond scales, flare ribbon sub-structure is well-aligned with regions of high vertical photospheric current density (Janvier et al. 2014). DKIST will allow even higher resolution (sub-arcsecond) measurements of these spatial and temporal correlations. Such measurements are critical to determining the flare energy flux into the solar chromosphere, a key parameter of numerical simulations. Finally, DKIST may allow regular observation of the fundamental scales of flare ribbon kernels (Graham and Cauzzi 2015), informing our understanding of the scales at which discrete coronal reconnection occurs.

Critical science to address:

1. What is the fundamental size of the smallest flare sources?
   Relevant Science Use Cases: 44, 57, 58, 195, 196, 204, 231

2. How well can flare ribbon evolution constrain our understanding of coronal mass ejection (CME) field evolution and dynamics?
   Relevant Science Use Cases: 154

3. What is the correlation between the magnetic field and the intensity distribution of sources within a flare ribbon? How are the energy deposition processes and local properties of the magnetic field related?
   Relevant Science Use Cases: 29, 36, 48, 57, 201

4. How does the substructure in flare ribbons and flare kernels (e.g., core/halo sizes) vary with observation wavelength?
Relevant Science Use Cases: 57, 204

5. How do flare ribbons and their substructures evolve along with the underlying magnetic field? What does this tell us about changes in the overlying three-dimensional field geometry?
Relevant Science Use Cases: 29, 48, 57, 227

6. How are the flare kernels observed in the photosphere and lower chromosphere correlated in space and time with hard x-ray sources that reveal the location of strong electron acceleration? What is special about these locations? Why does hard x-ray emission occur at the discrete locations observed?
Relevant Science Use Cases: 58, 123, 204

3.3 Magnetic Connectivity through the Non-Eruptive Solar Atmosphere

3.3.1 Mass and Energy Cycle in Low Solar Atmosphere

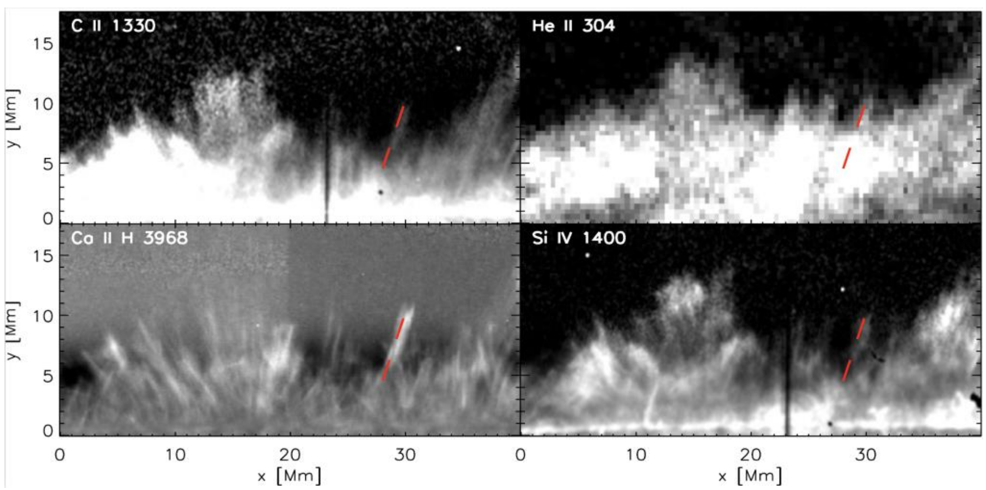


Figure 20. Simultaneous images of spicules in Ca II H 3968 Å (Hinode), C II 1330 Å and Si IV 1400 Å (IRIS) and a He II 304 Å (SDO/AIA). Future coordinated observations with DKIST, ALMA and other observatories (e.g., SDO/AIA) are key to addressing unresolved questions about spicule heating and their role in the mass and energy balance of the transition region and corona. Image from Skogsrud et al. 2015, ApJ (reproduced with permission; copyright 2015 American Astronomical Society).

How important are spicules, and other jet-like phenomena, to the chromosphere-corona mass cycle? What is the role of spicule heating in the coronal energy balance? Can we characterize and model the coronal rain phenomenon well enough to understand its role as a return flow?

All coronal plasma has its origins in the lower solar atmosphere, with the coronal mass budget determined by a balance between upward (e.g., evaporative or eruptive flows) and downward (e.g., coronal rain) mass transport. As many processes appear to be involved, the outstanding challenge is to determine which of them dominate the transfer of mass between the cool chromosphere and hot corona in regions of differing magnetic topology. Previous observations have provided a partial view of the mass cycle, but the small spatial and temporal scales involved have significant hindered advances. DKIST will provide a more complete view, especially when combined with coordinated observations using space-based observatories like IRIS, *Hinode* and Solar Orbiter, or the ground-based radio telescope array ALMA, which allows complementary temperature and soon polarization diagnostics of the solar chromosphere (see Yokoyama et al. 2018).

Jets are an important dynamical process in the chromosphere-corona mass cycle. They are observed to have a wide range of spatial scales, ranging from spicules (with widths of a few hundred kilometers), to jetlets (~1,000 km widths) to coronal jets (widths of a few thousand kilometers). Many questions remain about how they are formed and how efficiently each type injects plasma into the solar atmosphere.

Spicules appear to be the most ubiquitous jet-like feature in the solar chromosphere. They are highly dynamic, vary on time scales of 10-30s, and are finely-structured, with widths <300 km. They violently propel plasma upwards into the solar atmosphere at speeds of 10-200 km/s and may, either alone (De Pontieu et al. 2011) or in combination with other slower types of jets (e.g., Morton 2012), play a significant role in the mass and energy balance of the corona and solar wind. Despite having been observed over a wide range of wavelengths from EUV to visible, we do not yet understand the mechanism(s) responsible for spicule formation, how they are heated, often to transition region temperatures or higher, the role magnetic waves play in their dynamic evolution, or their full impact on the mass and energy balance of the outer solar atmosphere (Pereira 2019). Spicule induced mass transport to coronal heights is estimated by some authors to be two orders of magnitude larger than the solar wind mass flux (Beckers 1968, Sterling 2000), but others suggest that their role is rather limited compared to that of more uniform chromospheric evaporation due to small scale flaring processes (e.g., Klimchuk 2012). In fact, there is still some debate about the fundamental nature of spicules, i.e., whether they are indeed jets of accelerated plasma, or whether they correspond to warped two-dimensional sheet-like structures (Judge et al. 2011, 2012, Lipartito et al. 2014) and whether only one or multiple spicule types exist (De Pontieu et al. 2007a, Zhang et al. 2012).

DKIST observations in a variety of chromospheric spectral lines will provide revolutionary new views of the fine-scale structure, the magnetic and electric fields (Anan et al. 2014) and the thermodynamic evolution of spicules and other chromospheric jets. At high cadence (<20s), DKIST observations will be able to fully capture their dynamic evolution, and DKIST's ability to make simultaneous measurements of chromospheric and photospheric magnetic fields and flows will provide critical insight into the underlying initiation mechanism(s), clarifying the roles and relative importances of reconnection (see §3.3.3), magnetic tension amplification by ion-neutral coupling (Martinez-Sykora et al. 2017), micro-filament eruption (Sterling and Moore 2016) and other processes that have been proposed as important to spicule and larger-scale jet initiation.

While jet-like features are perhaps the most prominent illustration of the chromosphere-corona mass cycle, it is still not clear that they are the most important to the mass and momentum balance of the low solar atmosphere. Perhaps more gentle processes play an important role? One sensitive signature of mass transport, momentum flux and wave heating is the degree of elemental fractionation, i.e. the degree to which elements of low (lower than about 10eV) first ionization potential (FIP) are enriched or depleted compared to other elements (the FIP or inverse FIP effects; Meyer 1985a,b, Feldman 1992, Feldman and Laming 2000, Laming 2015). Because FIP fractionation is sensitive to the plasma's thermodynamic and electromagnetic properties it is subtly different depending on the atmospheric height of the region considered, the magnetic field geometry (open or closed) and connectivity, the plasma heating mechanisms in play, and the bulk plasma flow speed and dominant MHD wave modes present (Laming 2015). In fact, spicules themselves may be responsible for the absence of the FIP effect at temperatures below 10^6 K on the Sun (Laming 2015 and references therein). These sensitivities, when understood well, allow FIP fractionization measurements to be used to both constrain the solar wind source and determine the connectivity between in-situ heliospheric measurements and the source regions (e.g., Geiss 1995, Parenti et al. 2000, Brooks and Warren 2011, Brooks et al. 2015, Baker et al. 2015). Coordinated observations (§3.4.5) that combine chromospheric observations by DKIST, including polarization measurements to determine the magnetic field, with measurements of the heliospheric plasma properties by Solar Orbiter and Parker Solar Probe, will allow unprecedented identification and characterization of the underlying sources of the fast and slow solar wind.

Another key aspect of the chromosphere-corona mass cycle is the return flow from the corona to the lower atmosphere. One component of this is prominently visible at the solar limb as coronal rain, a finely structured and multi-thermal flow that appears to be driven by cooling instabilities (eg., Antolin and Rouppe van der Voort 2012, Antolin et al. 2015b, Mason et al. 2019, and references therein). The descending material is seen in the off-limb active corona at transition region and chromospheric temperatures and can be observed in what are typically chromospheric optical spectral lines (Kawaguchi 1970, Schrijver 2001, Antolin et al. 2010). One-dimensional hydrodynamic models (Müller et al. 2003) can reproduce catastrophic cooling events and rain-like downflows using steady footpoint-concentrated heating. Similarly, 2.5-dimensional and recent three-dimensional simulations show fine-scaled rain blobs forming even when a spatially smooth but localized footpoint-concentrated heating function is applied (Fang et al. 2013, Moschou et al. 2015). These studies support other observational evidence for footpoint-concentrated heating in active regions (Aschwanden 2001), and makes coronal rain observations important, not just to understand the return flow mechanism, but because the fraction of thermally unstable plasma in a coronal loop system can potentially be used to constrain heating mechanisms (Antolin et al. 2010). Progress depends on successfully leveraging the resolution and multi-wavelength capabilities of DKIST to unravel the complex, evolving, multi-thermal behavior of the rain. The rain's thermal state has been difficult to characterize, with the hydrogen likely out of ionization equilibrium and other elemental ionization ratios poorly constrained (Antolin et al. 2010, 2015b). Again, the implications extend beyond understanding the coronal rain itself. With its mix of hot (ionized) and cold (neutral) gas, coronal rain is an ideal laboratory to study the ion-neutral interaction effects, such as ambipolar diffusion, that are expected to play a key role more broadly in the dynamics of the partially ionized chromosphere.

Both models and observations of coronal rain are still quite limited in spatial resolution. Current observations do not yet resolve the peak in the coronal rain elemental width distribution. We thus do not have a full accounting of the total coronal rain drainage rate. An additional constraint on the thermally unstable mass fraction in a coronal loop system can come from measurement of loop oscillations. Coronal rain condensations are coupled to the magnetic field lines and are observed to track the oscillatory motion of the loops (Kohutova and Verwichte 2016). The evolution of the oscillation parameters over a complete thermal cycle can be used to deduce the fraction of the loop plasma mass that becomes thermally unstable. Comparing this seismic estimate with direct measurement of the total mass of the condensations is not only a consistency check, but will also indicate how much of the coronal rain mass remains unresolved (Froment et al. 2018), thus providing constraints on the fundamental spatial scales of coronal rain and the fine-scale structure of coronal loops.

Finally and critically, we do not yet have measurements of the vector magnetic field or even constraints on the magnetic field intensity within rain producing loop systems, a fundamental parameter for characterizing the underlying instability (i.e., Martínez-Gómez et al. 2019). Recent studies have been able to exploit the Zeeman effect in the CaII 854.2 nm chromospheric line to assess the presence of strong fields (100 - 300 G) for the case of bright post-flare loops (Kuridze et al. 2019), but this method might not be viable in more quiescent cases which are characterized by much weaker fields and lower intensities. However, significant progress is feasible if Hanle diagnostics in lines of neutral Helium such as the He I 1083 and 587.6 nm multiplets are employed (Schad, 2018). Joint polarimetric observations of these He I multiplets with DKIST first-light instrumentation may provide a first view of the sub-arcsecond spatial scale weak magnetic field (with a sensitivity of a few Gauss) in more quiescent loop systems.

Critical science to address:

1. What are the physical conditions (temperatures, flows, densities, magnetic flux density) in spicules and other jets?
   Relevant Science Use Cases: 5, 12, 14, 16, 22, 85, 72, 87,104, 146, 218, 266

2. What are the dominant initiation mechanisms of spicules and other jets? What roles do magnetic field reconnection, ambipolar diffusion, mini-filament eruptions and vorticity play?
   Relevant Science Use Cases: 12, 14, 15, 31, 72, 76, 139, 144, 164, 262, 266, 286, 289

3. How is the plasma in a spicule heated to transition region temperatures and above? Can we establish the roles of electric currents, shocks, instabilities and reconnection? How important is spicule heating to the coronal energy balance?
   Relevant Science Use Cases: 16, 104, 132, 137, 144, 182, 241, 264, 268, 269

4. Is there more than one spicule type? If so, are (how are) the different types of spicules related, and what are their relationships to chromospheric jets more broadly?
   Relevant Science Use Cases: 12, 72, 164, 241, 289

5. What are the relative importances of spicules, jets, jetlets and coronal jets to the chromosphere-corona mass and energy cycle?
   Relevant Science Use Cases: 15, 22, 24, 286, 289

6. How important are ion-neutral interactions to chromospheric dynamics and energetics?
   Relevant Science Use Cases: 15, 50

7. How is elemental fractionation (the FIP effect) affected by chromospheric conditions, the local magnetic field configuration, the local flow dynamics, and the local MHD wave field?
   Relevant Science Use Cases: 53, 61, 64

8. What conditions lead to thermal instability in coronal loop systems? What can coronal rain observations teach us about the chromosphere-corona mass cycle, the statistics of coronal heating and the importance of ion-neutral interaction effects?
   Relevant Science Use Cases: 16, 50, 107, 110, 170, 223, 267, 280

3.3.2 Coronal Heating, Solar Wind Origin and Acceleration

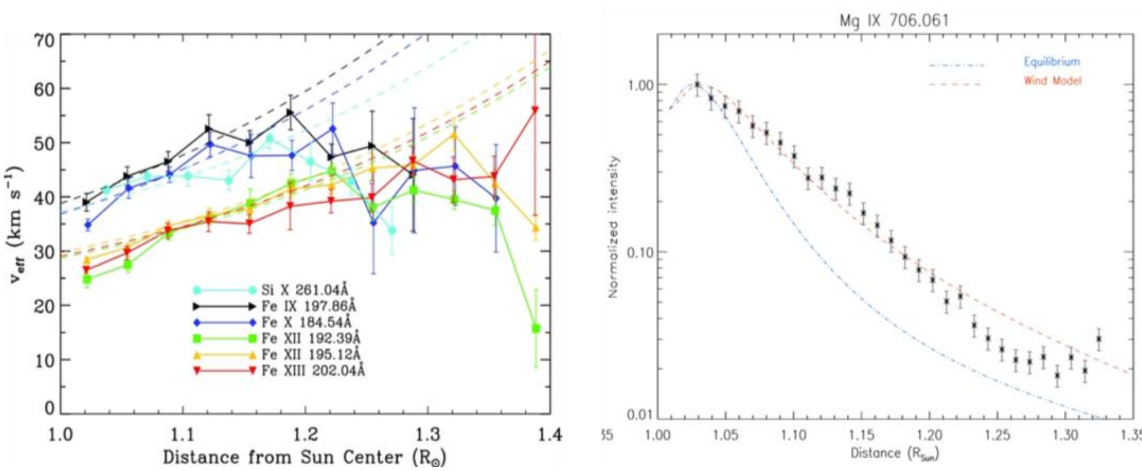


Figure 21. Hinode/EIS line width measurements in an off-disk coronal hole as a function of height (left). The decrease in width with distance off-limb beyond 1.1 R_{Sun} suggests wave damping. Mg IX 706 off disk line intensity in a polar coronal hole (right), measurements from SOHO/SUMER, estimates obtained by assuming ionization equilibrium (blue curve) and using non-equilibrium ion fractions (red curve). The red curve was obtained choosing wind speed vs. height profile that allowed predicted ion fractions to match observed line intensities. From Hahn et al. 2012, ApJ (left) and Landi et al. 2012, ApJ (right). Reproduced with permission; copyright 2012 American Astronomical Society.

Waves or nanoflares? What is the relative importance of different proposed coronal heating mechanisms? What are the solar wind momentum sources? What role does the chromosphere play in coronal heating?

The steep transition from the cool chromosphere to the million plus degree corona is the direct result of the cooling catastrophe that results when hydrogen in the solar atmosphere becomes fully ionized so that radiative recombination can no longer cool the optically thin plasma (Woods et al. 1990a,b). The plasma temperature climbs high enough so that electron conduction back down to the chromosphere, and resulting radiative losses from there, are sufficient to balance the heating above. Solving the coronal heating problem requires identifying the heat source which in the statistically steady state balances thermal conduction to the chromosphere and any other smaller direct energy losses from the corona by radiation or advection. Significant progress has been made in the last decades, and it is now apparent that no single heating mechanism is likely universally dominant (e.g., Parnel and De Moortel 2012, De Moortel and Browning 2015). The importance of mechanisms, such as reconnection, MHD or plasma wave dissipation, or turbulent dissipation, likely vary depending on coronal conditions, particularly the magnetic field configuration. Moreover, the mechanisms are highly intertwined and interdependent. Dissipation of current sheets can produce waves and waves in magnetically structured media can induce current-sheets (e.g., Velli et al. 2015), and observations indicate that even on very large scales eruptive flares can trigger oscillations in coronal loops and filament oscillations can induce eruption (see references in Jess et al. 2015) and associated flaring. Turbulence is similarly likely ubiquitous, and recent work suggests an important role for Alfvén wave induced turbulence (e.g., van Ballegooijen et al. 2011, Asgari-Targhi 2013, van der Holst et al. 2014).

Thus, while a number of general properties of coronal heating have been observationally established (De Moortel and Browning 2015): coronal heating is unsteady (impulsive), coronal magnetic fields store energy which can be dissipated via reconnection, the corona supports a rich wave field, the corona can only be understood in conjunction with its coupling to the chromosphere, details are less certain (e.g., Klimchuk 2015, Schmelz and Winebarger 2015). What is the relative importance of different heating mechanism? Do current sheets in the corona play an important role in heating, and if so, what plasma processes are involved in their dissipation? What is the fundamental scale of the substructure in multi-thermal coronal loops, and what processes determine this? During small scale reconnection events, how much energy is dissipated directly, how much is radiated as waves, and how much goes into acceleration of non-thermal electrons (Testa et al., 2014)? How does magnetic reconnection heat the plasma (Longcope and Tarr 2015)? How and where are the ubiquitous MHD waves in the corona dissipated (e.g., Poedts 2002, Gupta 2017)? How far out in the solar wind does heating extend (Martinović et al. 2019 and references therein)? What are the characteristic scales and magnitudes of the heating events? What triggers them?

DKIST will make significant contributions to answering these questions. Most fundamentally DKIST will enable careful, repeated and frequent measurements of the plasma properties of the inner corona at multiple heights, measurements essential to quantitative evaluation of suggested heating processes in varying magnetic environments. Observations of the line-continuum and line-line intensity ratios of ions, such as Fe IX to XV, that are also found in in-situ measurements of the fast and slow solar wind, will allow determination of the electron density, temperature and charge state evolution of the solar wind plasma, informing our understanding of the acceleration and heating processes (Landi et al. 2012, Landi et al. 2016, Boe et al. 2018). Comparision between theoretical studies of fast and slow magneto-acoustic wave mode conversion, shock formation and dissipation (e.g., Zhugzhda et al. 1995, Carlsson and Stein 1997), and observations will help constrain the role of these processes as a function of height in the chromosphere. For example, in models, high frequency (>10 mHz) propagating acoustic waves develop into radiatively damped weak shocks within the first few hundred kilometers above the photosphere (Carlsson and Stein 2002) while lower frequency waves (~4 - 10 mHz) develop into strong shocks in the chromosphere (above 1 Mm) where radiative damping is less effective (Priest 2000). Multi-height DKIST observations can assess this frequency dependence in regions of differing magnetic field configuration. Moreover, previous high-resolution observational work has reported evidence for shock induced turbulence (Reardon et al. 2008), and such turbulence may provide a mechanism for the dispersal of the wave energy beyond the local shock region itself. Turbulence may also play a role in wave mode conversion, coupling the compressive motions to Alfvénic fluctuations, which can continue to propagate outward, transmitting energy to higher layers of the solar atmosphere. Alternatively, counter propagating Alfvén waves may nonlinearly interact to produce MHD turbulence, dissipating the waves and heating the plasma (van Ballegooijen et al. 2011). DKIST observations can differentiate these in the solar atmosphere and/or determine their occurance frequency. Further, while direct observation of nanoflare heating lies beyond the capabilities of DKIST, DKIST observations can help distinguish between specific reconnection heating mechanisms. Heating models based on flux cancelation have been previously motivated by high resolution IMAX data from Sunrise (Priest et al. 2018) and heating events in simulations of three dimensional kink-unstable flux ropes may be diagnosable using DKIST coronal lines (Snow et al. 2018). With DKIST, high resolution chromospheric observations of intensity fluctuations and motions at the footpoints of hot coronal loops should reveal key telltale signatures of nanoflares in the overlying corona (Testa et al. 2014). When coupled with radiative hydrodynamic modeling (e.g., Kerr et al. 2016, Polito et al. 2018), such observations may be able to constrain the properties of the non-thermal particles or waves generated at nanoflare sites. Finally, though the details are uncertain, it has been suggested that the chromosphere may play an important role in coronal heating (e.g., Withbroe and Noyes 1977, Sturrock 1999, De Pontieu et al. 2017), since chromospheric plasma can be heated to transition region temperatures and higher and carried via jets to coronal heights. If so, the jet studies outlined in Section 3.3.1 will be highly relevant.

The hot outer solar corona escapes the Sun as the solar wind. The solar wind carries plasma out into the heliosphere, driving interactions with planetary space environments and influencing CME arrival time and geo-effectiveness, yet there is no consensus on the details of where it originates or how it is accelerated. The fast and slow solar wind show differing physical properties (e.g., Feldman et al. 2005, Ebert et al. 2009), likely come from different source regions and possibly result from different acceleration mechanisms. The fast wind originates in coronal holes, but how the detailed properties of the field and plasma within a coronal hole lead to the observed properties of the wind is not understood. Additional sources of momentum, beyond Parker's original gas pressure gradient mechanism (Parker 1958, 1963), are required for the plasma to reach the observed speeds. Those sources could be large-amplitude MHD waves (Alazraki and Couturier 1971; Jacques 1977, De Pontieu et al. 2007b), Type-II spicules (e.g., De Pontieu et al., 2009, Moore et al. 2011), resonant interactions with ion cyclotron waves (Hollweg and Isenberg 2002) or others (e.g., Cranmer and Winebarger 2019 and references therein), but they are to date poorly constrained by observations. The slow wind, on the other hand, has variously been proposed to originate from coronal hole edges, closed-open field boundaries in active regions, streamers, streamer tops or small coronal holes. The slow solar wind is likely associated with magnetic reconnection between closed loop-like magnetic flux systems and open flux that connects to the wind, but there is no consensus on the dominant underlying physical configuration (e.g., Feldman et al. 2005, Cranmer 2009). In fact, the differing properties of the fast and slow solar wind may have more to do with the expansion properties of the background magnetic field than the source properties themselves (Wang and Sheeley 2003).

The solar wind can be studied using either remote sensing or in-situ techniques. In-situ measurements typically provide direct information on plasma properties only after the plasma has undergone much of its evolution, though Parker Solar Probe (PSP) is revolutionizing these measurements, aiming to sample during its closest perihelia, regions of solar-wind heating and acceleration directly (e.g., Venzmer and Bothmer 2018). Remote sensing observations, on the other hand, allow frequent and repeatable measurements of the solar wind source regions, but can be difficult to interpret. Combining these types of measurements (Landi et al. 2012) is already yielding exciting results in the current early PSP era (Rouillard et al. 2020). DKIST will make significant contributions to those efforts (§3.4.5). Regular off-disk coronal measurements of the magnetic field and the plasma properties will capture the solar wind as it emerges from its source and extending up to a height of 0.5 solar radii above the limb. Since the spectral lines observed by DKIST are largely formed by photoexcitation, their intensity decreases with height at a much smaller rate than EUV spectral lines, making plasma diagnostics to the edge of the DKIST field of view possible (Landi et al 2016). Lower down, DKIST magnetic field measurements in the chromosphere and low transition region (from diagnostics such as He I 10830 Å) can be used in combination with IRIS and Hinode observations to study the acceleration physics from the chromosphere through transition region and into the corona.

Such coordinated observations will be able to address critical issues such as how the physical properties of the solar wind change with height, how that profile depends on position from the center to the edge of coronal holes, what defines coronal hole streamer boundaries, and does, or how does, reconnection at the boundary between closed and adjacent open field in active regions yield the observed slow solar wind properties. Plasma diagnostics will allow estimates of the mass and energy flow along magnetic field lines, and coronal line width studies will help in understanding wave propagation and damping (Hahn et al. 2012). Combining magnetic field, electron density and temperature measurements will make possible charge state evolution modeling of the accelerating solar wind and aid in the development of empirical models of the solar wind speed between 1 and 1.5 solar radii (Landi et al. 2012). Extrapolation to the freeze in height, with field extrapolations no longer strictly dependent on the photospheric field, will provide further links to in-situ instrumentation on PSP, SO and ACE and constrain the solar wind source locations (§3.4.5).

Critical science to address:

1. What is the relative importance of different coronal heating mechanisms? What are the characteristic scales and magnitudes of the heating events? What triggers them? What is the role of small-scale reconnection events (i.e., nanoflares)?
   Relevant Science Use Cases: 86, 94, 145, 219, 236, 240, 254

2. What roles do waves and turbulence play in heating and accelerating the fast and slow solar wind?
   Relevant Science Use Cases: 157, 194, 259, 265

3. Is reconnection at the boundaries between open and closed field regions at the boundary of active regions an important source of the slow solar wind?
   Relevant Science Use Cases: 61, 187, 278

4. What role does the chromosphere play in coronal heating? What roles do jets play in the heating and accelerating the fast and slow solar winds?
   Relevant Science Use Cases: 269

5. How frequently does reconnection occur in the chromosphere? Is the energy deposited by reconnection events sufficient to sustain the chromosphere or corona?
   Relevant Science Use Cases: 6, 10, 19, 43, 65, 108, 111, 116, 134, 150, 219

6. How are the low corona, where acceleration appears to occur, and the solar wind connected? What are the Lagrangian (along the wind trajectory) wind plasma properties: acceleration, density and temperature?
   Relevant Science Use Cases: 115, 222

7. How does the opening magnetic topology affect the wind expansion velocity in the source regions, and thus the wind properties measured in situ?
   Relevant Science Use Cases: 88, 115

3.3.3 Magnetic Reconnection in the Solar Atmosphere

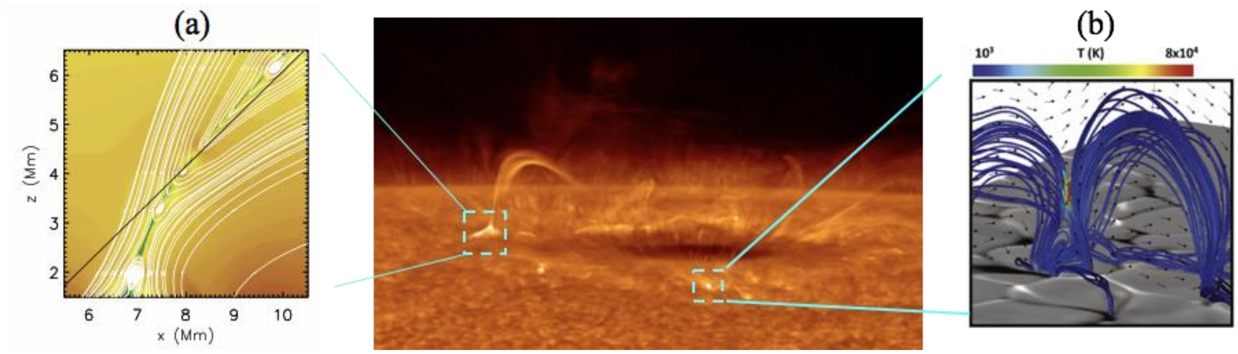


Figure 22. The chromosphere around a sunspot observed with the Hinode / Solar Optical Telescope using the Ca II H broadband filter, showing transient brightenings, likely due to heating by reconnection events (Middle, from Shimizu 2015, fiducial lines added here). (a) Numerical simulation of a jet, where intermittent reconnection is driven by plasmoid instability. From Rouppe van der Voort et al. 2017, ApJ. (b) Numerical simulation of an Ellerman-bomb, where reconnection happens between emerging bipolar fields. From Hansteen et al. 2017, ApJ. Reproduced with permission; copyright 2017 American Astronomical Society.

What is the three-dimensional geometry of the magnetic field near reconnection sites? What roles do ion-neutral collisions, current sheet instabilities and plasmoid ejection play? How efficiently does the reconnection heat and accelerate the solar plasma?

Magnetic reconnection is a fundamental process that transforms magnetic energy into kinetic and thermal energies in astrophysical plasmas. The magnetic energy is stored, maintained and amplified over extended periods of time (minutes to hours in magnetic network and hours to weeks in sunspots and active regions) before being released suddenly during reconnection events, with flares occurring on small spatial scales (kilometers) over very short times (minutes). These events can accelerate plasma in jet-like structures and induce local heating in the chromosphere and the layers above.

In addition to the ubiquitous spicules (§3.3.1), jets are observed in sunspot penumbra (Katsukawa et al. 2007, Tiwari et al. 2018) and the edges of sunspots (Morton 2012), light bridges (Toriumi et al. 2015, Tian et al. 2018), and the plage regions surrounding sunspots (Nishizuka et al. 2011). Some of these jet types often show morphologies reminiscent of reconnection sites (e.g., Shibata et al. 2007, Singh et al. 2012), but we have few measurements of the local magnetic field and its possible reconfiguration at jet sites. Heating is observed, as Ellerman bombs and UV bursts, point-like brightenings in the wing of chromospheric lines such as H I alpha and Ca II (e.g., Vissers et al. 2015, Rouppe van der Voort et al. 2017, Toriumi et al. 2017, Young et al. 2018), and these brightenings are often associated with bipolar moving magnetic features around sunspots or colliding bipolar structures in a region of emerging flux. This again suggests reconnection, as do similar brightenings associated with magnetic cancellation seen in the quiet-Sun (Rouppe van der Voort et al. 2016, Nelson et al. 2017), but direct measurements of the field are lacking. An important goal of DKIST is to make magnetic field measurements of such reconnection phenomena at high resolution, simultaneously over multiple heights, from the photosphere into the chromosphere. This will enable detailed diagnosis of the structure of the reconnection sites and reconstruction of the magnetic and thermodynamic history of the plasma in the reconnection volume, which in turn will inform our understanding of energy partition, plasma acceleration and magnetic field reconfiguration during reconnection. Together with recent in-situ measurements of the underlying microphysical processes in the Earth's magnetosphere (e.g., Burch et al. 2016, Torbert et al. 2018, Chen et al. 2020, Hesse and Cassack 2020) and laboratory experiments (e.g., Dong et al. 2012, Gekelman et al. 2016, Olson et al. 2016, Howes 2018, Takahata et al. 2019, Seo et al. 2020) these observations will lead to a better fundamental understanding of the mechanisms underlying fast reconnection (Ji and Daughton 2011, Coates 2016, Yamada et al. 2016) in astrophysical settings.

An important aspect of DKIST's contribution is the unique plasma environment offered by solar photosphere and chromosphere. The solar chromosphere is relatively dense and weakly ionized, with an ionization fraction on the order of 10^{-2}. This low chromospheric ionization fraction is of particular importance both because low ionization fractions, in the range of that found in the solar chromospheric, increase fast collisionless reconnection rates, and because such low ionization fractions, often even much lower than that in the solar chromosphere, occur over a wide range of astrophysical plasmas, such as the atmosphere of other cool stars, the warm neutral interstellar medium (ionization fraction of 10^{-2}, Jenkins 2013), dense cores of molecular clouds (ionization fraction of 10^{-7}, Caselli et al. 1998), and protostellar and protoplanetary disks (ionization fraction 10^{-10} or less, e.g., Armitage 2019). Collisionless reconnection rates increase with partial ionization because, in addition to increasing resistivity, ion-neutral collisions increase the effective ion mass, causing a reduction of the Alfvén speed, a steepening of current sheets, heating of the inflow and outflow regions of the reconnection site, and enhanced plasmoid instability (e.g., Forbes and Priest 1983a,b, Zweibel 1989, Chiueh 1998, Zweibel et al. 2011, Leake et al. 2012, Mei et al. 2012, Murphy et al. 2012, Zweibel 2015). Understanding the role of anomalous resistivity in a partially ionized plasma has broad implications for solar observations, likely being responsible for increased damping rates of MHD waves (De Pontieu et al. 2001), increased current dissipation and thus heating rates in the solar chromosphere (Khomenko and Collados 2012, Martinez-Sykora et al. 2012), increased flux emergence rates into the corona, reduced Alfvén wave flux from photospheric footpoint motion, and changes in the structure of MHD shocks, prominences and quiet-Sun magnetic features (see Anan et al. 2017 and references therein).

While solar reconnection occurs on scales well below those that DKIST will resolve, DKIST will be able to achieve high spatial and temporal resolution of small scale magnetic structures to help decipher the signatures of plasmoids (Rouppe van der Voort et al. 2017, French et al. 2019) and evidence for the inflows and Alfvénic outflows inherent in the reconnection process. It will achieve high spectro-polarimetric sensitivity, measuring the three-dimensional magnetic field structure in the chromosphere as well as photosphere during and after the reconnection event. In addition to determining the changes in magnetic field topology caused by reconnection, these measurements will allow estimates of the total amount of magnetic flux annihilated during reconnection and the reconnection rate. The energy released in a reconnection event, as estimated from these field measurements, can then be compared with the local heating rate derived from thermodynamic changes to further our understanding of the underlying partition between bulk flows and random motions.

Critical science to address:

1. What is the three-dimensional topology of the magnetic field at reconnection sites? How do the magnetic and electric fields reconfigure during reconnection?
   Relevant Science Use Cases: 6, 12, 16, 19, 36, 43, 65, 74, 134, 225, 254, 276

2. How frequently does reconnection occur in the chromosphere? What is the energy spectrum of reconnection events? What is the impact of these events on the overlying corona?
   Relevant Science Use Cases: 275

3. What are driving mechanisms/triggers of fast reconnection in the chromosphere? What roles do ion-neutral drift (ambipolar diffusion), current sheet instabilities and plasmoid ejection play?
   Relevant Science Use Cases: 16, 78, 234

4. What is the speed and structure of the reconnection inflows and outflows (reconnection rate) in the low solar atmosphere? How do they depend on the magnetic field geometry and plasma conditions?
   Relevant Science Use Cases: 6, 12, 16, 19, 78, 94, 108, 116, 134, 225

5. How efficiently does the reconnection heat the solar atmosphere? What fraction of the magnetic field energy is converted to bulk flow vs. heat?
   Relevant Science Use Cases: 12, 16, 78, 108, 137, 233

3.3.4 Waves in the Solar Atmosphere

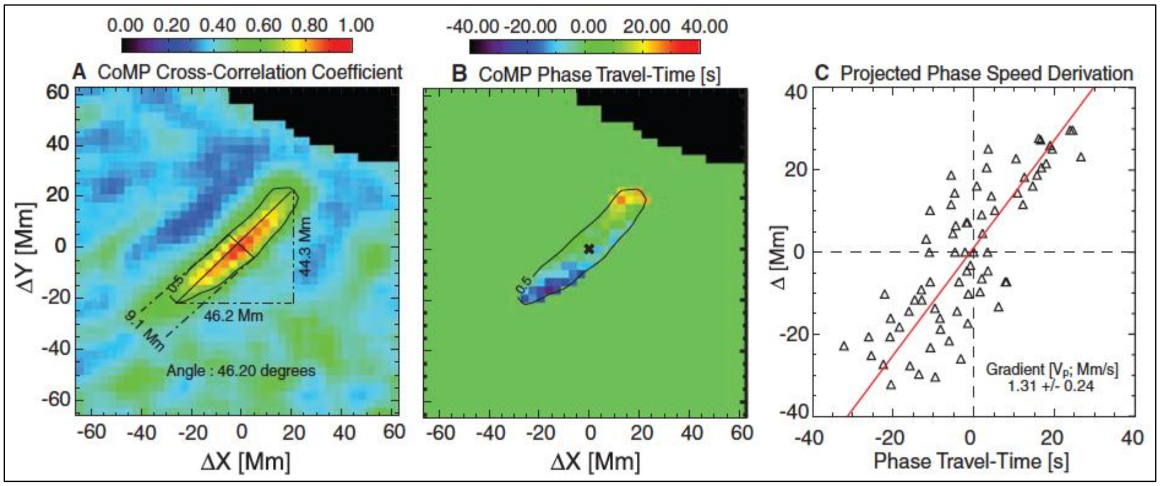


***Figure 23.** Travel-time analysis of CoMP Doppler velocity measurements. (A) A map of the cross correlation between the Fourier filtered time series (Gaussian filter centered on 3.5 mHz) at the reference pixel (marked with an x in B), and the filtered time series of neighboring pixels. Contour of 0.5 defines region within which the phase speed of the waves is then measured. (B) A map of phase travel times in that region. (C) The relationship between phase travel time and distance to the reference pixel, yielding the phase speed of the analyzed region. From Tomczyk et al. 2007, Science (reproduced with permission; copyright 2007 American Association for the Advancement of Science).*

What wave modes are present at what heights in the solar atmosphere? What is their source? What role do they play in chromospheric and coronal heating? How do these answers depend on the local magnetic field structure?

Two promises drive the use of DKIST to study MHD waves in the solar atmosphere (e.g., Kostik and Khomenko 2013): 1) MHD waves carry energy into the solar atmosphere and, if dissipated at the correct height, provide at least a partial solution to the longstanding coronal and chromospheric heating problems, and 2) the presence of magnetic fields in the chromosphere and corona modify the waves observed, providing an opportunity to use them to diagnose conditions there. The chromosphere is a particularly important region of the solar atmosphere. It modulates wave transmission into the corona (understanding the solar chromosphere is critical to constraining the mechanisms of wave energy transfer between the photosphere and the corona; see the recent review by Jess et al. 2015) and, while it is much cooler than the corona, its relatively high density and the efficiency of the cooling pathways available, imply that high energy input is required to sustain radiative losses. Typical chromospheric radiative losses are estimated to be on the order of 10^6–10^7 erg cm^{-2} s^{-1} in the chromosphere compared to 10^4–10^6 erg cm^{-2} s^{-1} in the solar corona (Withbroe and Noyes 1977, Anderson and Athay 1989). .

The possibility that the Sun's chromosphere and the corona are heated by the dissipation of magnetohydrodynamic (MHD) waves, has led to a substantial body of research, starting over seventy years ago with suggestions that acoustic waves generated by convection are responsible for heating the solar atmosphere (Biermann 1946, Schwarzschild 1948). With the observational discovery (Leighton 1960, Leighton et al. 1962) and correct theoretical interpretation (Ulrich 1970) of the resonant solar acoustic oscillations, the diagnostic potential of the solar p-modes modes in the study of the solar interior was realized with helioseismology. This was closely followed by an understanding of the observational and theoretical distinction between those modes and propagating atmospheric waves (see Stein and Leibacher 1974 for an early summary), and in the intervening years, studies of chromospheric and coronal waves have leveraged increasingly sophisticated space and ground based instrumentation, and the consequent ever-increasing spatial, spectral and temporal resolution observations, to advance our understanding of chromospheric and coronal wave behavior. Yet fundamental questions about wave energy transport and wave heating of the solar atmosphere persist (e.g., Erdelyi and Fedun 2007). What processes dominate wave generation? What modes are excited? How does the energy generated propagate into the solar corona? What is the role of mode conversion? What are the wave dissipation mechanisms that allow the solar corona to maintain its multi-million-kelvin temperature?

Answering these questions requires the tracking of waves with height in the solar atmosphere, while simultaneously diagnosing changes in wave energy and the corresponding localized atmospheric heating (Jess et al. 2015). DKIST, alone and in combination with space-based UV observations, will provide unprecedented observations across many atmospheric layers. These multi-height spectropolarimetric measurements will be ideally suited to unraveling the nature of the waves, the energy propagation channels accessed and atmospheric heating that results.

In a uniform plasma, there are three distinct types of MHD wave modes: the slow and fast magnetoacoustic waves and Alfvén waves. Solar observations are often interpreted in terms of these, but the manifestation of these modes in the stratified and highly magnetically structured solar atmosphere is much more complex (e.g., Banerjee et al. 2007, Tomczyk et al. 2007, De Pontieu et al., 2007b, Jess et al. 2009). In simple isolated magnetic geometries such as slabs or flux tubes, modes of the magnetic structures themselves (surface, body, kink, sausage, etc.) can be identified (e.g., Priest, 2014), but in general, with space filling magnetic fields, the modes are mixed and coupled, and the waves are subject to resonant absorption, phase mixing and guided propagation (e.g., Bogdan 2000, Nakariakov and Verwichte 2005, Priest 2014, Okamoto et al. 2015, Antolin et al., 2015a). This makes observations difficult to interpret, but also consequently rich in diagnostic potential. Much of the complexity originates in the solar chromosphere. While the coronal plasma can be treated as a single-fluid, low plasma-beta fully-ionized plasma, the chromosphere is a multi-fluid, partially ionized medium with a finite spatially varying plasma-beta coupled to a radiation field that is out of thermodynamic equilibrium (e.g., Hansteen et al. 2007). Additionally, waves in the solar chromosphere are subject to a highly structured (on sub-arcsecond to global scales) evolving field and flow (e.g., Wedemeyer-Böhm et al. 2009). Since the manifestation of magnetohydrodynamic waves differs in different magnetic and plasma regimes (high-beta vs. low-beta, active regions vs. coronal holes, structured (on scale of wave) vs. unstructured field, as examples), wave signatures change as the waves propagate upward into the solar atmosphere, making following the wave energy from its source to the site of energy deposition challenging.

Despite these difficulties, significant progress has been made and is anticipated with future observations (e.g., Banerjee et al. 2007). Convective motions in the photosphere excite both longitudinal magnetoacoustic and transverse Alfvénic perturbations. Of the compressive wave field excited in the photosphere, only waves above the temperature minimum acoustic cut-off frequency are expected to propagate into the atmosphere above. These magneto-acoustic compressive waves steepen, shock, and dissipate as they propagate into the chromosphere (Zhugzhda et al. 1995, Carlsson and Stein 1997). On the other hand, transverse Alfvénic perturbations can propagate through the chromosphere and into the corona with only weak damping. The weak damping allows the waves to reach greater heights but also makes their role in plasma heating problematic. One possibility is that the waves undergo mode conversion from Alfvénic to compressive, with the compressive motions providing an avenue for dissipation and heating (e.g., Hollweg et al. 1982, Ulmschneider et al. 1991, Kalkofen 1997). The height of mode conversion then becomes critical.

Observations of compressive wave motions support this general picture with some modification. High frequency power (three-minute period range) dominates the chromospheric wave field as expected, but it does so only in limited internetwork regions devoid of strong photospheric or chromospheric canopy fields (Vecchio et al. 2007, 2009). In plage regions, compressive wave power in the chromosphere reaches its maximum well below the acoustic cutoff frequency (e.g., Centeno et al. 2009), and low frequency magnetoacoustic waves also propagate upward from the photosphere in regions surrounding network elements (Jefferies et al. 2006, Vecchio et al. 2007). The presence of magnetic field thus appears to dramatically influence the frequency of the waves propagating into atmosphere. Two mechanisms have been proposed to facilitate this: inclined magnetic field creates wave-guides that effectively reduce the cut-off frequency (Michalitsanos 1973, De Pontieu et al. 2004) and radiative cooling of the wave temperature fluctuations can change the wave behavior, converting it from evanescent to propagating (Roberts 1983, Khomenko et al. 2008, Centeno et al. 2009). These two mechanisms can be distinguished by careful measurement of the background magnetic field and wave temperature-velocity phase relations (Kostik and Khomenko 2013, but see Heggland et al. 2009 for an alternative view). More generally, MHD wave properties depend in detail on the magnetic structure of the region within which they are propagating, and the propagation and amplitude of waves of different frequencies in the solar atmosphere depends on the partial ionization state of the plasma (Khomenko et al. 2018).

Direct detection of Alfvén wave perturbations is even more challenging than detection of compressive waves, but Alfvén waves have been successfully observed in the chromosphere (De Pontieu et al., 2007b, Jess et al., 2009), transition region (De Pontieu et al., 2014) and solar corona, both as time varying nonthermal linewidths (see review of Mathioudakis et al. 2013) and directly as linear polarization and Doppler velocity fluctuations (Tomczyk et al. 2007, Figure 23, but cf. Van Doorsselaere et al. 2008). The spectrum of the motions observed in the corona is similar to the solar p-modes, suggesting they have their origin in the solar photosphere (Tomczyk and McIntosh 2009), though other evidence indicates that they may be more closely related to the ubiquitous Alfvén waves observed on spicules (De Pontieu et al., 2007b, McIntosh et al., 2011). Observational evidence for mode coupling in both directions has also been reported. Upward propagating transverse motions coupled to longitudinal motions, subsequently dissipated, were identified in quiet-sun network bright points by careful cross correlation of wavelet identified wave packets at multiple heights (McAteer et al. 2003, Bloomfield et al. 2004), and evidence for photospherically generated longitudinal magnetoacoustic oscillations propagating upward before undergoing mode conversion to predominantly transverse motions were found in observations of spicules (Jess et al. 2012).

While these observations are compelling, to fully disentangle the signal of the different wave modes as they travel upward through the complex solar atmosphere from the photosphere to corona requires simultaneous intensity, polarimetry (magnetic field) and Doppler measurements at many heights in order to deduce the background magnetic field, thermodynamic state of the plasma and wave perturbations. Such measurements are required for many different magnetic field regimes. The high-resolution limb spectropolarimetry needed to achieve these measurements is difficult because low photon statistics off of the solar limb limit the accuracy of the Stokes profiles deduced and because low photon counts make the use of adaptive optics, needed to achieve the high resolutions required, challenging. DKIST is poised to meet these challenges. Its large aperture and coronographic capabilities, will allow spectropolarimetric measurements of chromospheric and coronal waves on unprecedentedly small spatial scales and at high cadence.

Critical science to address:

1. What waves are found in the solar chromosphere, transition region and corona? Can a detailed "census" of MHD wave activity link the wave modes present with the magnetic structure properties, or are the apparent modal types observed dominated instead by the plasma emission processes?
   Relevant Science Use Cases: 17, 40, 42, 79, 102, 112, 126, 166, 179, 180, 193, 216, 221, 258

2. What are the wave energy densities vs. frequency distributions (spectra at high spatial and temporal frequencies) of the various wave modes at different heights in the solar atmosphere? How does this depend on the underlying magnetic field and structures?
   Relevant Science Use Cases: 26, 169, 172, 173, 184, 186, 195, 265

3. What mechanism is responsible for the significant longitudinal wave energy observed in the solar atmosphere at frequencies below the temperature minimum acoustic cutoff frequency?
   Relevant Science Use Cases: 109, 186, 216

4. Do the wave modes and mode conversion rates observed agree with those predicted by numerical simulations of well-localized MHD waveguides and mode conversion sites?
   Relevant Science Use Cases: 46, 177, 242

5. What mechanisms underlying the excitation of the MHD waves which propagate upward into the solar atmosphere?
   Relevant Science Use Cases: 24, 45, 103, 109, 140, 168, 173, 185

6. Where in the atmosphere is the wave energy dissipated and by what mechanisms?
   Relevant Science Use Cases: 45, 84, 101, 130, 141, 168, 174, 175, 256

7. What wave modes are associated with spicules, and how do these affect the dynamic and thermal evolution of the spicules?
   Relevant Science Use Cases: 179, 262, 266

8. What role do torsional Alfvèn waves play in chromospheric and coronal heating? What is their origin, and on what scales are they generated?
   Relevant Science Use Cases: 13, 178, 183, 193, 285

9. Is there enhanced wave activity in regions with strong transverse gradients in the background plasma properties (e.g., quasi-separatrix layers)? How is the wave field associated with reconnection events?

3.3.5 Flux Emergence into the Non-Eruptive Solar Atmosphere

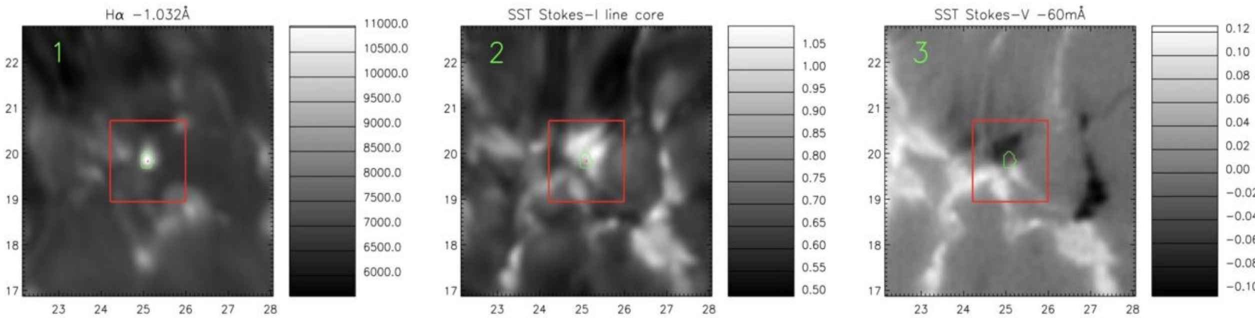


Figure 24. Swedish 1-m Solar Telescope (SST) observations of an Ellerman bomb in Hα −1.032 Å (left), co-spatial Fe I 6302 Å line core Stokes-I (middle) and co-spatial Fe I6302 Å −60 mÅ Stokes-V (right). Ellerman bombs occur near solar active regions or areas of enhanced photospheric magnetic activity, and result when sunspot flux emergence interacts with pre-existing opposite polarity magnetic flux. From Reid et al. 2016, ApJ (reproduced with permission; copyright 2016 American Astronomical Society).

How does magnetic flux emergence impact energy storage and release in the chromosphere and corona? How are the underlying magnetic reconnection geometries and heights reflected in the observations of different small-scale flux emergence/cancelation event types?

Magnetic flux emergence allows for mass, energy and magnetic field to flow from the solar interior through the photosphere and into the chromosphere and corona above. The impact of flux emergence depends on the amount of field emerging, its spatial distribution and the preexisting structure of the atmosphere into which it is emerging. For example, a small bi-pole will have vastly different impact when emerging into a coronal hole, the quiet Sun or adjacent to a delta-spot active region. The emergence of magnetic field through the solar photosphere and its reconnection with pre-existing field at different heights thus leads to a variety of dynamic phenomena with different temporal and spatial scales: global magnetic field restructuring (Török et al. 2014), flaring active regions (Toriumi and Wang 2019), emerging flux regions or arch filament systems (e.g., Centeno et al. 2017, Su et al. 2018), Ellerman bombs and Quiet Sun Ellerman bomb-like Brightenings. Larger scale field reconfiguration and destabilization is considered in §3.2.2. The discussion in this section is focused on flux emergence on scales below those of an active region and the local response to that emergence. Tracking the consequences of emergence allows us to understand the fundamental energy storage and release mechanisms which may be responsible for heating the chromosphere and corona.

Ellerman bombs (Ellerman 1917) are point-like brightenings seen at a wing of chromospheric lines (such as H I alpha and Ca II). They are often observed to be associated with bipolar moving magnetic features around well-developed sunspots or as colliding bipolar structures in emerging flux regions (e.g., Rutten et al. 2013, Reid et al. 2016). The atmospheric heating and associated bi-directional flows observed are thought to be caused by magnetic reconnection near the temperature minimum (e.g., Matsumoto et al. 2008), with rapidly evolving flame-like features in the wings of the Balmer Hα line suggestive of small scale reconnection when observed at high resolution with the one meter Swedish Solar Telescope (Watanabe et al. 2011). While Ellerman bombs primarily occur in the active regions, and are sometimes associated with arch-filament systems (e.g., Zachariadis et al. 1987, Georgoulis et al. 2002, Ma et al. 2015, but see Rutten et al. 2013 who suggest these are distinct phenomena), suggesting that larger scale underlying flux eruption may also be occurring (Pariat et al. 2004), recent observations indicate that smaller, shorter-lived and lower Hα-wing-intensity-contrast events also occur in the quiet-sun. These quiet-Sun Ellerman-like brightenings (Rouppe van der Voort et al. 2016, Sheyte et al. 2018) are similar to Ellerman bombs, but with typical size scales of ~ 0.25 by 0.5 arcsecs and lifetimes of less than a minute. Bright flame-like emission in the wings of Hα, similar to that observed for Ellerman bombs, suggests a common reconnection origin, but the heating profile and the characteristics of the magnetic field evolution observed may imply a somewhat different reconnection scenario (Rouppe van der Voort et al. 2016). Similarly, UV bursts are reconnection events that differ from both Ellerman bombs and quiet-Sun Ellerman-like brightenings in their magnetic topology, atmospheric penetration height and reconnection energy, with the plasma in these events heated to transition region temperatures (Nelson et al. 2017, Young et al. 2018, Ortiz et al. 2020).

This full range of small-scale flux emergence events is well suited for study using the planned DKIST instrument suite. High-resolution multi-thermal moderate field-of-view observations can resolve the finely structured thermal properties of the plasma with height, and high sensitivity spectropolarimetric observations can be used to determine the height-dependent vector magnetic field and Doppler velocities. These quantities in turn can be used to estimate the local electric fields and energy fluxes. Electric field measurements, derived from time-series of vector magnetic field and Doppler velocity maps (e.g., Fisher et al. 2012, Kazachenko et al. 2014), are important for determining the rate of electromagnetic energy transport into the solar atmosphere, the Poynting flux through the photosphere. To date, such measurements have been made only in strong field regions due to the limited reliability of vector magnetic field deductions in weak field regions (Kazachenko et al. 2015). Using DKIST's unprecedented vector magnetic field measurement capabilities, electric field determination can be dramatically improved, and when combined with transition region and coronal observations, can be used to address a range of open questions about the net transfer of magnetic energy into the solar atmosphere: How much magnetic energy reaches the chromosphere? Why are active region cores the sites of the hottest and most dense coronal loops? Is there a measurable correlation between the input of energy at the photosphere and consequent emission in the chromosphere, transition region and corona? Is the injected energy dissipated immediately, or stored with some typical latency time? Importantly, these questions can be addressed as a function of solar activity to uncover the underlying energetics of the solar cycle.

A recent study of a UV burst with the Sunrise balloon-borne telescope (Smitha et al. 2018) revealed dynamic substructure on scales of 75 km, and likely smaller, within a chromospheric heating site. DKIST will not have UV capabilities, but the He I D3 and λ10830 lines may serve as useful proxies when studying plasma at transition region temperatures (Libbrecht et al. 2017). Coordinated observations with space-based assets are also anticipated. Numerical models will play a critical role in data interpretation. Radiative magnetohydrodynamic simulations of magnetic reconnection during flux emergence show reconnection events similar to Ellerman bomb and other burst events (Danilovic 2017, Hansteen et al. 2017). The occurance of these in simulations of emerging active regions suggests a possible role for an underlying emerging large-scale twisted loop structure (e.g., Isobe et al. 2007b, Archontis and Hood 2009). Detailed modeling of expected DKIST spectropolarimetric measurements in the photosphere and chromosphere will enable careful comparisons between the simulated and observed plasma flows and magnetic field evolution at the Ellerman bomb sites (Socas-Navarro et al. 2006, Kondrashova 2016) to determine if such structures are also implicated in observations of the Sun. Additionally, direct detection of the brightness temperature excess at bomb sites and in the surrounding atmosphere will be possible with coordinated observations using DKIST and radio instruments such as the Atacama Large Millimeter/submillimeter Array (ALMA). These will allow careful assessment of magnetic reconnection heating efficiency in the partially ionized chromospheric plasma, and help clarify the overall importance of Ellerman bombs and other burst and localized brightening events to the energy budget.

Critical science to address:

1. What fraction of chromospheric and/or coronal heating is due to discrete reconnection events in response to flux emergence? How do emergence and cancelation impact energy storage and release in the chromosphere and corona?
   Relevant Science Use Cases: 233, 236

2. What magnetic field reconfiguration scenarios lead to Ellerman bombs, Quiet Sun Ellerman bomb-like Brightenings and UV bursts? How do they differ? How do the properties of fine-scale structures (jets and plasmoids) reflect this evolution?
   Relevant Science Use Cases: 10, 19, 108, 134, 150

3. How do arch filament systems form and decay on the disk and at the limb? How does flux emergence/cancelation contribute to the development of magnetic flux ropes, filaments and sheared arcades?
   Relevant Science Use Cases: 30, 106, 128, 163

4. How is the heating of active region cores, the sites of the hottest and most dense coronal loops, related to the net Poynting flux that enters the chromosphere from below?
   Relevant Science Use Cases: 82, 96, 206, 207, 217

5. What is the spatial distribution of the vertical current in the solar photosphere, and what is the dynamics underlying its distribution and neutralization there and in the atmosphere above during flux emergence?
   Relevant Science Use Cases: 74, 217, 273

3.3.6 Multilayer Magnetometry and Magnetic Field Extrapolation

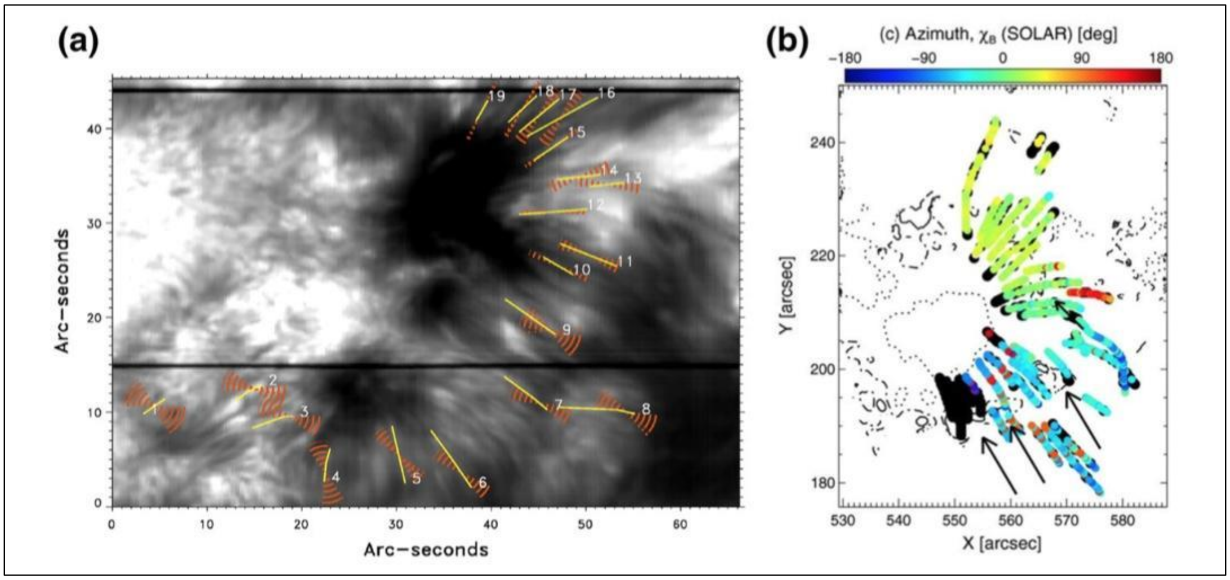


***Figure 25.** Orientation and azimuthal magnetic field direction of super-penumbral fibrils. In (a), yellow lines trace the core of Ca II 8542 Å intensity orange cones show the range of transverse magnetic-field azimuth compatible with the linear polarization measurements. In some regions the fibril and horizontal field orientations appear aligned (fibrils 9 – 19), while in others they do not (fibrils 1 -5). From de la Cruz Rodríguez and Socas-Navarro 2011, A&A (reproduced with permission; copyright 2011 European Southern Observatory). In (b), magnetic field azimuth along selected super-penumbral fibrils (inferred from He* I *at 10830 Å observations). Azimuths of the chromospheric fibrils are generally consistent with those of the penumbral filaments below (not shown). Black dots mark locations of significant deviation. They are largely restricted to where fibrils are rooted. From Schad et al. 2013, ApJ (reproduced with permission; copyright 2013 American Astronomical Society). Combined figure from Wiegelmann et al. 2014, A&A Rev.*

How does the magnetic field change in height and evolve in time through different layers of the solar atmosphere? How do we best use multi-layer magnetic field observations to constrain chromospheric/coronal field extrapolations?

The stratified solar atmosphere is threaded by magnetic field. Most existing solar instruments employ one or few spectral lines at a time and thus simultaneously probe the magnetic field over a limited range of heights in the atmosphere. Moreover, the rapid decrease of the field intensity with height implies very weak chromospheric polarization signals, making their measurement very challenging with existing facilities (Schad et al. 2013). A common need underlying much of the first critical science proposed for DKIST is thus multi-line high-sensitivity spectropolarimetry. In meeting this need, DKIST will enable simultaneous multi-height measurements of the solar atmosphere that will revolutionize our understanding of the coupling between the different atmospheric layers.

The chromospheric plasma is highly dynamic, inhomogeneous and out of local thermodynamic equilibrium. Magnetic fields play a central role in its behavior. Observations of the upper solar chromosphere, particularly near active regions, are dominated by intricate filamentary structures called fibrils. These fibrils are seen in images taken in the cores of strong chromospheric lines, such as Hα, Ca II K, and Ca II IR triplet (e.g., Hansteen et al. 2006, Cauzzi et al. 2008, Pietarila et al., 2009) and the He I 587.6 and 1083 nm lines (Schad et al. 2013). Fibrils are assumed to be aligned with the magnetic field, but even above sunspots, where the photospheric umbral field is strong and quite uniform, fine-scale chromospheric filaments are detected. Umbral flashes show filamentary finestructure, with an apparent associated horizontal magnetic field, that appears to be at or below the scale of current resolution limits (e.g., Socas-Navarro et al. 2009).

The assumed alignment of chromospheric fibrils with the magnetic field is an important tool in active region field extrapolation (Wiegelmann et al. 2008, Jing et al. 2011, Yamamoto and Kusano 2012). Extrapolation in turn is critical to assessments of the free energy available for solar flares and eruptions, chromospheric heating, and active region flaring potential and stability. However, since the early conjecture by George Ellery Hale that fibrils around sunspots resemble lines of magnetic force (Hale 1908a), a conjecture made before his momentous measurement of the field using the then recently described Zeeman effect (Hale 1908b, see Harvey 1999 for a brief history), the observational evidence for a direct association between fibrils and the local magnetic field direction has remained sparse. This is largely due to the small amplitude of the polarized signals (< 0.1% linear polarization) within the primarily horizontally oriented (relative to solar surface) chromospheric fibrils. Attempts to directly measure the alignment between the thermal and magnetic structure of super-penumbral fibrils have yielded disparate results, ranging from often but not always aligned (de la Cruz Rodríguez and Socas-Navarro 2011) to aligned within ±10 degrees with no evidence for misalignment (Schad et al. 2013). A recent Bayesian statistical analysis (Asensio Ramos et al. 2017) finds penumbral and plage fibrils to be well aligned but with non-negligible dispersion. That study concludes that higher signal-to-noise observations are needed to discern whether the misalignment seen in some simulations which include ion-neutral coupling (Martínez-Sykora et al. 2016) is compatible with that seen on the Sun. More broadly, understanding the three-dimensional connectivity of the chromospheric field to the photosphere, particularly at the outer footpoints of the fibrils, requires higher resolution spectropolarimetric measurements (Schad 2013). DKIST will allow such observations.

The connectivity of the magnetic field through the atmosphere is an important issue outside of active regions as well. In the quiet-Sun, the magnetic field in the photosphere is organized by supergranular motions into strong flux concentrations on the network scale and mixed-polarity internetwork magnetic field on the scale of granulation. The field expands above the photosphere into the chromosphere and corona, and the presence of the weak small-scale internetwork magnetic field has a considerable effect on the overall field geometry with height, which deviates significantly from a simple funnel expansion model (Schrijver and Title 2003, Aiouaz and Rast 2006, Martinez Sykora et al. 2019). This is critical because the magnetic field forms the underlying channel for energy transport into the solar chromosphere and corona, thus playing an important role in the acceleration of the solar wind (e.g., Gabriel 1976, Aiouaz et al. 2005, McIntosh et al. 2007, Tian et al. 2008, see also previous sections in this Research Area). Typically, beyond idealized potential or force free field extrapolations, the variation in field strength and topology with height is poorly known.

Nonlinear force-free extrapolations can be improved. Typically, such extrapolations depend on photospheric boundary conditions. That boundary condition is not consistent with the force free assumption because, due to the high plasma-beta in the photosphere, gas pressure and gravity play important roles in the photospheric force balance. Measuring the field instead in the chromosphere, where magnetic field is much more dominant, where the field configuration is much more force-free at least at sufficiently great heights (Zhu et al. 2016), can significantly improve the reliability of field extrapolations (Fleishman et al. 2019); when combined with photospheric measurements, even very incomplete chromospheric field measurements allow significant improvement. Additionally, careful comparison between independent extrapolations using photospheric and chromospheric field measurements can aid in determining relative line formation heights and in resolving the 180-degree field ambiguity (Yelles Chaouche et al. 2012). Thus reliable multi-height magnetic field measurements using DKIST will not only contribute to more reliable extrapolation of that field to greater heights, but will also strengthen deductions of the local field at the site of measurement.

Critical science to address:

1. How does the magnetic field change with height and evolve in time through the different layers of the solar atmosphere, in quiet Sun, filament channels and active regions?
   Relevant Science Use Cases: 8, 47, 80, 131, 138, 205, 206, 257, 263

2. How do we best employ multi-layer magnetic field observations in constraining chromospheric/coronal field extrapolations?
   Relevant Science Use Cases: 51, 80, 158, 159, 263

3. Is the magnetic field well-aligned with thermal (intensity) features observed in the solar chromosphere?
   Relevant Science Use Cases: 8, 47, 51, 85, 176, 218

4. How does the basic underlying quiet-sun magnetic field topology change with height (what are the mean deviations from a simple funnel expansion model) and how does this affect inferences of the global energy flux into the solar atmosphere?
   Relevant Science Use Cases: 47, 131, 141

3.3.7 Magnetic Topology, Helicity and Structures

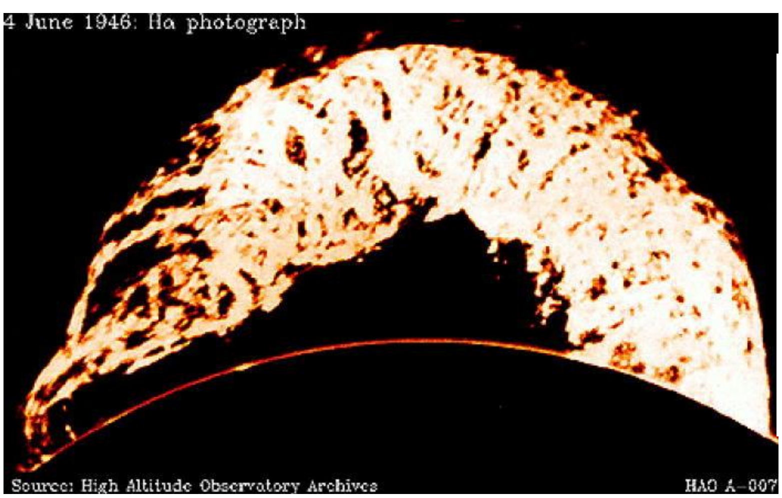


Figure 26. The Grand Daddy Prominence. Photographed by W.O. Roberts at Harvard College Observatory, Climax, Colorado on 4 June 1946 through a filter centered on Hα. The prominence extends ~200000 km above the solar surface. Courtesy of the High Altitude Observatory. (https://www2.hao.ucar.edu/Education/Sun/grand-daddy-prominence).

What role does the near conservation of helicity play in the structuring of the solar corona and coronal mass ejections? Are measurements of helicity useful indicators of imminent eruption?

Magnetic helicity is a property of the field which helps describe its topology, whether it is twisted or linked, writhes or is sheared (e.g., Moffatt 1969, Berger 1999, Moffatt 2014). It is strictly conserved in ideal magnetohydrodynamics (Woltjer 1958) and during two-dimensional reconnection, and approximately conserved in three-dimensional reconnection (Taylor 1974, Berger 1984, Hornig and Rastätter 1997). Magnetic helicity cascades to larger scales (Alexakis et al. 2006) and is converted from one form to another as it moves to larger scales. This means that as magnetic fields reconfigure in the solar atmosphere, magnetic helicity is lost only slowly.

Many solar magnetic structures contain self-helicity (internal twisting) and/or mutual helicity (tangling about each other), with helicity observed on the Sun on scales ranging from the largest global to the smallest quiet Sun magnetic fields (e.g., Pevtsov and Balasubramaniam 2003, Welsch and Longcope 2003, and references therein). The intense magnetic field structures that form in and rise through the Sun's convection zone and are thought responsible for sunspots and most solar activity, are likely highly twisted. Untwisted, such tubes would lose their integrity as they ascend, and observations of sunspots show that they rotate as they emerge (e.g., Evershed 1909, Brown et al. 2003). That rotation is likely associated with an underlying large-scale twisted flux tube rising through the photosphere (e.g., Sturrock et al. 2015), and the helicity that enters solar atmosphere on all scales from below is important for the structure and behavior of the field there.

Some coronal loops appear to be tangled about each other forming a braided pattern (Parker 1983, Cirtain et al. 2013, Pontin et al. 2017), and the degree of coronal loop braiding overall has been used to estimate the role of small scale reconnection in coronal heating (Schrijver 2007, Knizhnik et al. 2017). The appearance of braided structures, however, depends critically on the details of the field line windings within them and substructure can be difficult to distinguish in observations (Berger and Asgari-Targhi 2009, Pontin et al. 2017, Li and Peter 2019), so careful high-resolution spectropolarimetric observations are vital. Further, contrary to expectation, coronal loops have quite uniform width along their length (Klimchuk 2000, Watko and Klimchuk 2000), and explanations for the observed lack of expected field expansion rely on loop substructure, either to provide magnetic tension (e.g., López Fuentes et al. 2006) or to allow fine scale interchange reconnection that allows for cross field loss of the hot loop plasma (Schrijver 2007, Plowman et al. 2009). Distinguishing these observationally is important in understanding the thermodynamic structure of the corona and its maintenance.

In addition to its importance to coronal loop substructure and heating, the accumulation of magnetic helicity in the corona appears to be of key importance to the magnetic energy build-up that precedes the loss of stability when a coronal mass ejection is initiated (Zhang and Low 2005, Zhang et al. 2006, Yeates and Hornig 2016). The precise stability implications of the helicity accumulation are still somewhat uncertain (Amari et al. 2003, Phillips et al. 2005), and some measures of helicity may be more reliable instability indicators than others (Pariat et al. 2017), but beyond the exact triggering mechanisms, coronal mass ejections associated with filament eruptions often reveal large-scale helical magnetic structures that partially unwind during an eruption (e.g., Kurokawa et al. 1987, Xue et al. 2016). Coronal mass ejections may play an essential role in relieving the solar atmosphere of accumulated helicity (Zhang et al. 2006). Detailed observational assessment of the coronal helicity budget and its role in coronal mass ejection initiation are crucial, and DKIST will significantly enhance our ability to deduce the magnetic helicity in pre-and post-eruptive structures. Moreover, highly twisted structures typically have a high magnetic energy, and that twist can lead to local instability (e.g., the kink instability), reconnection, flaring and small scale eruptions beyond coronal mass ejections proper.

Prominences (or filaments on the disk) are cool plasma structures (at chromospheric temperatures) embedded into the hot corona (e.g., Parenti 2014, Gibson 2018). They are observed in emission off of the disk and as filaments in absorption when observed on-disk. These helical structures are central to those coronal mass ejections associated with filament eruptions, but direct measurements of their magnetic field topology are limited (e.g., Casini et al. 2003, Xu et al. 2012, Kuckein et al. 2012, Sasso et al. 2014). Based on magnetostatic models and plasma stability considerations, the magnetic field in prominences is thought to be fundamentally tangential to the solar surface. This may be true even in the feet (barbs) of the prominence, which can be the sites of swirling motions sometimes called solar tornados (e.g., Levens 2016a,b, Mghebrishvili et al. 2015, 2018). Such tornados may reflect the rise and expansion of a twisted flux rope into the corona or the presence of a large vortex flow in the photosphere (see Mghebrishvili et al. 2015 and references therein). They are implicated in prominence stability (Mghebrishvili et al. 2018). Understanding this complex evolving dynamics is critical to assessing the role of prominences in the solar mass cycle (§3.3.1) and coronal mass ejection initiation (§3.2.1).

Magnetic helicity in the solar atmosphere has two sources, the emergence of helical field through the photosphere from below (e.g., Leka et al. 1996, Tian and Alexander 2008) and field footpoint motions due to photospheric flows (e.g., van Ballegooijen 1999, Chae 2001) including differential rotation (e.g., van Ballegooijen 1999, DeVore 2000). Observations aimed at understanding the atmospheric helicity budget can either focus on these sources of helicity or attempt a direct measurement of the helicity in the solar atmosphere itself (see reviews van Driel-Gesztelyi et al. 2003, Démoulin 2007, Démoulin and Parait 2009 or more recent references in Linan et al. 2018). To date, the latter has relied on field extrapolation while the former has been built on measurement of the photospheric field and flows and models of their implication for helicity injection into the atmosphere. DKIST observations will contribute to the improvement of both of these techniques. DKIST's on-disk, multi-layer magnetometry (§3.3.6) will allow for more direct inference of the sheared and twisted field in the chromosphere and photosphere (e.g., Kuckein et al. 2012), while DKIST coronal field measurements will help verify coronal field extrapolation models (§3.3.6) and constrain active region models (e.g., Dove et al. 2011). The observations will be regular and sustained allowing study of active region evolution and filament formation (Sun et al. 2012).

Critical science to address:

1. What is the helicity content of coronal loops? Does the helicity vary along the loop length, and can helicity variations be used in understanding the lack of large scale loop expansion with height? To what extent is braiding observed in coronal loops? What are the implications of observed braiding for reconnection and heating?
   Relevant Science Use Cases: 21, 33, 50

2. What is the topology of the magnetic field in a prominence/filament? Does the topology differ for different prominence types?
   Relevant Science Use Cases: 16, 30, 34, 70, 71, 75, 105, 138, 163, 209, 210, 248, 259, 261

3. How well can the helicity budget of the solar atmosphere be constrained by photospheric and chromospheric helicity flux measurements?
   Relevant Science Use Cases: 99, 152

4. Can the helicity in eruptive structures be measured, and does it increase in the run up to an eruption? Does the observed helicity buildup before a coronal mass ejection support a particular trigger mechanism?
   Relevant Science Use Cases: 11, 12, 29, 36, 48, 95, 111, 133, 226

5. What is the best way to model the coronal magnetic field from measurements? Are the magnetic fields in the solar atmosphere better approximated by a nonlinear force-free models than a linear ones, or neither? Does this depend on the magnetic structure being observed?
   Relevant Science Use Cases: 80, 159, 287

6. What is the underlying magnetic field structure of a prominence? How does it evolve with time? What is the origin of the vigorous vortical motions observed as solar tornados? What is the role of these in prominence stability and in driving mass motions and heating?
   Relevant Science Use Cases: 13, 34, 99, 118, 148, 149, 171, 182, 226, 248, 259, 261

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

3.4.1 Long-Term Studies of the Sun

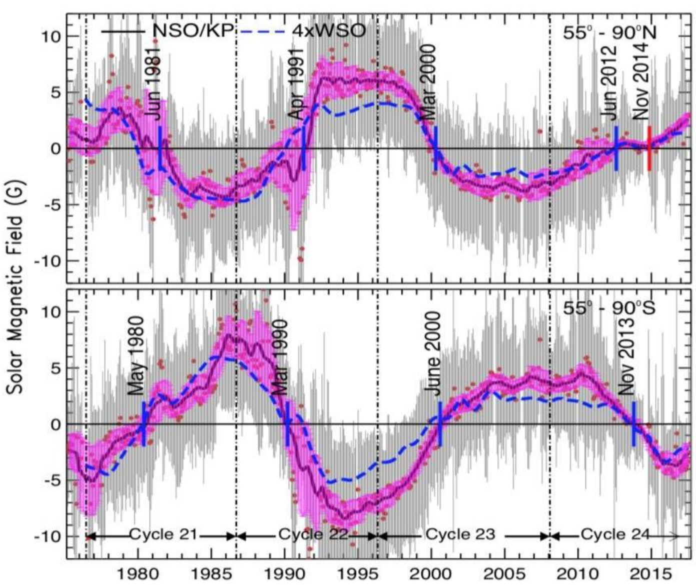


Figure 27. Polar field strengths from NSO/KP (red dots with 1σ error bars (gray)) over the latitude range 55-90 degrees in the solar northern (top) and southern (bottom) hemispheres. A smoothed curve with 1σ error bars in purple and pink respectively. A dashed blue curve over plots polar field measurements from the Wilcox Solar Observatory. Field reversals, determined from NSO/KP smoothed curve, are marked by blue vertical lines. The red vertical line marks the completion of polar reversal in Cycle 24. From Janardhan et al. 2018, A&A (reproduced with permission; copyright 2018 European Southern Observatory).

What are the cycle dependencies of the properties of the small-scale magnetic flux? Does internetwork magnetism show cycle variations? How do the polar magnetic field and flows evolve with the solar cycle? Are there systematic changes in prominence/filament magnetic fields which reflect a helicity cycle?

DKIST will provide regular, sustained and repeated photospheric, chromospheric and coronal measurements of specific targets using very similar instrumental configurations over many years. The advantages of such repeated long-term observations of the Sun are most evident in the context of the large-scale solar dynamo. Though the global magnetic field of the Sun evolves over the 11-year activity cycle, its detailed behavior likely depends on physical processes that occur on smaller spatial and shorter temporal scales. Many questions regarding the connections between small-scale processes and long-term behavior remain unaddressed due to a lack of high-resolution high-sensitivity spectropolarimetric observations of the kind DKIST will make over an extended period of time. In addition, DKIST will make regular detailed maps of the coronal magnetic field, a unique observational capability currently missing. Together with coordinated in-situ observations by space missions such as the Parker Solar Probe and Solar Orbiter, these synoptic coronal measurements will be used to understand the Sun's cycle-dependent influence on the heliosphere (§3.4.5). Both types of synoptic observations can also used as benchmarks in the study of activity cycles of other stars (e.g., Brun & Browning 2017), allowing further contextual understanding of the Sun's behavior.

Facular-scale magnetic elements are the building blocks of the magnetic field at the solar surface. In some dynamo models they play an essential role in transport, flux cancelation and field reversal (e.g., Charbonneau 2010 and references therein), but systematic study of their motions and mutual interactions over time scales during which they are subject to differential rotation and meridional flow (such as those of Lamb (2017)) has not been undertaken in a latitude and cycle-dependent manner. In particular, facular fields that survive cancellation converge by meridional circulation at polar latitudes (e.g., Tsuneta et al. 2008). There they form large-scale unipolar polar caps, with dynamo implications and global heliospheric influence (Petrie 2015), but our knowledge of the details of their distribution, dynamics and behavior in the polar regions is limited by spatial resolution constraints associated with foreshortening (Petrie 2017).

The spatial resolution capabilities and polarimetric sensitivity of DKIST are essential to addressing this problem. The multi-instrument capabilities of DKIST will enable polar field maps at complementary wavelengths, over different fields of view and at cadences that maximize the coverage and resolution of long- and short-term polar field evolution at different heights in the atmosphere. These advantages extend to the application of local helioseismic, local correlation tracking and structure tracking techniques at high latitudes. With SDO/HMI (resolution 0.5 arcseconds per pixel), solar meridional and zonal flows can be recovered up to latitudes of about 75 degrees. DKIST's better than 0.1" arcsec resolution and superior sensitivity will allow application of these techniques at latitudes reaching 90 degrees during March and September when the solar poles are most visible. Though making such high resolution near limb observations over a large enough field of view will be challenging, achieving them repeatedly over the course of a solar cycle will likely yield crucial insights into the time dependent nature of high latitude meridional and zonal flows, a critical missing piece in our understanding of global flux transport, highly relevant to its role in the global dynamo process.

The contribution of small-scale magnetic structures (below the resolution element of current observations) to the total solar irradiance is also still not fully understood (discussion in §3.1.3). In particular, the radiative output of magnetic elements, and the spectral distribution of that output, is strongly dependent on the spatial substructure of the elements (Okunev and Kneer 2005, Criscuoli and Rast 2009, Uitenbroek and Criscuoli 2011). Not knowing that substructure introduces significant uncertainty into present day irradiance models (Peck et. al 2019). Given that quiet sun covers approximately 90% of the solar surface and contributes substantially to the disk-integrated magnetic surface flux, changes over the solar cycle in the size distribution or structure of small-scale magnetic elements could play a significant role in the inferred irradiance trends (Harder et al. 2009, Ermolli et al. 2013). Systematic, long term observations with DKIST, combining the highest spatial resolution imagery with the highest concomitant polarimetric sensitivity, will be essential in addressing this problem.

In addition to magnetic element contributions, variations of the temperature gradient in the deep solar photosphere (below 60 km above the 500 nm continuum) may contribute to cycle-dependent irradiance variability (Faroubert et al. 2016). Global structural changes are suggested by observations of the frequencies of the acoustic p-modes, which show solar-cycle variation (e.g., Fossat et al. 1987, Libbrecht and Woodard 1990, Salabert et al. 2015), and are evident in MHD simulations, which display decreasing temperature in the low photosphere with increasing internetwork magnetic field strength (Criscuoli 2013). Observational confirmation of these suggestions of structural change by direct measurement of the temperature gradient over the solar cycle is needed, particularly at high resolution so that the role of currently unresolved magnetic elements can be elucidated. The method introduced by Faurobert et al. (2016) derives the temperature gradient on an absolute geometrical scale based on spectroscopic observations at different heliocentric angles. It is well tailored to exploit high resolution observations, suited to ground-based observations (Faurobert et al. 2018) and it can be readily extended to synoptic DKIST observations in multiple spectral lines.

Beyond these studies of small scale fields and irradiance variation, synoptic studies of prominence/ filaments are important. Prominences/filaments in active regions and in the quiet Sun participate in and change with the solar cycle (e.g., Zhang and Low 2001, Pevtsov et al. 2014, Mackay et al. 2018) and make a significant contribution to space weather (e.g., Kilpua et al. 2019). Filament models usually rely on measurements of the underlying photospheric field and emission patterns in the chromosphere. This is because, though filament magnetic fields have been intermittently measured in the past (e.g., Leroy et al. 1983, Xu et al. 2012, Kuckein et al. 2012, Sasso et al. 2014, Diaz Baso et al. 2019a,b), they have not been regularly measured, so we have only limited understanding of the range of properties displayed or the variation of those with the solar cycle; no cycle-length synoptic program to directly measure chromospheric filament magnetic fields has been undertaken. This will be possible with DKIST. DKIST's multi height capabilities will clarify the three-dimensional helical magnetic structure of prominences/filaments (§3.3.7) and its evolution, and be able to supplying space weather models with direct field measurements. Additionally, it may be possible to extend and enhance space weather models and prediction by providing measurements of the underlying near-surface flows (Hindman et al. 2006). Synoptic, continuous, high-cadence and high-resolution observations for several hours at a time, in conjunction with high-resolution local helioseismological analysis, will allow improved measurements of the local subsurface shear layer, which is likely central to filament formation, dynamics and evolution.

More broadly, synoptic DKIST observations of the low solar corona will benefit collaborative science with the Parker Solar Probe and Solar Orbiter missions (§3.4.5 below). The in-situ measurements from these missions often require heliospheric field models for context and interpretation. DKIST's Cryo-NIRSP instrument will be able to make direct coronal spectropolarimetric measurements over one solar rotation before and then spanning the spacecraft encounter windows. These measurements can help provide stronger constraints on the heliospheric field models. While the best input for those models is still uncertain and line of sight integration through the optically thin corona will pose difficulties, initially measurements of the forbidden Fe XIII line at 1075 nm will be used diagnose the magnetic field. These will include measument of the Stokes V component, accessible to DKIST because of its anticipated exquisite polarization sensitivity and calibration accuracy.

Critical science to address:

1. What are the cycle dependencies of the properties (scale distribution, emergence rate and latitude, cancellation and transport efficiencies, helicity) of the small-scale magnetic flux? Does internetwork magnetism in the quietest regions of the Sun show cycle variations? Does the quietest granulation itself show any statistical variation with cycle?
   Relevant Science Use Cases: 20, 27, 54, 82, 208, 243, 247, 250

2. What are the root causes of irradiance variations with the cycle? How does the spectral output of small scale magnetic structure change with the cycle? Can we identify variations in the thermodynamic state of the quiet-Sun photosphere with the cycle?
   Relevant Science Use Cases: 54, 247

3. What is the spatial distribution of the polar magnetic field? How does it vary with solar cycle? How do the polar facular field elements interact over short and long timescales, particularly during times of rapid polar field changes such as polarity reversals?
   Relevant Science Use Cases: 27, 151, 249

4. What are the meridional and zonal flow patterns at the poles, at and below the surface? How do they vary over the solar cycle? How do these patterns relate to the history of flux transport from lower latitudes?
   Relevant Science Use Cases: 244, 260

5. What cycle and hemisphere dependent patterns of filament and cavity magnetic fields will direct and systematic measurement reveal? How do these patterns relate to the measured photospheric field, filament morphology and streamer/pseudostreamer structure? Can direct filament field measurements improve the performance of space weather models?
   Relevant Science Use Cases: 211, 213, 248, 272, 278

6. What are the surface and subsurface flow patterns and how do they and the near surface shear layer vary in time and space? How do they inform our

understanding of filament formation and evolution? Can they be use to improve space weather modeling and forecasts?
Relevant Science Use Cases: 245, 251

3.4.2 Turbulence and Reconnection Processes

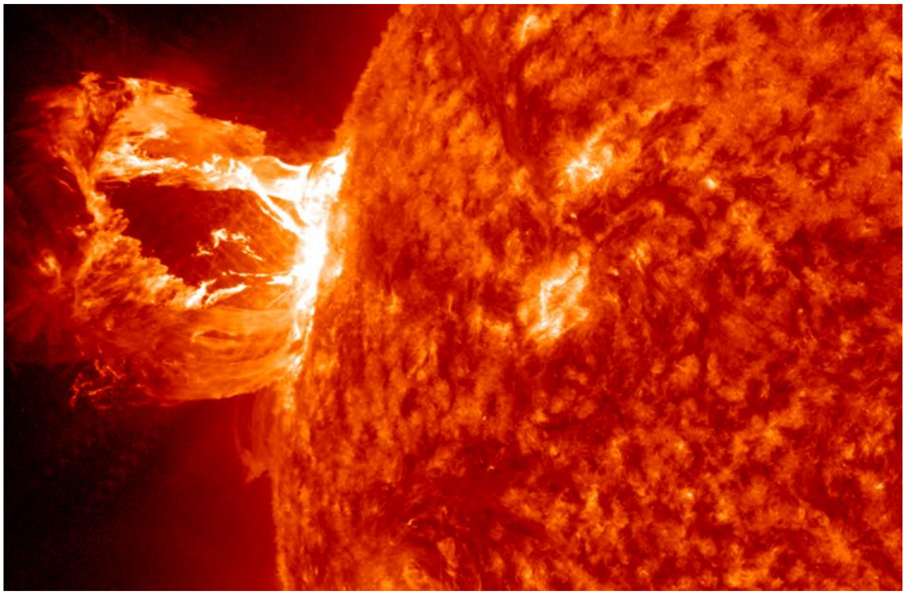


Figure 28. Prominence eruption on 16 April 2012 observed with SDO/AIA at 304Å. The resulting Coronal Mass Ejection was accompanied by an M1.7 flare at 17:45 GMT. Courtesy NASA/SDO/AIA. ***https://www.nasa.gov/mission_pages/sunearth/news/News041612-M1.7flare.html***

Where is the turbulence and what causes it? Is there evidence for magnetic island / plasmoid formation during reconnection in the solar atmosphere? How role do ion-neutral collisions play in these processes?

The observational capabilities of the DKIST offer the opportunity to study the Sun as a plasma laboratory in order to learn more about the processes underlying reconnection, turbulence and dynamo action in the regime of strong nonlinearity, low molecular diffusivity and partial ionizaton.

Turbulence is a state of fluid motion that is characterized by unpredictable flow trajectories, a wide range of spatial and temporal scales, and a high degree of vorticity. The fundamental aim of turbulence research is to understand its properties well enough to be able to predict the transport of scalar and vector quantities. While, based on an assessment of molecular transport coefficients (Parker 1979, Miesch 2005, Lingam et al. 2017 and references within these), the solar convection zone is very likely turbulent below the photosphere, granulation may not be (Loughhead and Bray 1959, Nordlund et al. 1997). Solar granulation is dominated by the local dynamics of a strongly radiatively cooled highly stratified boundary layer (e.g., Nordlund 1985, Rast 1995, Stein and Nordlund 1998, Nordlund et al. 2009). Upwelling fluid entering the photosphere from below is laminarized by rapid expansion due to the steep mean stratification, and downflowing plumes, initiated in the photosphere, advect flow instabilities out of the readily observable region (Rast 1998). While the two-dimensional transport properties of the observed photospheric flows (e.g., Abramenko et al. 2011, Agrawal et al. 2018) are interesting, critical to some dynamo models (e.g., Charbonneau 2010 and references therein), and may contain clues about the convective driving scales at depth (Lord et al. 2014, Cossette and Rast 2016), at the resolution of current observations these flows show little direct evidence of turbulence.

It is very possible that at DKIST resolution the granular flows will appear significantly more structured than they do at lower resolution. Very high resolution Doppler imaging with Imaging Magnetograph eXperiment (IMaX) instrument (Martínez Pillet et al. 2011) on the first flight of the Sunrise stratospheric balloon (Solanki et al. 2010) revealed that, in small compact regions, granular upflows reach peak speeds approaching those found in downflows (McClure et al. 2019). This substructuring may continue to even smaller scales. Moreover, with DKIST spatial resolution and sensitivity it may be possible to resolve the flow gradient structure in the deep photosphere (Khomenko et al. 2010) and/or the onset of turbulent instabilities at the shear interface between the granular upflows and the intergranular downflow lanes. In numerical simulations these instabilities lead to recirculation of small scale mixed polarity magnetic field several minutes after new downflow plume formation (Rempel 2018). Observations of the properties of such recirculating flows and fields may provide key constraints on the relative importance of deep and shallow recirculation to the operation of the Sun's small scale dynamo (§3.1.1), and perhaps more broadly address the detailed structure of the photospheric boundary layer with implications for deep convection below (Rast and Trampedach 2020). Such future work may be able to both leverage and augment the rich history of research focused on the Earth's convective planetary boundary layer (e.g., Willis and Deardorff 1976, Kaimal et al. 1976, Lenschow and Stankov 1986, Moeng et al. 2009, Sullivan and Patton 2011, van Heerwaarden et al. 2014), to understand how the mean boundary layer structure is established at the interface between deep convection and discrete downflow (on Earth upflow) plume structures. Additionally, though the concept of turbulent spectral line broadening (e.g., Gray 2005) may not be useful in high resolution photospheric observations (Asplund et al. 2000, Khomenko et al. 2010), it is still used in the interpretation of stellar photospheric lines (e.g., Sheminova 2019) as a way to capture unresolved motions, and may also provide insight in the case of less than "perfectly" resolved solar observations (Ishikawa et al. 2020). There is some evidence that a more careful assessment of the solar photospheric velocity field could improve stellar photospheric spectral line modeling (Takeda and UeNo 2017). Confident progress toward elimination or accurate representations of non-thermal broadening parameterizations in spectral modeling of solar chromospheric, transition region and coronal lines awaits DKIST resolution of small-scale flow structure (e.g., Cauzzi et al 2009, De Pontieu et al. 2015, Leenaarts et al. 2018).

In the so-called "local dynamo" scenario, convective turbulence in the quiet Sun is responsible for the creation and structuring of weak small-scale magnetic field (§3.1.1), with convective motions at the granular and subgranular scales determining the topology of the field and its degree of "entanglement." The Hanle effect is a key tool for investigating this aspect of solar magnetism because depolarization of scattered photons is sensitive to the presence of small-scale tangled magnetic fields (e.g., Trujillo Bueno et al. 2004). The Zeeman effect, by contrast, is blind to mixed polarity field on scales much smaller than those that can be resolved. Since the amplitude of the Hanle scattering polarization signal is very low, the limited resolution and polarimetric sensitivity of current observations only allows determination of an upper limit to its value and spatial variation (e.g., Zeuner et al. 2018). With the increased resolution and polarimetric sensitivity of DKIST, the degree to which the Zeeman and Hanle measurements differ will become a critical measure of the scale at which the field is generated. However, fundamental advances in our understanding of the Hanle signal are required. For example, interpretation of the scattering polarization signal at a single wavelength depends on knowledge of the anisotropy of the illuminating radiation field. This is difficult, but can be overcome either by using realistic radiative hydrodynamic models of the solar photosphere to constrain the radiation field (Trujillo Bueno et al. 2004) or by employing differential measures of two or more spectral lines with similar formation properties and varying Hanle sensitivity (e.g., Kleint et al. 2010, 2011). The broad spectral coverage offered by the ViSP spectro-polarimeter will allow the simultaneous monitoring of multiple lines with differing Hanle sensitivities, allowing the development of inversion methodologies and contributing to a deeper understanding of the processes that can affect scattering polarization. Consequent detemination of both the strength and direction of the weak fields pervading solar photosphere and systematic monitoring of this "turbulent magnetic field" over a solar cycle (§3.1.1) will then provide evidence as to whether the field is of a local or larger-scale origin.

Pre-DKIST evidence for turbulence has been found in the vicinity of chromospheric shocks which result from the steepening of acoustic waves as they propagate upward from the photosphere (Reardon et al. 2008, De Pontieu et al. 2015). The generation of post-shock turbulence may provide a mechanism for the dispersal of the wave energy beyond the local shock region itself, and may thus be important for chromospheric heating. Because the region in which the energy is deposited is permeated by magnetic field, it may also play a role in wave-mode conversion, coupling the acoustic waves to Alvénic motions that continue to propagate outward, transmitting energy to higher layers of the solar atmosphere (Reardon et al. 2008). While direct investigation of shock heating by plasma processes at the dissipative scale is out of reach, DKIST may be able to probe the larger-scale properties of the shock region to infer the MHD shock type (e.g., Delmont and Keppens 2011, Priest 2014) and the shock instability processes. Short-period acoustic waves propagating upward into the solar chromosphere develop into radiatively damped weak shocks within the first few hundred kilometers above the photosphere, while longer-period waves develop into strong shocks in the upper chromosphere (above 200km), where radiative damping is less effective (Priest 2000). A number of shock instability mechanisms have been identified in other settings, MHD wave breaking (Moore et al 1987), radiative instability of the shock front (e.g., Smith 1989, Mignone 2005) and shock front distortions due to plasma inhomogeneities (Brouillette 2002, Zhou 2017 and references therein, Markhotok 2018). In order for any of these to occur in the chromosphere, not only must the instability mechanism be feasible, but it must occur on a time scale short compared to shock-damping rates (Hollweg 1987, Lanzerotti and Uberoi 1988). Only preliminary numerical explorations of shock interactions within the complex solar atmosphere have been undertaken (Santamaria et al. 2016, Popescu Braileanu et al., 2019a,b). Idealized studies of shock-instability mechanisms in a magnetized and partially ionized plasma constrained by observations at DKIST's spatial and temporal resolution, should lead to a more complete understanding of the physical process responsible for shock-induced turbulence in the solar chromosphere. This in turn may then help to constrain the underlying the plasma processes that result in chromospheric heating and particle acceleration.

Magnetic reconnection is similarly a process that occurs at fundamental scales well below DKIST resolution, but to the understanding of which DKIST can contribute. Observations of macroscale flows associated with a canonical reconnection configuration of a flaring region are quite convincing (Wang et al. 2017a), but smaller scale evidence that can be used to constrain the physical processes involved are more elusive. Many studies, starting with the pioneering work of Forbes and Priest (1983a,b), indicate that magnetic reconnection is enhanced as a result of magnetic island formation in the plasma current sheet. Magnetic island formation appears to be ubiquitous, occurring with or without ion-neutral collisions and with or without a guide field which tends to reduce the importance of ambipolar diffusion (e.g., Loureiro et al. 2007, Bhattacharjee et al. 2009, Leake et al. 2012, Mei et al. 2012, Murphy et al. 2012, Ni et al. 2015, Innes et al. 2015, Peter et al. 2019). Further, while the magnetic islands likely lie well below current and future observational capabilities, bright localized plasmoid-like ejecta (sometimes distinguished as blobs) have been reported in post coronal mass ejection current sheets in the solar corona (e.g., Riley et al. 2007, Wang et al. 2007, Takasao et al. 2012, Guo et al. 2013) and at smaller scales in chromospheric jets and Ellerman bomb events (e.g., Hu et al. 1995, Shibata et al. 2007, Singh et al. 2012, Rouppe van der Voort et al. 2017). It may be possible to use the statistics of these macroscale events to constrain the reconnection magnetic field and flow configuration and the underlying reconnecttion processes (e.g., Lin et al. 2007, Lin et al. 2008, Song et al. 2012, Guo et al. 2013, Rouppe van der Voort et al. 2017). DKIST spatial and temporal resolution will be essential for this. Further, very recent work suggests that, while magnetic island substructure in the reconnection current sheet is not resolvable, it may be possible to assess the overall complexity of the underlying unresolved field by measuring a reduction in linear polarization (French et al. 2019).

Critical science to address:

1. Is there evidence of turbulence in quiet-sun solar granulation? What can be deduced about the structure of the granular boundary layer from the recirculation of magnetic field following granule fragmentation?
   Relevant Science Use Cases: 13, 21, 25, 39, 41, 54, 55

2. What are the time-dependent properties of the turbulence generated by shock passage in the chromosphere? What processes are responsible for the generation of turbulent flow?
   Relevant Science Use Cases: 84, 255

3. What is the origin of nonthermal line broadening in the solar chromosphere, transition region and corona? How do resolved observations of the Sun inform stellar spectral line modeling?
   Relevant Science Use Cases: 145, 182, 217, 255, 270

4. Is there evidence for magnetic island / plasmoid formation and consequent enhancement of reconnection rates in the solar atmosphere? What role do ion-neutral collisions play?
   Relevant Science Use Cases: 19, 78, 91, 108, 134, 154, 203, 211, 214, 234

5. Can we untangle the signatures of reconnection processes in the small scale evolution of flaring regions?
   Relevant Science Use Cases: 58, 227

3.4.3 Sun-Grazing Comets

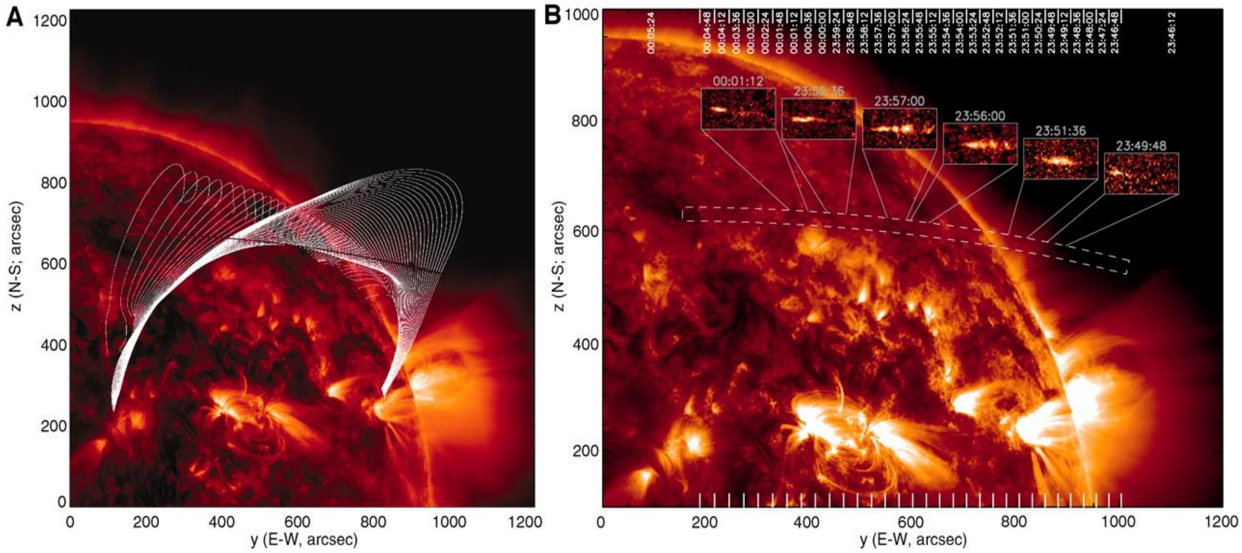


Figure 29. (A) EUV (AIA 171 Å) image of the solar corona, overlaid in black with the projected orbit of the comet C/2011 N3. Orbital positions marked by plus signs were used as starting points in a three-dimensional PFSS extrapolation of the Sun's magnetic field lines shown in white. (B) Composite of AIA 171 Å images of the comet moving within the dashed outline. The six insets show an enlarged view of the comet at selected times in running difference images. From Schrijver et al. 2012, Science (reproduced with permission; copyright 2012 American Association for the Advancement of Science).

What can we learn from Sun-grazing comets about the solar corona and cometary composition and structure? Are Sun-grazing comets a significant source of solar wind pickup ions?

Comets are among the most pristine bodies within the solar system. They provide critical clues about our solar system's formation and the origin of life on Earth. Typically, 0.3-5 km in radius, comets are composed of a mixture of icy, organic and silicate materials. Sun-grazing comets, those with perihelion distances of less than a few solar radii ($< 3.45\ R_S$ from the Sun's center, within the fluid Roche limit, Jones et al. 2018), are valuable tools in both cometary and coronal studies. The intense solar radiation during their close perihelion passages evaporates thick layers of near-surface material, exposing their otherwise invisible pristine interiors, and their high-speed intrusion into the million-degree magnetized solar corona, in extreme cases skimming or plunging into the solar surface (Brown et al. 2015), makes them natural probes of regions of the solar atmosphere inaccessible to human-made in-situ instruments.

Over the past two decades, solar space missions have contributed significantly to the study of Sun-grazing comets. The LASCO white-light coronagraph onboard SOHO has observed more than 3200 Sun-grazing and near-Sun comets, with an average occurrence rate of one every two-to-three days (Battams and Knight 2017). Additionally, a key advance over this past decade, has been the detection of Sun-grazing comets, notably comets C/2011 N3 (SOHO) and C/2011 W3 (Lovejoy), in the lower corona, usually blocked by a coronagraph's occulting disk, using (E)UV instruments onboard SDO, STEREO, and SOHO. Such observations have provided unique diagnostics of the coronal plasma and magnetic fields (e.g., Schrijver et al. 2012, Raymond et al.

2014, Downs et al. 2013). In this same period, ground-based solar telescopes have also successfully observed Sun-grazing comets, including C/2012 S1 (ISON) with NSO's Dunn and McMath-Pierce Solar Telescopes (Wooden et al. 2013) and with the Mees Observatory's coronagraph on the summit of Haleakala, Maui, HI (Druckmuller et al. 2014), and DKIST is well poised to play a unique role in these studies over the coming decades (Raymond et al. 2019).

Unlike virtually all other remote sensing diagnostics of the solar corona, which are subjected to either line-of-sight integration or height ambiguity, Sun-grazing comets take a very localized path through the corona, thus serving as probes. The comets interact with the plasma producing observable signatures along a specific path through the three-dimensional corona. To date, this has largely been exploited at UV and EUV wavelengths. For example, O III and O VI emission from photo-dissociated cometary water has been used to diagnose the magnetic field direction and plasma density in the corona (Raymond et al. 2014). Using DKIST's coronographic capabilities, comparable analysis may be possible by observing lines of photo-dissociated silicates, such as Si IX, with Cryo-NIRSP. Similarly, observations of Lyman-alpha emission during passage of Sun-grazing comets has been used to estimate the coronal density, temperature and solar wind velocity (Bemporad et al. 2015). The same techniques may be possible with DKIST using H-alpha or Paschen-alpha. Moreover, ion tails have been seen accompanying a few Sun-grazers in white light (Jones et al. 2018), and their presence in exocomets is inferred from Ca II absorption (Kiefer et al. 2014). Observations of interactions between comet tails and the heliospheric current sheet during cometary crossings may provide constraints on the current sheet morphology and the solar wind structure in the inner heliosphere (see Jones et al. 2018 and references therein). Such observations in the inner corona by DKIST would be groundbreaking.

Beyond diagnostics of the solar corona, DKIST promises to contribute directly to the cometary science. Most fundamentally, it will enable measurements of the size and composition of cometary cores (Bryans and Pesnell 2016) as they are exposed very close to the Sun, too close for observation using night-time telescopes. While some Sun-grazing comets, such as Lovejoy and ISON are discovered at great distances from the Sun and followed to their perihelia, many are not active enough to be observed at larges distances and are first noticed close in to the Sun, within the field of view of the LASCO coronagraph. At these distances, cometary material sublimates rapidly and is photo dissociated to form atomic species which are then ionized through successive ionization states (Bryans and Pesnell 2012, McCauley et al. 2013). Optical and infared line emission is largely confined to a small region surrounding the nucleus of the comet. Time-dependent variations in the emission allow characterization of both the cometary material and the local coronal plasma environment. DKIST's unique combination of capabilities will make these otherwise very difficult spectrographic measurements of pristine cometary material possible. Its near infrared capabilities will enable measurements of cometary dust temperatures and dust sublimation rates. These are particularly important in advancing our understanding the origin of cometary neutral tails (e.g., Cremonese et al. 2002), and may be critical in determining the inner source of pickup ions in the solar wind (e.g., Bzowski and Królikowska 2005). Finally, previous attempts to determine the tensile strength (if any) of Sun-grazing comets, an important measurement in the context of planetesimal formation, from their breakup (Öpik 1966, Klinger et al. 1989) have been inconclusive. DKIST will bring much higher spatial resolution to bear on the assessment of cometary fragmentation processes.

Critical science to address:

1. What is the composition of the Sun-grazing comets? What are their typical sizes?
   Relevant Science Use Cases: 279

2. What are the dust ablation rates as a comet nears the Sun? How does this inform our understanding of the origin and observed distributions of neutral Na and Fe in cometary tails? How does it inform our understanding of the dust distribution in the inner corona?

3. What is the tensile strength of cometary material? What are the dominant physical processes in comet fragmentation? What causes fragmentation events that occur before tidal forces dominate?

4. What interactions occur between cometary and coronal material? How can we use DKIST measurements of time-dependent changes in the molecular and ion state as the outgassed material to retrieve the local coronal plasma properties and magnetic field?
   Relevant Science Use Cases: 218, 279

5. Are Sun-grazing comets significant contributors to the inner source of dust and solar wind pickup ions?

3.4.4 Mercury Transit Science

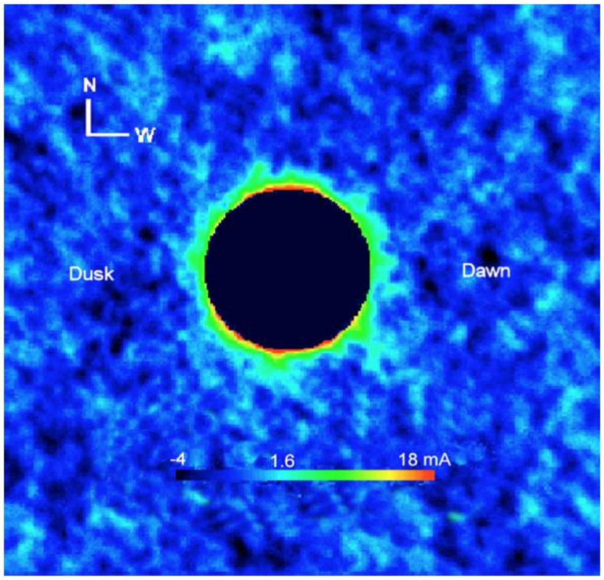


Figure 30. The distribution of equivalent width of sodium absorption around the disk of Mercury during the 8 November 2006 transit. Noise outside the region of sodium absorption is the result of fluctuations in solar intensity. The strongest absorption is found over Mercury's north and south poles, without the dawn/dusk terminator difference found in the previous transit (Schleicher et al. 2004). From Potter et al. 2013, Icarus (reproduced with permission; copyright 2013 Elsevier).

What can we learn about Mercury's atmosphere and its seasonl variations from DKIST observations of Mercury's transit across the Sun? Can the resonance absorption lines of K and Ca be observed at DKIST sensitivities?

There was some hope that early DKIST observations might overlap with the 11 November 2019 Mercury transit. Unfortunately, it was not possible to meet that aggressive goal which lay outside of the nominal DKIST construction timeline. We include a brief description of the science goals of Mercury transit observations here to illustrate the scientific flexibility of the DKIST observing system and to point to future possibilities within the DKIST lifetime. The next partial Mercury transits visible from Haleakala are one ending in the early morning of 7 May 2049 and one midday to sunset on 8 November 2052.
(https://eclipse.gsfc.nasa.gov/transit/catalog/MercuryCatalog.html,
https://www.timeanddate.com/eclipse/in/usa).

Mercury has a non-spherical seasonally varying exosphere (e.g., Domingue et al. 2007, McClintock et al. 2008, Cassidy et al. 2015, Vervack et al. 2016, Merkel et al. 2017) and a dynamic magnetosphere with dayside reconnection and magnetotail activity resembling that found at Earth (Slavin et al. 2009, 2010; Bagenal 2013). Full characterization of this unique atmosphere is challenging. Traditional remote sensing techniques are difficult due to the Sun's proximity and downlink limitations led to NASA's MESSENGER orbiter carrying a single point rather than slit scanning spectrometer. To date, observations of absorption by Mercury's atmospheric constituents during rare solar transits has offered some of the highest spatial, temporal and spectral resolution observations (Figure 30, Schleicher et al. 2004, Potter et al. 2013, Schmidt et al. 2018). So far only sodium in Mercury's atmosphere has been measured via its absorption signature, but with DKIST's sensitivity, observations of the K and Ca atomic resonance absorption lines may be possible. The distribution of these in the Mercury atmosphere would constrain source and loss processes (Burger et al. 2012). It may also be possible to use broad-band absorption measurements to determine the dust density distribution around the planet.

Scientific use of Mercury transit measurements has progressed rapidly despite the rarity of transit events. Detection of Na I absorption in transit spectroscopy was first made by Schleicher et al. (2004). This provided convincing evidence for a dawn-side enhancement in Mercury's exosphere. Sodium absorption as measured by Potter et al., 2013 was markedly different because of what is now understood as seasonal variation also seen in MESSENGER orbiter data. This was confirmed by later observations (Schmidt et al. 2018) which showed nearly identical Na distribution as the earlier 2004 observations taken during the same Mercury season. Further, the quality of the 2018 observations allowed measurements that spatially resolved the Mercury atmospheric scale height (~100 km) and enabled study of the exospheric time-dependence induced by solar wind interactions. During future transits, DKIST capabilities will enable spectral analysis of Doppler velocities, ~90 km resolution of the atmospheric stratification and temporal resolution of solar wind and interplanetary magnetic field angle influences.

Critical science to address:

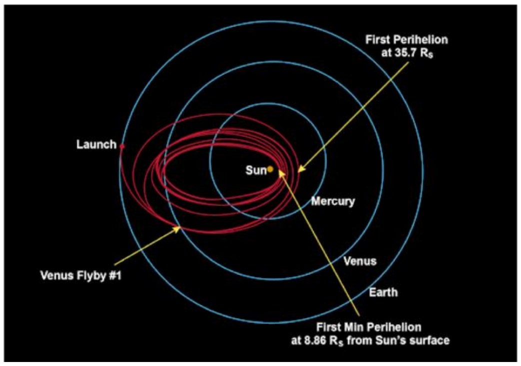
1. Can K and Ca atomic resonance absorption be measured along with Na in the Mercury exosphere during transit?
   Relevant Science Use Cases: 253

2. Can broad-band dust absorption be used to characterize the dust distribution around Mercury?
   Relevant Science Use Cases: 253

3. Can Doppler shifts due to exospheric motions be detected?
   Relevant Science Use Cases: 253

3.4.5 Synergistic Opportunities with In-Situ Measurements

(*a*) (*b*)



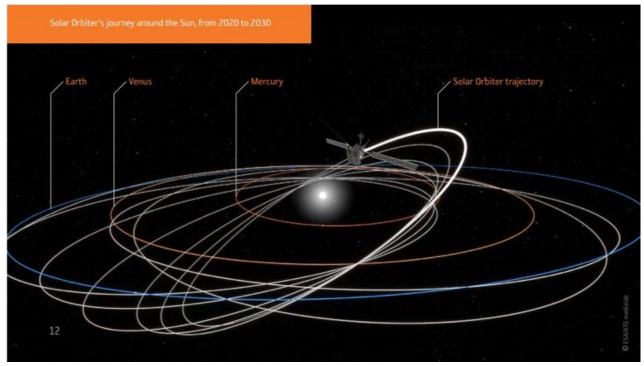


Figure 31. The Parker Solar Probe and Solar Orbiter missions will make in-situ and remote sensing measurements of the Sun and inner heliosphere from unique perspectives. (a) Parker Solar Probe will reach to within 9 solar radii of the solar surface in December 2024 (http://parkersolarprobe.jhuapl.edu), and (b) Solar Orbiter will orbit the Sun with a maximum inclination of 24 degrees (up to 33 degrees in an extended mission) with respect to the solar equator and a perihelion distance of about 60 solar radii (https://sci.esa.int/web/solar-orbiter).

How well can the magnetic connectivity be established between processes on the Sun and the in-situ measurements of Parker Solar Probe and Solar Orbiter? Which aspects of the in-situ measurments originate at the Sun and which result from subsequent instabilities in the solar wind?

DKIST, Parker Solar Probe and Solar Orbiter will together allow unprecedented synergistic study of the connectivity between the solar corona and the inner heliosphere. Parker Solar Probe and Solar Orbiter will make in-situ measurements of the inner heliospheric electric and magnetic fields and plasma kinetic properties, while DKIST and Solar Orbiter will image and make spectropolarimetric measurements of high precision of the solar atmosphere from the deep photosphere to the corona. The combined capabilities of these assets will revolutionize our understanding of how stars create and control their magnetic environments (Martinez Pillet et al. 2020).

Parker Solar Probe's close approaches to the Sun and Solar Orbiter's inclined orbit with perihelia inside the orbit of Mercury (Figure 31), will allow direct sampling of the solar wind plasma before it has undergone extensive evolution and mixing. The plasma sampled will preserve many of the signatures of its origins, allowing assessment of the origin and acceleration mechanisms underlying the different solar wind components. Moreover, the proximity to the Sun of Parker Solar Probe's perihelia allows periods of co-rotation with the solar surface and more importantly with the magnetic field that originates there. This will enable studies of the relationship between temporal variations in the wind and short term changes at the source. Separating these from the variations due to the spacecraft motion across solar wind structures is critical to understanding both the source behavior and the secondary development of the wind itself. Similarly, periods of quasi-corotation by Solar Orbiter will enable extended observations of the same solar region (Müller et al. 2013). These periods will help connect solar activity evolution to changes in the wind over somewhat longer time periods. Finally, Parker Solar Probe will spend about fifteen hours below ten solar radii, during which it will likely sample the sub-Alfvénic solar wind, allowing direct assessment of the conditions under which solar wind heating and acceleration likely occur (e.g., Cranmer and van Ballegooijen 2005). These scientific goals all require, or strongly benefit from, knowing how the regions of in-situ heliospheric measurements are connected to the magnetic field and particle source regions in the solar atmosphere. DKIST's ability to quantitatively map the magnetic field of the chromosphere and low solar corona will significantly improve our ability to map the connectivity between the particle and fields measured in the inner heliosphere and their source regions on the Sun (§3.3.2, §3.3.6). That mapping currently relies on field extrapolation (e.g., Badman et al. 2020) or magnetohydrodynamic models that employ moderate resolution synoptic photospheric magnetograms (van der Holst et al. 2019, Riley et al. 2019). Both of these methods will significantly benefit from high-resolution, multi-height DKIST data.

Moreover, the chemical composition of the solar wind is a key indicator of its origin (e.g., Geiss 1995, Parenti et al. 2000, Brooks and Warren 2011, Brooks et al. 2015, Baker et al. 2015), and the First Ionization Potential (FIP) bias can be used to help trace that origin and establish magnetic connectivity with in-situ measurements (§3.3.1). The origin of FIP fractionation likely lies in the solar chromosphere, a region that DKIST will be able to study thoroughly. There is evidence that active regions emerge with photospheric abundances and develop a FIP bias in the chromosphere, which then propagates into the corona (Laming 2015). This is supported by an observed lag between magnetic activity indices and abundance fluctuations in the solar wind at 1 AU (WIND spacecraft at L1; Alterman and Kasper 2019). With the synergistic capabilities of DKIST and Solar Orbiter, the underlying causes for these correlations can be more directly examined. In-situ instrumentation on Solar Orbiter is designed to measure abundance ratios, and the FIP bias measured in situ combined with chromospheric observations using DKIST will be used to more precisely assess the plasma's origin. Similarly, there is a relationship between in-situ measurements of helium at 1 AU, solar activity and solar wind speed (Aellig et al. 2001, Kasper et al., 2007, 2012; Alterman and Kasper 2019). The lowest helium abundances are observed during solar minimum and are correlated with regions of slower wind speed. The helium abundance in the fast solar wind changes little with solar cycle. The mechanisms underlying these correlations are unknown, but the combination of in-situ measurements and DKIST's unique capabilites will, again, allow new ways to investigate this fundamental problem. Previous observations indicate that depletion likely occurs below the solar corona (Laming and Feldman 2001, 2003), and models suggest that the process is sensitive to the partially ionized state of the chromospheric plasma (Laming 2015). Parker Solar Probe will make helium abundance measurements close to the Sun, reducing uncertainties in source region identification. DKIST will not only assist with that mapping but enable key chromospheric observations to address the underlying helium depletion processes.

The dust content of the inner solar corona is also a question of significant importance. It has practical importance both for the survival of the Parker Solar Probe and for coronal spectropolarimetric measurements using DKIST. Observing the white-light scattered by dust (F-corona) and electrons (Thomson scattering), the WISPR camera on the Parker Solar Probe images the large-scale structure of the corona before the spacecraft passes through it. In doing so, as perihelion is reduced, it will determine whether a dust-free zone exists near the Sun. During the innermost perihelion passage of 2024, the boundary of the WISPR field-of-view will extend down to two solar radii above the solar photosphere, close to the outermost height that will be observable by DKIST (1.5 solar radii, 0.5 solar radius above the limb). This proximity of the fields of view will provide a unique opportunity to test whether the diffuse coronal He I 1083 nm brightness reported by Kuhn et al. (1996, 2007) can be accounted for by helium neutralization on the surface of dust particles within in the hot corona, as proposed by Moise et al. (2010). That hypothesis has been difficult to test, but it is important because the He I 1083 nm line is the only permitted infrared transition available to DKIST for spectropolarimetric observations of the corona.

If the neutral helium signal indeed originates within the corona, new coronal Hanle magnetic field diagnostics are possible (Dima et al. 2016). Combined with linear polarization measurements in the Si X 1430 nm forbidden line, which is in the saturated Hanle regime under coronal conditions, polarization observations of the He I 1083 nm permitted line would enable inference of all three components of the coronal magnetic field. This would critically constrain the coronal magnetic topology, which in turn would allow improvements in the accuracy of the coronal-heliospheric models used to predict the heliospheric magnetic configuration. Such improvements are particularly important during periods in which the Sun is more active and the corona is consequently more complex than it is currently (e.g., Raouafi et al., 2016). The use of Parker Solar Probe data taken during its latter close encounters, when the Sun will likely be significantly more active than it is currently, will to some degree depend on such improvements. With this in mind, the DKIST Critical Science Plan includes a synoptic program item (§3.4.1 above) aimed at regular measurement of the solar coronal magnetic fields, in anticipation of Parker Solar Probe encounters. The lines and techniques employed in these synoptic measurements will likely evolve as we learn how to generate the best input data for the coronal models, but initially the observations will be taken in the forbidden Fe XIII line at 1075 nm, as with the current HAO/CoMP instrument but with the added capability of regularly measuring the Stokes V component, which will be accessible to DKIST because of its anticipated polarization sensitivity and can be used to infer the line-of-sight magnetic field.

Another important problem, the solution to which the synergistic capabilities of DKIST, Parker Solar Probe and Solar Orbiter may significantly contribute, is the so-called open flux problem (Linker et al., 2017, Riley et al. 2019). A significant portion of the solar surface magnetic field opens out into the heliosphere, forming coronal holes. This occurs where facular fields of a dominant polarity cover a large area of the solar surface, usually at the polar caps but also sometimes at low latitudes, and the solar wind ram pressure is sufficient to open much of the field at height. The open flux problem describes the disparity between, total open magnetic flux at the Sun, as estimated from moderate-resolution magnetographs of coronal hole regions (defined as regions dark in EUV and x-ray emission), and the total open flux as determined from in-situ measurement at 1 AU (Linker et al. 2017). The former value falls significantly below the later. This discrepancy is critical to solar wind and heliospheric modeling, which relies on the solar value, as determined from surface observations, for a boundary condition. The mismatch in measured values implies either that significant open flux is found below the sensitivity of current instrumentation, that the polar magnetic flux for example is significantly underestimated due to difficulties observing it (Riley et al. 2019), or that the open flux measured at 1 AU does not map exclusively to coronal holes. The later possibility connects the open flux problem to that of the origin of the slow solar wind, supporting suggestions that the slow solar wind arises from mixed open and closed field regions, possibly at the coronal hole boundaries (e.g., Linker et al. 2017, Owens et al. 2020 and references therein). However, it is currently uncertain what the true magnitude of the open flux problem is, whether it persists if the in-situ measurements are made in the inner heliosphere, or whether its origin lies with field reconfiguration in the solar wind inward of 1 AU. Parker Solar Probe and Solar Orbiter field measurements will be able to address this directly, within the limitations of single-point measurements (Owens et al. 2008 and references therein), and observations with the spatial resolution and polarization sensitivity available to DKIST will reveal the amount of small-scale open flux that currently remains undetected in less sensitive full-disk solar magnetograms. Together these measurements will either reconcile the in-situ and remote sensing open flux deductions or elucidate the magnitude and perhaps the source of the discrepancy.

Finally, one of the most prominent early results of the Parker Solar Probe mission has been observations of magnetic switchbacks (Bale et al. 2019, Kasper et al. 2019, Dudok de Wit et al. 2020, Horbury et al. 2020, Mozer et al. 2020), rapid changes (over intervals ranging from seconds to tens of minutes, perhaps hours) in the radial magnetic field orientation away from and then back to its original orientation, with field deflections sometimes representing full reversal with respect to the Parker spiral. Such field switchbacks are accompanied by rapid enhancement of the radial wind speed, and they are often called velocity spikes for that reason. The correlation between the magnetic field perturbations and jet like flows suggests that these events are large-amplitude Alfvénic structures being advected away from the Sun by the solar wind (Bale et al. 2019). Their origin remains uncertain. Clustering and correlation statistics of their occurrence during the first Parker Solar Probe perihelion encounter (10 day period, centered on perihelion at at ~36 R_{Sun}) suggests that they are remnants of stronger events in the low corona (Dudok de Wit et al. 2020), but comparison between perihelion (one day period at ~36 R_{Sun}) and pre-perihelion (one day period five days earlier at ~48 R_{Sun}) intervals during the second encounter suggests the number of switchbacks and the magnetic field rotation angle of the field within the switchbacks increases with increasing distance from the Sun (Mozer 2020). Theoretical work is also inconclusive, indicating that switchback like structures which originate in the lower solar corona can indeed survive in the solar wind out to Parker Solar Probe distances (Tenerani et al. 2020), but also that such structures can form in the expanding solar wind itself as growing Alfvénic fluctuations (Squire et al 2020). Sudden reversals of the magnetic field and associated jet like flows are not new to Parker Solar Probe. They have been observed over several decades in earlier in-situ measurements (see references within Horbury et al. 2020 and Dudok de Wit et al. 2020). What separates the Parker Solar Probe observations from others is the occurrence of switchbacks in relatively slow solar wind environments, and the large number and magnitude of the events. Thousands of such events have been observed by Parker Solar Probe, some in tight clusters separated by relatively event free regions. This clustering, the significant correlation of magnetic field deflection observed for clustered events and the similarity of the flows to other coronal jets supports a low coronal origin (Horbury et al. 2020). This has led to the suggestion that they are local folds in the magnetic field that originate as ubiquitous interchange reconnection events, possibly driven by the global circulation of open flux (Fisk and Kasper 2020). DKIST's chromospheric and low corona observing capabilities will be able to contribute directly to the assessment of the origin of switchbacks, by assisting in determining connectivity to the source regions, as discussed earlier, and/or by looking for evidence of interchange reconnection heating or jets in those source regions.

Critical science to address:

1. How can DKIST chromospheric and coronal heliospheric field measurements be best used to improve our ability to map the magnitic connectivity between the particle and fields measurements of Parker Solar Probe and Solar Obiter and their footpoints on the Sun? How can the in-situ measurements be used to understand and calibrate line-of-sight averaging effects in remote sensing coronal observations?
   Relevant Science Use Cases: 153, 155, 156, 158, 159, 246, 254

2. How do we best combine Parker Solar Probe and Solar Orbiter in-situ and DKIST remote sensing measurements to understand solar wind origin and acceleration? How well do elemental abundance measures in the chromosphere, corona and in situ in the inner heliosphere constrain the solar wind origin and acceleration mechanisms?
   Relevant Science Use Cases: 60, 61, 64, 88, 90, 115, 162, 222, 286

3. What do joint Parker Solar Probe and DKIST observations imply about the neutral helium abundance in the solar corona?
   Relevant Science Use Cases: 235

4. What constraints can DKIST place on the number, magnitude and correlation and clustering statistics of switchbacks if they originate with interchange reconnection events in the low solar corona?
   Relevant Science Use Cases: 284

5. How does superior spatial resolution and polarimetric sensitivity of DKIST improve our estimates of the Sun's open magnetic flux as a function of height? Is the open flux reconciled with in situ field measurements at 1 AU or elsewhere in the inner heliosphere?
   Relevant Science Use Cases: 90, 160, 246

4 References

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APPENDICES

APPENDIX A. SCIENCE USE CASES

APPENDIX B. ACRONYM GLOSSARY

Appendix A. Science Use Cases

- These abstracts were captured from the DKIST Community Jira site on 24 April 2020 and include author requested changes via email to 26 May 2020. They span a wide range in development and maturity, and should not be considered final or complete.
- Use Case numbering reflects vagaries of the Jira site on which these were developed.

UC-5: 3D Velocity Field Reconstruction of Coupled Transverse and Rotational Plasma Motions in Spicules (Rahul Sharma, University of Alcalá)

The dynamical and thermal evolution of spicules will be investigated by exploiting the highest spatial and spectral resolution spectra in G-Band, H-alpha and Ca II lines. These thin magnetic flux-tube structures are key features that populate the highly dynamical and complex solar chromosphere region and are believed to be the channels that transfer mechanical energy from photosphere to corona through waves and oscillations. It is now known, from both imaging and spectroscopic data, that spicule dynamics consist of field-aligned, transverse and torsional flow components. However, there is still no common agreement on how best to interpret these complex plasma motions from a theoretical and modelling perspective. It is thus highly crucial to estimate the motions in and around spicule structures using the highest spatial and spectroscopic instruments available. It is the key purpose of this research to combine state-of-the-art DKIST imaging and spectroscopic to reconstruct the 3D velocity field of spicules, allowing us to understand more fully the energy transport along these conduits between the lower solar atmosphere and the corona.

UC-6: Sunspot Penumbral Jets: Magnetic Setting, Coronal Emission, Twisting, and Relation to Penumbral Bright Dots (Sanjiv K. Tiwari, Lockheed Martin Solar and Astrophysics Laboratory)

Sunspot penumbral jets (PJs) and bright dots (BDs) are two dynamic small-scale events, among others, seen in the chromosphere and the transition region/corona, respectively. Their formation mechanism is not fully understood. PJs were proposed to form from component (acute angle) reconnection of the magnetic field in spines with that in interspines and were proposed to contribute to transition-region and coronal heating above sunspots. In a recent investigation, it is proposed that PJs form as a result of reconnection between the opposite polarity field at edges of filaments with spine field, and it is found that most of these jets do not significantly directly heat the corona above sunspots, but could indirectly drive coronal heating via generation of MHD waves or braiding of the magnetic field. However, there exist larger jets, repeatedly forming at tails of penumbral filaments, which directly display their signature in coronal wavelengths. BDs, discovered by IRIS, are also seen in Hi-C's sunspot data. Despite various proposals, e.g., by reconnection between spines and interspines, or by impact of downflows from the corona, the formation mechanism of BDs remains elusive. Simultaneous high cadence observations of sunspots in different wavelengths at high spatial resolution from DKIST, combined with IRIS and *Hinode*, will be required to address the above questions on the formation of PJs and BDs and on their contribution to heating the atmosphere above sunspots.

UC-8: Spectro-polarimetry of Chromospheric Umbral Fine Structure (Vasco Henriques, Rosseland Centre for Solar Physics, Institute of Theoretical Astrophysics, University of Oslo)

It is clear that fine fibrils, observable in multiple spectral lines, are present in the chromosphere of the umbra of sunspots. These are associated with umbral flashes, a wave phenomenon, even if the appearance is often jet or fibril-like. The physical quantity that is inhomogeneous in these fibrils, if any, is still unknown. This is due to the challenge of obtaining observations with high signal-to-noise, in the chromosphere of an umbra, while resolving features that are about 0.1 arcsec wide and evolving over a time period of seconds. Bright fine-structures with flash-like profiles also exist and have a relationship with dark fibrils. However, such relationship indicates atmospheres that are downflowing as opposed to the traditional upflowing atmospheric model for umbral flashes. In fact, single-line umbral flash profiles can be fitted with very different atmospheres. In the extremes of the possible family of solutions, fully downflowing and fully upflowing solutions lead to very similar spectral profiles where a distinction requires spectra where both line wings are acquired in a time scale much lower than that of the feature evolution. Further, signal from seeing and nearby features needs to be minimal as very different profiles are present simultaneously in the umbra of sunspots (bright and dark for the same wavelengths). Full-Stokes spectro-polarimetry, via filtergrams and dense raster-scans (combinable in the case of DKIST), with sufficient signal-to-noise and absence of profile mixing, open the gateway for sufficiently constrained non-LTE inversions. Acquiring such profiles and maximizing constraints requires a well thought setup but such is possible with DKIST. Multi-line inversions should provide an answer to the nature of the inhomogeneities and their formation mechanism. Further, successful spectro-polarimetry for all classes of features in the umbra, would open a diagnostic into the properties of the chromosphere of the umbra itself. Previous work suggests an approach based on spectropolarimetry in Ca II 8542, as well as fast and dense rasters with limited FOV in the blue of the chromospheric Ca II H and K resonance lines. These lines, as well as Fe I 1565, are invertable together. Other diagnostics are carefully added only to the extent that they do not jeopardize the main goal of achieving well constrained atmospheric modelling at all main MHD variables. Tracking of waves horizontally and flash inhomogeneities are largely foregone to guarantee this goal.

This Science Case makes use of all the possible Calcium II lines: DL-NIRSP 8542, Ca II H and Ca II K from ViSP, together with photospheric 1565 using state of the art iterative radiative transfer fitting using inversions (first using NICOLE, then STiC as H and K require PRD). He I 1083 is to be used as an independently fitted diagnostic (using HAZEL).

UC-9: Chromospheric Oscillations in Sunspots: Running Waves and Umbral Flashes (Vasyl Yurchyshyn, Big Bear Solar Observatory, New Jersey Institute of Technology)

Our objective is to study the spatial structure, dynamics, temporal evolution, and spectral properties of umbral flashes (UFs) and umbral dynamic fibrils (spikes). In our recent study, we found that bright UFs tend to appear in a form of lanes stretched along light bridges (LBs) and clusters of umbral dots (UDs), while weaker and diffused UFs appear elsewhere in the umbra. This finding is important since the LBs and UDs are the location where the umbral loops are presumably rooted. This spatial correlation is suggestive that the enhanced heating by waves in the vicinity of LBs may contribute to heating of bright umbral UV loops. On the other hand, UFs also appear not in association with LBs and the pattern of their spatial distribution may reflect the hidden structure of the sunspot. In this study the spatial and temporal resolutions are very critical for the success of the effort.

UC-10: Co-ordinated observations with DKIST and ALMA (Sven Wedemeyer, Rosseland Centre for Solar Physics, Institute of Theoretical Astrophysics, University of Oslo)

The interferometric Atacama Large Millimeter/submillimeter Array (ALMA) consists of 66 antennas located in the Chilean Andes at an altitude of 5000 m and is a true leap forward in terms of spatial resolution at millimeter wavelengths. The resolution of reconstructed interferometric images of the Sun is anticipated to be close to what current optical solar telescopes can achieve. In combination with the high temporal and spectral resolution, these new capabilities open up new parameter spaces for solar millimeter observations. The solar radiation at wavelengths observed by ALMA originates from the chromosphere, where the height of the sampled layer increases with selected wavelength. The continuum intensity is linearly correlated to the local gas temperature in the probed layer, which makes ALMA essentially a linear thermometer. During flares, ALMA can detect additional nonthermal emission contributions. Measurements of the polarization state, which will become possible for the Sun in the next years, facilitate the valuable determination of the chromospheric magnetic field. In addition, spectrally resolved observations of radio recombination and molecular lines may yield great diagnostic potential, which has yet to be investigated and developed. Co-observing of ALMA and DKIST provides very complementary diagnostics for the chromospheric plasma at high spatial and temporal resolution and also offers valuable context information. Many different scientific applications for a large range of chromospheric targets from quiet Sun to active regions and prominences are possible, ranging from ultrahigh cadence wave studies to flare observations.

Regular observations of the Sun with ALMA are carried out since late 2016 and first data has been delivered to the PIs. This first generation of solar ALMA observations will allow for further developing the observing and post-processing strategies and for properly evaluating how to co-observe with DKIST in the future. Co-ordinating such observations is time critical due to a number of factors, including the large difference in time zone between DKIST and ALMA and the limited time during which ALMA is in suitable configuration.

UC-11: The Pre-eruptive Magnetic Feld Evolution of Active Regions (Stephanie Yardley, University of St. Andrews)

Despite decades of observations the trigger and driver mechanisms that lead to the formation and eruption of coronal mass ejections (CMEs) are still undetermined. The main source of these eruptions are active regions; concentrations of strong magnetic fields, with the eruptive activity able to continue through all stages of magnetic field evolution, from birth to dispersal into the background field. Low-altitude magnetic reconnection associated with flux cancellation appears to play an important role in CME occurrence (Yardley et al. 2018b) as it can form an eruptive configuration and reduce the magnetic flux that contributes to the overlying, stabilizing field. But at what height in the atmosphere (e.g., photosphere, chromosphere) does the associated magnetic reconnection occur? Is the pre-eruptive magnetic field configuration a sheared arcade or a magnetic flux rope? To answer these questions requires the analysis of the magnetic field evolution simultaneously at different atmospheric heights, which is only possible with high temporal and spatial resolution multi-height spectropolarimetric observations provided by DKIST.

UC-12: The fine-scale structure of chromospheric jets and their formation process (Gerry Doyle, Armagh Observatory and Planetarium)

With the availability of higher spatio-temporal resolution observations from both the space (e.g., IRIS, SDO/AIA etc) and ground-based (e.g., SST/CRISP, ROSA etc.) instruments, the solar chromosphere has shown a ubiquitous presence of jet-like plasma ejecta at diverse spatio-temporal scales (e.g., spicules, network jets, anemone jets, swirls, penumbral jets, pseudo-shocks etc). In this work, we aim to observe the fine structured and highly dynamic chromosphere in the quiet-Sun, coronal hole, and active regions, where a variety of plasma ejecta are eventually evident. These features contribute in transporting energy and mass in their respective overlying atmospheres in entirely different ways. For example, the coronal hole will most likely be subjected to the much longer spicules in a dominant ways, while the quiet-Sun may be subjected with the mixture of spicules, network jets, swirls etc. On the other hand, the sunspot groups (active regions) may possess very energetic ejecta like penumbral jets, plasma flows, pseudo-shocks, etc. Therefore, the morphological, physical (drivers), kinematic evolution of such various jets in the diverse ambient magneto-plasma atmosphere (QS, AR, CH) will provide unprecedented information and distinction on how they evolve and their role in energy and mass transport. Such data will also enable us to understand the evaluation of the role of magnetic reconnection and/or waves in their formation, as well as, their contribution towards coronal heating and formation of the nascent solar wind. We propose two observing sequences (i) combination of DL-NIRSP, VTF, and VBI; and (ii) combination of DL-NIRSP, ViSP, and VBI for the targets of AR (both near the Sun center and limb), QS (on-disk), and CH (at higher latitudes). The high cadence temporal image data (VBI & VTF); polarimetric scans (DL-NIRSP), and intensity-mode spectral profiles (ViSP) will be obtained in various jet enriched regions. Their magnetic field information, velocity information, and emissions will be constrained, which will provide details on their triggering and evolution. Moreover, various atmospheric heights and/or plasma temperatures will be taken into account in the analyses of jets, and thereby their role in various layers of the Sun's atmosphere.

UC-13: The multi-scale nature of vorticity in the solar atmosphere (Eamon Scullion, Northumbria University)

Vortex motions are present in a wide variety of phenomena and across a range of temporal and spatial scales in the lower solar atmosphere. Current observations at the diffraction limit taken with the best ground-based telescopes, allow us to detect the faint signatures of vortex motions, for e.g., in moving magnetic features and whirlpools in the photosphere, as well as, in rapidly evolving type-II spicules and small-scale magnetic tornadoes (aka chromospheric swirls) in the chromosphere and long-lived, large-scale giant tornadoes off-limb. Convective motions near the solar surface are thought to drive much of these phenomena, channeling energy outwards into the chromosphere and corona. As a result, vorticity is very much inherent to such a convectively driven system. The widespread, ubiquitous nature of these twisted transients makes them an effective powerhouse of many forms of wave propagation and wave energy transport to the upper layers, as well as efficient generators of currents, within the quiet Sun and coronal holes. This indirect impact of vorticity, across a range of scales, could lead to such events having an important contribution to coronal and chromospheric heating, which requires further exploration. Understanding the nature of vorticity, at different spatial scales, could also lead to new insights into the transport of mechanical energy and its dissipation in the solar atmosphere. The multi-scaled nature of vorticity possibly implies a spectrum of vortex phenomena (beyond simply large-scale or small-scale) in the solar atmosphere, with a resulting energy spectrum. We can explore the possibility of scaling / power laws (such as Kolmogorov) concerning vorticity and the energy budget in vortex motions, through statistically investigating various parameters such as the vortex lifetime, size and rotational velocity distributions. Such scalability (if it exists) will provide a unique insight into the potential dissipative processes taking place in the solar atmosphere.

UC-14: Thermodynamic Evolution of Limb Spicules (Bart De Pontieu, Lockheed Martin Solar and Astrophysics Laboratory)

The inner heliosphere is energized by the deposition of a flux of nonthermal energy in the outer solar atmosphere that is generated by the interplay of convection and the magnetic fields near the surface. One signature of this energy deposition is the presence of jets in the chromosphere, transition region, and corona. The most ubiquitous jets in the solar chromosphere, spicules, have a large potential for playing a significant role in the mass and energy balance of the corona and solar wind: the mass flux they carry to coronal heights is estimated to be two orders of magnitude larger than the solar wind mass flux. These highly dynamic features violently propel plasma upwards into the solar atmosphere (at speeds of 10 to 200 km/s). Magnetic waves of various types and significant strength are observed in association with these jets which appear to undergo significant heating to at least transition region temperatures. However, we do not understand the mechanism(s) responsible for the heating of these chromospheric features, the role of magnetic waves in the dynamic evolution of these features, nor do we understand their full impact on the mass and energy balance of the outer solar atmosphere.

UC-15: Role of Magnetic Field in Generating Type II Spicules (Bart De Pontieu, Lockheed Martin Solar and Astrophysics Laboratory)

The most ubiquitous jets in the solar chromosphere, spicules, have a large potential for playing a significant role in the mass and energy balance of the corona and solar wind: the mass flux they carry to coronal heights is estimated to be two orders of magnitude larger than the solar wind mass flux. These highly dynamic features violently propel plasma upwards into the solar atmosphere (at speeds of 10-150 km/s) with evidence for different spicule types, and have been observed in a variety of diagnostics using imaging and spectroscopy in a wide range of wavelengths from the EUV to visible. Recent numerical models suggest that the interaction between weak magnetic fields and strong flux concentrations, mediated by ambipolar diffusion in the partially ionized chromosphere, plays a role in the formation of spicules. DKIST observations will be able to provide observational constraints for these types of models and shed light on how spicules form.

UC-16: Magnetic and Electric Field Diagnosis of Chromospheric Jets, Prominences, and Post-flare Loops (Tetsu Anan, National Solar Observatory)

A key signature demonstrating the existence of magnetic reconnection is an intense electric field. Electric fields diffuse magnetic fields and accelerate charged particles. In addition, the electric field acts on neutral atoms that move across the magnetic field. Comparison of electric field measurement with the recently developed three-dimensional MHD model finally enables us to decipher the role of reconnection in solar atmospheres. However, we need spectro-polarimetric observations with high polarimetric sensitivity, high spatial resolution, and high temporal cadence, which current instrumentations cannot achieve, to detect polarization signals produced by electric fields (Anan et al. 2014). The spectro-polarimeters of the DKIST might allow us to measure electric fields associated with chromospheric reconnection, which drives a chromospheric jet, if plasmoids or turbulence enlarge the spatial scale of the magnetic diffusion region. We are also interested in electric fields in prominences and post flare loops.

UC-17: Explorations of ubiquitous, high frequency MHD waves in the solar chromosphere (Masahito Kubo, National Astronomical Observatory of Japan)

The purpose of this project is to explore ubiquitous wave-like phenomena in the period much shorter than usual three-minute oscillations in the chromosphere. Thanks to the improvement of the cadence of new instruments, many high frequency wave-phenomena have been detected in recent days. However, their origin and their role in the coronal/chromospheric heating are not yet understood well. We can reveal their physical quantities by high-speed imaging spectroscopic observations making use of high throughput.

UC-19: Ellerman bombs and magnetic reconnection over multiple atmospheric layers (Yukio Katsukawa, National Astronomical Observatory of Japan)

Ellerman bombs are suitable targets for studying how magnetic reconnection drives plasma heating in the stratified atmosphere. Based on magnetic-field measurements in the photosphere, we believe collision of opposite polarities associated with flux emergence and cancellation is a preferable site to setup reconnection. However, we have not attained 3D magnetic structures around the reconnection site. The DKIST instrument suite provides magnetic fields and velocities in both the photosphere and the chromosphere at multiple heights with unprecedented spatial resolution, which allows us to study how efficiently magnetic reconnection drives heating and plasma flows in collisional and partially ionized plasma. The solar chromosphere provides unique opportunity to directly observe magnetic reconnection in astrophysical plasma with high spatial resolution.

UC-20: Long-Term High-Resolution Observations of the Sun's Polar Fields (Gordon Petrie, National Solar Observatory)

The Sun’s polar fields play a leading role in organizing the large-scale structure of the solar atmosphere and in determining the strength of the interplanetary magnetic field. They are the site of the largest and longest-lived coronal holes over most of the cycle, and the main source of the fast solar wind. They are also believed to supply the seed field for the subsequent solar activity cycle, where the large-scale magnetic configuration of the Sun alternates between poloidal and toroidal phases dominated by the polar fields and the active regions at low latitudes, respectively. Accurate measurements of the polar field are therefore essential for understanding the solar cycle and predicting its strength. However, present-day synoptic observations do not have sufficient spatial resolution or sensitivity to overcome the restricted viewing angle and diagnose accurately the dominant facular-scale (~5-10 arcseconds) structure of the magnetic vector field closest to the poles. Furthermore, we rely on coronal models extrapolated from photospheric data under restrictive assumptions for information on atmospheric structure. The unprecedented spatial resolution and sensitivity of the full-Stokes observations from DKIST’s ViSP and VTF instruments, observing the poles long-term on a regular basis, would allow us to build up a detailed picture of the cyclical creation and cancellation of photospheric polar fields, and enable a more sophisticated physical understanding of these processes. In turn, this would lead to a more realistic picture of global atmospheric structuring and potentially crucial clues on the creation of new activity cycles. Complementary off-limb polar observations from Cryo-NIRSP would provide direct, detailed, model-independent information on the restructuring of the atmospheric field. Model coronal fields extrapolated from DKIST solar-surface observations would be quantitatively compared to Cryo-NIRSP coronal field measurements to investigate atmospheric magnetic structure and refine model assumptions. The beginning of DKIST operations will likely coincide with solar activity minimum when the polar fields are at their strongest, making them an especially important early DKIST science target.

UC-21: Photospheric Flow Structure and Evolution (Brian Welsch, University of Wisconsin, Green Bay)

DKIST can resolve dynamic processes on smaller spatial and temporal scales than has previously been possible. Horizontal flows in magnetized regions, inferred by feature tracking and/or local correlation tracking (LCT) at and above the photosphere, will be investigated using high time-resolution sequences. The morphology, magnitudes, and evolution of these flows on the smallest observable scales have implications for our understanding of fundamental properties of convection, atmospheric heating, and evolution.

Scientific questions to be addressed include the following:

- Flows at different spatial scales: How do flows on the smallest spatial scales compare to flows on larger scales? How do frequency distributions (histograms) of flow speeds differ? How do spatial power spectra of flow energies compare?
- Flow structure as a function of height: The photospheric pressure scale height is of the order of 100 km, and flows are likely to vary substantially with height. How do flows at varying heights differ?
- Flow lifetimes at the smallest scales: Are turnover times sufficiently fast to cause turbulence between upward- propagating and downward-propagating, reflected waves? A model proposed by van Ballegooijen et al. (2011) requires that "small-scale footpoint motions have velocities of 1–2 km/s and timescales of 60–200 s".
- Flow morphologies at small scales: flow vorticity can produce "footpoint braiding," which has long been thought to be an important factor in coronal heating and energy loading leading to transient energy release. Are vortical flows more common at smaller spatial scales?

UC-22: Chromosphere-Corona Mass Cycle (Kevin Reardon, National Solar Observatory)

The cycling of material between the chromosphere and corona has been recognized as playing an important role in the mass and energy budget of the solar atmosphere. This cycle includes both cool material being heated and transported upwards into the corona, as well as the condensation of coronal plasma and a return flow back to the chromosphere. Previous studies have focused on specific portions of this cycle, but DKIST gives us the opportunity to obtain a complete picture of the full cycle.

We propose observations targeted at measurements of the mass transport between the chromosphere and corona and getting detailed observations of the boundary between plasmas in vastly different temperature regimes.

UC-23: Multi-wavelength Spectroscopy of Solar Flares (Fatima Rubio da Costa, Stanford University)

A multi-wavelength study of solar flares with very high spectral and temporal resolution will allow us to estimate the dynamics of the lower solar atmosphere and have some insights about the energy deposition, one of the current key questions in solar flares.

UC-24: Convectively Driven Gravity Waves in the Lower Solar Atmosphere (Benjamin Brown, University of Colorado, Boulder)

The lower solar atmosphere is stably stratified, and in this region solar granulation drives internal gravity waves. These waves probe the properties of the lower atmosphere and may also transport a significant mechanical flux, which could contribute to the chromospheric energy balance. Observations with IBIS claim to have detected these internal gravity waves and to have measured their energy flux, but those observations are inconclusive owing to low temporal and spatial resolution. Here we propose DKIST observations of these solar atmospheric g-modes, likely achieving nearly an order of magnitude improvement in both temporal and spatial resolution. Measuring these modes will provide important information on the possible wave energy flux and will also provide first observations of convectively driven gravity waves, testing theories for the coupling of convection and g-modes in stratified atmospheres.

UC-25: Amplification of Magnetic Fields around Newly Formed Intergranular Lanes (Michael Knoelker, High Altitude Observatory, National Center for Atmospheric Research)

According to numerical simulations, newly formed downflow lanes (in exploding granules) exhibit laminar flow in the beginning followed by small scale turbulent flow in the vicinity of the new downflow lane. Both the laminar flow and the turbulent component amplify the local seed field and carries it upward into the photosphere from below. Thus, at the resolution of DKIST we expect to be able to observe the onset of magnetic field amplification from a diffuse seed field that was previously present exploding granule. The initial amplification is expected to be mostly due to strongly converging laminar flows. When does the transition to the flow being dominated by turbulence occur? What is the role of vortical flows at the edge of granules in the transition to turbulence?

UC-27: Solar Cycle Evolution of Small-Scale Magnetism (Derek Lamb, Southwest Research Institute)

What is the relative role of flux emergence and horizontal flux transport as a function of latitude and feature size? Does the small-scale dynamo operate as a constant background processes, or does it really leverage the recycled active flux?

UC-28: Fine-scale Structure of Sunspot Penumbrae (Sanjiv K. Tiwari, Lockheed Martin Solar and Astrophysics Laboratory)

We will use DKIST high spatial resolution and high-sensitive spectropolarimetric data to investigate fine-scale structure of sunspot penumbrae. In Tiwari et al. (2013), we showed that the averaged filament harbors clear downflows all along the sides of filaments, whereas in individual filaments downflows were found often in localized patches. The opposite polarity field (with respect to the field in spines) was detected only in one third of the selected filaments, and was completely diluted in the averaged filament. We also found that spines are intrusions of umbral field into penumbra (Tiwari et al. 2015). We expect that DKIST will resolve the internal structures in penumbral filaments, most probably some of them by direct analysis of observed Stokes profiles from ViSP and DL-NIRSP, and others by using depth-dependent inversion codes, and verify our above findings that were based on spatially coupled inversion of *Hinode*/SP data. We will also investigate structure of penumbra in chromospheric lines. Observations in higher atmosphere will provide constraint to MHD simulations.

UC-29: Flare Polarimetry - Magnetic Field Restructuring (Lucia Kleint, FHNW Switzerland / KIS)

Flares influence the magnetic structure of the solar atmosphere. We propose to observe the restructuring of the magnetic field in 3D by using photospheric and chromospheric polarimetry. We will derive temporal sequences of the vector magnetic field before, during, and after flares. Additionally, we will investigate the linear polarization ("impact polarization") and whether it may arise from particle beams or simply from anisotropy of the radiation field.

UC-30: Evolution of Magnetic Field and Electric Currents in a Filament Channel (Sanjay Gosain, National Solar Observatory)

Hinode observations have detected the signatures of emergence of a flux rope in a filament channel. Motivated by these observations, we would like to make high sensitivity measurements of magnetic fields at different heights in the filament channel using DKIST in a light bucket mode. We propose to use Fe 1.5 micron, He 10830, Ca 854 nm, with the DL-NIRSP, and 525 nm, 6173 nm, and 630 nm with the ViSP. The cadence required is a few minutes (5-10 minutes). Angular resolution ~0.5 to 1 arcsec. Deep integrations for achieving SNR ~5e-4 in visible and IR to get high sensitivity magnetic field measurements. Contextual G-band and H-alpha images would be desirable.

UC-31: Coronal Jets in "On-Disk" Coronal Holes (Alphonse Sterling, NASA Marshall Space Flight Center)

We will observe H-alpha (intensity, Doppler) and magnetic field properties of coronal jets occurring in low-latitude coronal holes. We expect to elucidate the magnetic field changes that lead to the formation and destabilization of miniature filaments (“minifilaments") whose eruption is often the genesis of the jets.

UC-32: 3D Structure of Supersonic Downflow in the Outer Penumbral Region (Sanjay Gosain, National Solar Observatory)

Hinode SOT/SP observations show that outer penumbral region of mature sunspots exhibit small patches of supersonic downflows. These patches are typically of sizes in the range of 0.5 to 2 arcsec. The spectral profiles in these patches exhibit dual lobes, especially in Stokes-V profiles. Simple analysis suggests that these pixels consist of a two-component atmosphere. There is a single stationary/subsonic component and a supersonic downflow component. The magnetic field strength in the two components are also different. With very high angular resolution of DKIST and using multi-line observations, we propose to resolve the 3D structure of these features, which are believed to be the longest extension of Evershed flow channels.

UC-33: Magnetic Helicity in the Solar Corona (Axel Brandenburg, NORDITA)

We will estimate the magnetic helicity above the surface and within the lower corona. We will explore the possibility of using linear polarization of diffuse emission in the infrared. At large wavelengths, Faraday rotation leads to the destructive superposition of different polarization planes along the line of sight. However, for a helical magnetic field the plane of intrinsic polarization can, at certain positions, rotate in the opposite direction such that the Faraday depolarization would be canceled at certain wavelengths. We will measure polarized emission in all the 13 identified coronal lines covering wavelengths from 500 nm to 5 μm. We will perform radial scans at all four quadrants of the lower corona.

UC-34: Chromospheric and Coronal Observations of Loop Prominence Systems (Juan Carlos Martinez Oliveros, Space Sciences Laboratory)

Solar limb flares can produce white-light ejecta observable above the limb of the Sun and imageable without the aid of a coronagraph. To our knowledge, the modern literature contains only three such events: SOL1980-06-21 (X2.6), an event visually observed by J. Harvey and T. Duvall (Hudson and Willson, 1983; Chupp, 1990), SOL1989-08-14 (~X20; Hiei et al., 1992) and SOL2003-11-04 (>X17; Leibacher et al., 2004) and most recently Martıńez Oliveros et al. (2014) and Saint- Hilaire et al. (2014). In all cases the flares occurred at heliographic positions near the limb, and the emissions were observed in the lower atmosphere (below 1.03 R elongation). In many cases white-light ejecta are observed to continue away from the Sun in the form of coronal mass ejections (CMEs), at substantial elongations and with specialized telescopes (e.g. coronagraphs), but these sources clearly have different morphologies from the sources mentioned above. Martıńez Oliveros et al. (2014) and Saint-Hilaire et al. (2014) made an initial report of chromospheric and coronal emission sources observed by the Solar Dynamics Observatory/Helioseismic and Magnetic Imager (SDO/HMI) for two flares in 2013 May: SOL2013-05-13T02:17 (X1.7) and SOL2013-05- 13T16:01 (X2.8), each associated with a CME and a meter-wavelength type II radio burst. These sources appear in an image annulus extending about 25 00 above the limb, and these reports provide a first scientific use of such data. We compare the detailed observations of these sources with X-ray observations from the Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI; Lin et al., 2002), and with other SDO observations. We have completed a mini-survey of M- and X-class flares in 2011, and find that almost half produced coronal signatures in HMI's limb annulus.

UC-36: Dynamics of Electric Currents and Magnetic Field Topology of Solar Flares (Alexander G. Kosovichev, New Jersey Institute of Technology)

The focus of this project is on a detailed analysis of physical processes, magnetic field topology and dynamics of electric currents in the vicinity of the Polarity Inversion Line (PIL) in the low atmosphere prior and during solar flares using high-resolution observations.

UC-37: Fine Structure Field and Flows in Sunspots (Choudary Debi Prasad, California State University Northridge)

Inverse Evershed Flow (IEF) moves plasma from the superpenumbral boundaries and beyond towards the sunspot through the chromospheric fibrils. With spatial resolution of about 70 km, we would like to understand the following two properties of the flow. (1) What is the finest size of the channel that carry material in the form of supersonic flows towards the spot and generate shock? (2) How does he structure of the flow channel change due to the interaction between the mass and wave motion? (3) How does the magnetic field and plasma pressure change at the source and sink locations connected by the chromospheric fibrils that carry IEF material intermittently.

UC-38: Physics of Sequential Chromospheric Brightenings; CME/Flare disk precursors (Michael S. Kirk, Catholic University of America)

Sequential Chromospheric Brightenings (SCBs) have been established to be precursors of large-scale, coupled Flare-CME systems. These brightenings, about 2-3 arc seconds or smaller, occur several minutes before flares, and occur in a traceable spatial sequential pattern over the active region. We have previously shown that the timing and extent of these brightenings, their unipolar structure and their Doppler signature are unique and different from the actual flare brightenings. In this work, we would like to investigate the complete Doppler, magnetic and intensity substructure of the SCBs to investigate the reconnection and/or heating processes associated with SCBs in the lower atmosphere from the chromosphere through the corona.

UC-39: Convective and MHD Fine Structure of Granulation and Mesogranulation (Juri Toomre, University of Colorado, Boulder)

The evolving detailed spatial structure of granulation and mesogranulation, and the magnetism associated on these scales, has fundamental mysteries. From current observations, it is ambiguous whether mesogranulation exists as a distinct convective scale, or a dynamical self-organizing property of the underlying granules alone. However, the organization of magnetic fields on mesogranular scales (~5-10 Mm horizontal extent) is clear as is the correlation tracking of granular structures themselves, which move in accord with the magnetic structures. Here we propose observations to study the detailed structure of granular flows and their intense networks downflow lanes, and to study the longer lived and larger scale mesogranulation. This will be done using a sequence of complimentary observations employing VBI, VTF and DL-NIRSP to both study the larger context of convective flows and the detailed flows around single well-studied granules. The intensity and Doppler velocity aspects will be substantially influenced by the 5-minute oscillations and careful attention must be devoted to how some of these effects are ameliorated, lest they drown or confuse the underlying convective dynamics which we will here study. Contact will be made with modern high-resolution RMHD simulations of solar photospheric convection and dynamos.

UC-40: Observations of Sausage Waves in the Lower Solar Atmosphere with DKIST (Abhishek Kumar Srivastava, Indian Institute of Technology (BHU))

The strongly magnetized structures at the solar atmosphere, e.g. in the photosphere and lower chromosphere, can act as MHD waveguides in which various magnetohydrodynamic (MHD) wave modes may evolve and propagate coupling the photosphere into the upper regions of the Sun's atmosphere [Jess et al. 2009, Srivastava et al. 2017, Grant et al. 2018, Wang et al. 2002, Morton et al. 2011, and references cited therein]. In such waveguides, e.g., pores, sunspots (large-scale) and MBPs (small-scale), and in their overlying atmosphere, the plasma and magnetic field are systematically structured and thus lead various physical effects on the properties of the evolved waves (e.g., propagation, attenuation, mode-conversion, mode coupling, trapping, and of course damping, etc). Therefore, understanding the localized behaviour of MHD wave modes in these structured waveguides, idealised as fluxtubes, may reveal their role in heating, energetics and even momentum transfer of the plasma confined there.

Often, the magnetic flux tubes are considered to be the building blocks of the lower solar atmosphere. Moreover, since the presence of MHD waves modulate the background plasma and/or magnetic field of these flux tubes, therefore, understanding their properties may shed light on the localized physical conditions also. In various kinds of MHD modes (e.g., slow highly field-aligned magneto-acoustic, torsional Alfven, slow/fast kink or sausage), the sausage waves are important illusive wave modes as earlier studies often claim that they carry the overwhelming wave flux in certain waveguides [Freij et al. 2016, Stangalini et al. 2018, Morton et al. 2012, and references cited there]. Once excited, their existence depends upon the equilibrium conditions (e.g., density contrast, length and width), and, they also strongly possess the long wave-length cutoff feature. The magnetoacoustic sausage modes modulate the tube cross-section, and can carry a significant amount of energy upwards. They may also couple with other modes, e.g., the kink or torsional mode depending upon the conditions of the driver mechanism, likely at their most commonly believed source region: at thephotosphere. Therefore, sausage waves may carry partial energy of the net Poynting flux required for chromospheric and coronal heating [Morton et al. 2012].

In the present observing proposal, we wish to observe large-scale photospheric strong magnetic sources (e.g., pores and compact sunspots with less spread penumbra) and their overlying atmosphere extending upto the top of the chromosphere. We will analyze the high-cadence time-series imaging data (VBI) covering the near-photosphere to the chromosphere, and the corresponding magnetic field measurements through appropriate Stokes profiles as observed by DL-NIRSP at two proposed heights using DKIST. We also wish to observe the intensity and velocity information above the photospheric target using ViSP. The signatures of sausage waves will be obtained using intensity and velocity signatures, as well as the estimation of the re-constructed magnetic fields of the target. The coupling of sausage waves with other wave modes and their capacity of energy and momentum transfer will also be explored, and assessed ultimately giving insight into under what circumstances are these waves the dominant carrier of non-thermal energy. Moreover, in the light of the high-resolution observations, the effect of the spatial structuring of plasma and magnetic field in the observed magnetic structures will be explored on the propagation and dissipation properties of sausage waves.

UC-41: Effect of Magnetic Fields on the Turbulent Dynamics of Quiet-Sun Regions and Plages (Irina N Kitiashvili, NASA Ames Research Center/BAERI)

Investigation of turbulent properties of solar convection is important for understanding the multi-scale dynamics observed on the solar surface. The new generation of DKIST instruments will provide unique high spatial and temporal resolutions that are critical for studying the structure and dynamics of small-scale magnetic fields in the turbulent radiating environment. In this study we will primary focus on investigation of turbulent properties of the solar magnetoconvection in the photosphere and low chromosphere in the quiet-Sun regions and plages (including diagnostics of the hidden magnetic flux that can be probed through the Hanle effect, formation and dynamics of magnetic flux tubes).

UC-42: Searching for Signatures of Surface and Body MHD Modes in Small-scale Magnetic Structures (Peter Keys, Queen's University Belfast)

Recent studies have observed a plethora of MHD wave phenomena in magnetic features of varying scales in the solar atmosphere. However, the identification of such waves in the lower solar atmosphere is a complex problem because the various eigenmodes available in the MHD Hilbert space have overlapping properties. This has limited studies to low order modes. One aspect of MHD wave modes that has only been identified in observations very recently, is the spatial characteristics of the mode across the flux tube. This is a key component in understanding energy transfer from the waveguide to the quiescent environment and therefore represents a crucial step in the contribution of the various wave modes to heating the solar atmosphere. As such, this proposal is commensurate with the DKIST science objectives with respect to wave generation and heating in the atmosphere. By availing of the high-resolution observations and spectropolarimetry made possible with DKIST, our proposal aims to gain new insights into the surface and body characteristics of wave modes in small-scale magnetic structures at multiple heights in the solar atmosphere.

UC-43: Magnetic and Plasma Dynamics in Sunspot Light Bridges (Vasyl Yurchyshyn, Big Bear Solar Observatory of New Jersey Institute of Technology)

Recently sunspot light bridges (LBs) became a focus of several new studies. An LB is a bright granular structure that often splits the sunspot umbra in two parts and appears either when a sunspot is forming or disintegrating. The width of an LB varies from a fraction of an arcsecond to several arcseconds. They have a granular of filamentary structure and they represent a magneto-convection structure with vigorous plasma flows. When compared to the rest of the umbra, magnetic fields in LBs are weaker and more inclined with respect to the local vertical.

Actively evolving LBs are often associated with recurrent and intermittent plasma ejections, oscillating jets, and "walls" that were interpreted as leakage of the photospheric p-modes. High resolution data on these phenomena are needed to get insights not only on the type and parameters of plasma flows, which have not been studied yet, but also on dynamics of the magnetic reconnection process. Our GST experience showed that the small-scale sunspot dynamics still remains unresolved and DKIST will most certainly contribute to the solution of this problem.

UC-44: Spatial and Thermal Structure of White Light Flares (Vasyl Yurchyshyn, Big Bear Solar Observatory of New Jersey Institute of Technology)

As the temporal and spatial resolution of solar instrumentation has improved white light emission has been detected even in weak C-class flares (Matthews et al. 2003; Hudson et al. 2006; Jess et al. 2008; Kowalski et al. 2015), which lent observational support to an early suggestion by Neidig (1989) that “optical continuum is probably present in all flares” (see also Metcalf et al. 2003). At the same time, recent high resolution data and studies of flares with the New Solar Telescope (NST, e.g., Yurchyshyn et al. 2015; Kumar et al. 2015; Lim et al. 2016) did not show any convincing evidence of widespread photospheric intensity enhancements when observed using the TiO band at 705.7nm.

The main problem in explaining the WL emission is that it appears to be difficult to directly heat the photosphere to the required temperatures using known to us energy transport mechanisms. Alfvén waves were suggested as a possible mechanism for local acceleration of electrons in the chromosphere (Fletcher & Hudson 2008) although their efficiency was questioned (Judge et al. 2014). There is a suggestion (Krucker et al. 2015) that electrons may be re-accelerated in the chromosphere, which may cause them to penetrate deeper into the chromosphere. However, at this moment no evidence of such re-acceleration has been observed. The question whether electrons are able to penetrate into deep and dense layers of the solar atmosphere is currently under scrutiny. Hence, the questions about the origin of WL emission in flares, the energy sources of this emission, its location and timing with respect to any other line and continuous emission still remain wide open and need further investigation, which will be a focus of the proposed study.

UC-45: Investigating the Dynamic Chromosphere: Probing the Paradigms of Energy Transfer by Transverse MHD Waves (Richard Morton, Northumbria University)

The observed dynamics of the chromospheric fine-scale magnetic structure indicate that this region of the Sun's atmosphere contains a significant basal flux of mechanical energy [1-4], which has been interpreted in terms of transverse waves. The associated energy estimates indicate that the waves could play a key role in the transfer the magneto-convective energy from the photosphere to the corona. Crucially, recent results have hinted that multivariate relationships exist between the wave diagnostics (e.g., frequency, amplitude, power).

For a major advancement of solar atmospheric wave physics, probing of these relationships with DKIST will reveal new insights into: (i) the fundamental driving mechanisms of transverse waves; (ii) their damping mechanisms and coefficients (i.e., length scales, quality factors); (iii) the waves contribution to the heating of the solar atmosphere. With the unprecedented spatial/temporal resolution capabilities of DKIST, accurate large-scale statistical measurement of these parameters can be gathered. This will allow us to quantify the transverse wave contribution to solar atmospheric heating to a level of accuracy never achieved before. Hence, this ambitious proposal will address major DKIST science objectives and aims, i.e., understanding the 'Structure and dynamics of the chromosphere'; and utilising the vast improvement in spatial and temporal resolution possible with DKIST to examine transverse waves in chromospheric magnetic structures, extending antecedent investigations into previously inaccessible spatial and temporal domains in order to probe the generation of the waves and their role in energy transport in the chromosphere.

UC-46: MHD Wave-Mode Conversion in Thin Magnetic Flux Tube Structures (Rahul Sharma, University of Alcalá)

Ubiquitous observation of all the three types of wave-modes (Alfvén, fast and slow magneto-acoustic) were reported literature in recent years and yet many questions regarding the propagation of these wave-modes remains unanswered. These wave-modes are excited in lower solar atmosphere (gas-pressure dominated photosphere) and channelized to corona (magnetic-pressure dominated) through thin magnetic-flux-tube structures across the solar transition region, where the ratio of these two pressures is equal to unity. When the confined wave-modes in thin magnetic waveguides, passes through the transition region, there are possibilities for the resonance between different wave-modes which could lead to transfer of energy from one wave-mode to the other. This mechanism can be observed as change in relative amplitudes of wave-modes, allowing us to better understand the energy transport between the lower solar atmosphere and the corona. The observational proposal aims to exploit the highest spatial and spectral resolution spectral-imaging in multiple wavelengths at DKIST in combination with co-temporal and co-spatial observations from IRIS.

UC-47: Finding the Foot Points of the Quiet Corona (Karin Muglach, Catholic University of America)

Despite the many the well-constrained quantities we use to describe the photospheric magnetic field, we do not have a simple means to address the question of how much of that flux connects to corona and heliosphere. Force free field extrapolations are known to be inaccurate; the force-free assumption only applies in the upper chromosphere and above. The problem is also complicated by the dynamic evolution of the mixed-polarity magnetic features sometimes referred to as the magnetic carpet (Schrijver and Title, 2003). Stochastic driving of magnetic footpoints provides magnetic free energy to the chromosphere and corona through the Parker field line braiding mechanism (Parker, 1983). The chromospheric magnetic field is the missing stepping stone that connects the photosphere to the force-free upper atmosphere. In this study, we will focus on tracing changes at the boundary of photospheric magnetic elements (in the network) to changes in the magnetic and thermal environment of the chromosphere and above. The polarization sensitivity and wavelength coverage provided by DKIST provide a new and powerful tool for diagnosing the chromosphere. Our study will address the following questions:

- How does the chromospheric magnetic field evolve in response to magnetic accumulation/cancellation at supergranule vertices? Is the evolution steadily or fitfully?
- Are magnetic restructuring and heating simultaneous processes in the chromosphere?
- Do fibrils extend simply upward or are they arches?

Our observing plan has been constructed to make use of the high spatial resolution and polarization sensitivity afforded by DKIST. Chromospheric spectropolarimetry can now be effectively accomplished with this large aperture telescope and state-of-the-art inversion techniques (multi-atom NLTE code, STiC).

UC-48: Relationship between Flare Ribbon Emission and Magnetic Restructuring in Low Atmosphere (Chang Liu, NewJersey Institute of Technology)

The photospheric response to solar flares, also known as coronal back reaction, is often observed as sudden flare-induced changes in the vector magnetic field and sunspot motions. However, it remains obscure whether evolving flare ribbons, the flare signature closest to the photosphere, are accompanied by changes in vector magnetic field therein. With DKIST we propose to explore the relationship between the dynamics of flare ribbons in the chromosphere and variations of magnetic fields in different depth of low atmosphere. The expected results can provide new insights into the photosphere-chromosphere-corona coupling under the context of energy and momentum transportation in the flare-related phenomena, and help advance and constrain flare/CME models.

UC-49: Brightness Contribution of Unresolved Magnetic Fields (Serena Criscuoli, National Solar Observatory)

Magnetohydrodynamic simulations of the solar photosphere and chromosphere show that the magnetic field is organized at spatial scales that are not accessible with modern instrumentation. We plan to utilize observations acquired with the DKIST to investigate the contribution of these 'hidden' fields to the radiative emission at different spectral ranges of relevance for solar and stellar variability studies.

UC-50: Fundamental Scales and Magnetic Field Strengths of Thermally Unstable Coronal Loops (Tom Schad, National Solar Observatory)

The primary objective of this experiment is to measure the fundamental scales of coronal loops undergoing condensating, thermal non-equilibrium (i.e., coronal rain) in order to (1) answer open questions regarding coronal loop structure and the chromosphere-coronal mass cycle, as well as (2) provide critical constraints for the modeling of coronal structure, heating, and dynamics. The observing strategy, described herein, will target the evolution of coronal rain observed off-limb using a broad multi-wavelength imaging, spectroscopic, and spectropolarimetric approach. For cooling coronal loops, the resulting data set will provide measurements of the distribution of cross-section widths, Hα Doppler temperatures, Doppler and plane-of-sky velocities and accelerations, as well as track the thermal evolution of individual rain blobs. We will analyze the trajectory of individual rain blobs to locate coronal oscillations. Simultaneous spectral measurements in Hα, Ca II , and He I will be used to probe possible drift velocities between ionized and neutral species in the partially ionized coronal rain. And, finally, this experiment is unique among all previous cool corona studies in that we will probe the vector magnetic field directly within the cooling loops using the powerful polarized diagnostic of He I λ10830. This combination of measurements will help address three key questions, among others, regarding the solar corona:

1. What role does the thermal instability have in the corona-chromosphere mass cycle?
2. On what scales is the solar corona organized and on what scales do the heating mechanisms operate?
3. How is the coronal magnetic field fundamentally stratified along coronal loops?

UC-51: An Investigation of the Relative Alignment between Chromospheric Fibrils and the Magnetic Field Vector (Tom Schad, National Solar Observatory)

In 1908, George Ellery Hale studied chromospheric flocculi (or fine structure) in newly available (at that time) Hα spectroheliograms and noted a 'definitenesss of structure, indicated by radial or curving lines, or by some such distribution of the minor flocculi as iron filings present in a magnetic field'. His conjecture that fibrils may denote the direction of a local magnetic field vector is one that is often assumed true. Confirmation of this hypothesis, however, is not a simple task; nor is the question of limited impact. Due to the relatively weak ionization ratio of the solar photosphere and chromosphere, as well as the lower density of the chromosphere, partial ionization effects allow a decoupling of the thermal structure and magnetic structure. Such ambipolar diffusion provides a heating term that may be significant in the upper chromosphere. One cannot thus assume that linear structures correspond directly to the local magnetic field vector at a given moment in time. Now, more than a century after Hale's observations, DKIST's great light-collecting capability allows us to capitalize on advancements in the modeling of non-LTE line formation and atomic-level polarization in order to test Hale's conjecture. This proposal seeks to conduct the most extensive study of the relationship between thermal and magnetic structure in the chromosphere to date, by utilizing the advanced chromospheric polarimetric diagnostics of the DKIST.

UC-52: Magnetic Fine Structure of Unipolar Photospheric Regions (Karin Muglach, Catholic University of America)

Several recent studies have shown indirect evidence that unipolar regions inside active region plage and coronal holes may contain substantial minority-polarity magnetic fields. Using extreme-ultraviolet images and line-of-sight magnetograms from the Solar Dynamics Observatory, Wang, Warren and Muglach (2016) and Wang (2016) have found that unipolar flux concentrations, both inside and outside ARs, often have small, loop-shaped Fe IX 17.1 and Fe XII 19.3 nm features embedded within them, even though no minority-polarity flux is visible in the corresponding HMI magnetograms.

They also note a tendency for bright coronal loops to show compact, looplike features at their footpoints in agreement with findings of Chitta et al. (2016). Based on these observations, we suggest that present-day magnetograms may be substantially underrepresenting the amount of minority-polarity flux inside plages and strong network, and that reconnection between small bipoles and the overlying large-scale field could be a major source of coronal heating both in ARs and in the quiet Sun. High resolution magnetic field measurements with DKIST will be able to address this issue.

UC-53: Fine-Scale Mapping of the FIP Effect (Valentin Pillet, National Solar Observatory)

UC-54: Synoptic Observations of the Temperature Gradient in the Low {hotosphere (Serena Criscuoli, National Solar Observatory)

This Science Use Case aims at measuring the mean temperature gradient in the quiet Sun and at detecting possible variations with the solar magnetic activity cycle. We shall use a new measurement method that gives access to the physical quantities on a geometrical scale without relying on photospheric models and radiative transfer calculations. We also intend to follow the variations of the velocity fluctuation power spectra related to the structural changes of the quiet photosphere.

UC-55: Evidence for Turbulence in Granular Flows (Mark Rast, University of Colorado, Boulder)

Solar convection is expected to be highly turbulent, and turbulent broadening is often an ingredient of spectral line modeling. However, expansion and overturning of the upflowing fluid in the steep stratification of the photosphere laminarizes the flow, and direct evidence for turbulent flows is elusive. Turbulence is expected to develop at the shear interface between granular up and downflows (along the edges of intergranular lanes). While this is consistent with a micro-turbulent contribution being needed to account for spectral line profiles in granular downflows but not upflows, flow gradients along the line of sight also contribute to line broadening. Since downflow plumes generated in the photosphere accelerate with depth, such gradients likely exist. We propose to assess the scale and magnitude of turbulent flow contributions. We will use high spatial and spectral resolution measurements to carefully map Doppler velocities and non-thermal broadening with position and depth over a 10 x 10 arc second quiet region of the photosphere. High resolution polarimetric measurements of a 5 x 5 subregion will allow assessment of the sensitivity of the result to the presence of magnetic fields.

UC-56: The Fine Structure and Connectivity of Flows and Magnetic Fields in Sunspots: From Deep to High and Inwards to Outwards (Alexandra Tritschler, National Solar Observatory)

The Evershed flow is the most conspicious and vigorous flow pattern observed in the photospheric layers of sunspot penumbrae. It has been studied extensively over the past decades and its main properties are very well established. The origin of the flow and the cause of its fine structure, however, is still subject of vivid debates. This must be partly ascribed to the fact that it is still a challenge to fully resolve the penumbral fine structure with existing instrumentation (even when seeing-free). The question of the origin of the Evershed flow is certainly of fundamental importance, however, the question of the origin of the chromospheric flows (and its fine structure) observed above sunspots (the so-called inverse Evershed flow), and their relation to the photospheric conditions is of equal importance. In order to address these questions we propose observations using diagnostics with sufficient height coverage provided by the ViSP (spectropolarimetry from photosphere to low chromosphere), VBI-Blue (for context, FOV, and highest cadence and spatial resolution), and the DL-NIRSP (spectropolarimtery in photosphere and chromosphere).

UC-57: Fine-scale Flare Precursors and the Associated Dynamic Structure of Magnetic Field in Low Atmosphere (Ju Jing, New Jersey Institute of Technology)

The study of precursors of flares is fundamental for understanding the basic magnetic instability leading to catastrophic eruptions. However, high-resolution observations of the fine structure (below 500 km) of flare precursor brightenings and magnetic activities were previously unavailable, and now are accessible to only a few large ground-based telescopes world-wide. With DKIST we propose to investigate the fine dynamic structure of flare precursors in the low atmosphere. Particularly we will study their evolution toward the unstable state prone to eruptions and the associated dynamic structure of magnetic field. We will analyze the phenomena in the context of theoretical ideas and modern simulations of magnetic reconnection to understand the underlying cause of eruptions.

UC-58: Fine-Scale Structure and Dynamics of Solar Flare Ribbons (Yan Xu, New Jersey Institute of Technology)

Solar flares have been observed and investigated extensively over a century. Many theoretical models developed over this time suggest that key physical processes such as reconnection and acceleration occur at very small, length scales on commensurately short times scales. Due mainly to the limited resolving power, a majority of previous observations and models focused on large scale structures. While the processes occur in the corona, they are manifest in the chromosphere, when they may be more readily observed at the smallest scales. DKIST's unprecedented spatial and temporal resolution make possible the observation of these flare signatures shedding light on the scales of these processes. We plan to make imaging-spectroscopic observations and investigate these flare signals in great detail, especially in He I 10830 and Ca II k lines.

UC-59: Coordinated Observations with DKIST and Sunrise III (Andreas Lagg, Max Planck Institute for Solar System Research)

The Max Planck Institute for Solar System Research (Goettingen, Germany) is leading the project of a third flight of the Sunrise balloon borne observatory. Two successful flights (2009 and 2013) resulted in more than 100 papers in refereed journals. For the planned re-flight in 2022 the Sunrise instrumentation will be extended significantly. A multi-line full-Stokes spectro-polarimeter (SUSI) for the wavelength range from 300-340 nm will analyze the largely unexplored near-UV region with a huge potential to decipher the height-stratification of the solar atmosphere from the deepest photospheric layers up to chromospheric heights with unprecedented height resolution. The second new instrument, a full-Stokes spectro-polarimeter from 650-850 nm (SCIP) will also benefit from a large spectral range for multi-line analysis, but with much better known spectral lines. The third new instrument (TuMag) is an imaging spectro-polarimeter in two spectral lines (photosphere and chromosphere).

The launch window for the Sunrise-III observatory is around summer solstice (21-Jun). The duration of the flight is approximately 1 week, so that the earliest launch date is June 1st, and the latest is in the first week of July.

We ask for multi-instrument (VTF, VBI and DL-NIRSP), multi-target support during the week of the flight. Sunrise-III shall define the pointing of DKIST. The detailed scientific observing program will be developed in the months before the actual launch, when the performance of the new instrumentation is well known.

Depending on the availability of other instruments, like the ones on board the Solar Orbiter spacecraft, or the *Hinode* SOT/SP, the co-observations will be extended to those instruments.

UC-60: Coronal Helium Abundance from joint DKIST and Solar Orbiter Observations (Vincenzo Andretta, INAF/Osservatorio Astronomico di Capodimonte)

The helium abundance relative to hydrogen from in-situ measurements of the fast and slow solar wind has long been known to be smaller than its value in the solar convective envelope. In the slow solar wind, the degree of helium depletion has also been shown to depend upon the wind speed and the level of solar activity.

Measurements of the helium abundance in the corona, together with measurements of the coronal outflow velocity, will provide evidence for the degree of correlation between wind speed and helium abundance and allow identification of the source regions of the slow wind streams with different helium abundance.

Measurements of the helium abundance in the solar corona can be obtained by simultaneous observations from Solar Orbiter remote-sensing instruments Metis and EUI, with support from DKIST/Cryo-NIRSP during favourable orbital configuration phases. The Metis coronagraph can also provide measurements of the coronal outflow velocity. Additional information can obtained from other Solar Orbiter remote-sensing and in-situ instruments.

UC-61: DKIST and Solar Orbiter Observations for Understanding the Creation of Upflowing Plasma on the Sun - On Disk Observations (Louise Harra, PMOD / WRC)

The project aims to explore the physical processes that create upflowing plasma that constitutes part of the solar wind. This includes both the fast and slow solar wind, and hence covers a range of sources. DKIST will provide photospheric magnetic fields. This will allow measurements of small magnetic fragments at the regions of up flowing plasma. We will use *Hinode*-EIS and IRIS coordinated with DKIST. This topic is a key science goal for the Solar Orbiter mission. The science data from SO remote sensing will be available from 2021, but there will be some periods when the remote-sensing data is available during the cruise phase where some ad-hoc observations may be made from DKIST that could be used for solar wind science. Once the science mode begins then there are opportunities for joint studies in this topic – for this particularly option we are interested in periods of conjunctions. The targets will be coronal holes, coronal hole boundaries and upflow regions at the edges of active regions. Because of the limited opportunities for observing with Solar Orbiter it is requested that this CSP is run in coordination with *Hinode* and IRIS several times well in advance of the Orbiter optimum observing periods.

UC-62: Are Quiet-Sun Internetwork Fields Turbulent? The Zeeman View (Luis Bellot Rubio, Instituto de Astrofisica de Andalucia)

The main goal of this Science Use Case is to investigate the magnetism of the solar internetwork by means of the Zeeman and Hanle effect. We will take advantage of the large photon collecting power of DKIST to measure the elusive linear polarization signals produced by the weak internetwork magnetic fields at high polarimetric sensitivity (~10^-4), high spatial resolution (~100 km) and high cadence (~20 s). These data will be used to:

1. Determine the vector magnetic field in the internetwork reliably, using all four Stokes parameters of visible and infrared spectral lines.
2. Study the magnetism of the quiet-Sun internetwork over most of the solar surface.
3. Determine whether or not internetwork fields are "turbulent", as assumed to explain spatially and temporally unresolved Hanle measurements.
4. Assess the compatibility of the Zeeman and Hanle views of the quiet Sun.

UC-63: Short-Term Evolution of Internetwork Magnetic Fields (Luis Bellot Rubio, Instituto de Astrofisica de Andalucia)

Clues on the nature of the ubiquitous internetwork magnetic fields can be obtained from an understanding of their temporal evolution on short-time scales, in particular their modes of appearance and disappearance. However, the long integration times needed to detect the weak fields of the solar internetwork have precluded a systematic investigation of this aspect. DKIST will allow the temporal evolution of the weakest fields of the solar internetwork to be determined at high spatial resolution for the first time. This will make it possible to compare the observed behavior with that shown by dynamo simulations of the solar surface. In addition, coordinated observations with Solar Orbiter PHI's instrument will permit stereoscopy of the magnetic field vector, through which the 180 degree azimuth ambiguity of the magnetic field can be resolved uniquely for the first time. Magnetic stereoscopy is is especially important near the solar poles, to determine the polarity of the field, but can also be exploited early in the nominal science mission to determine the proper orientation of the magnetic field emerging in the quiet Sun.

UC-64: FIP Fractionation as Tracer of Solar Wind Source Regions from Joint DKIST and Solar Orbiter Observations (Susanna Parenti, Institut d'Astrophysique Spatiale)

Understanding the formation and evolution of the solar wind and heliosphere is still a priority in the solar and heliospheric communities. The 1D sampling of the in situ instruments, the lack of in situ measurements sufficiently close to the Sun, and the indirect measurements of the plasma and magnetic field of the solar atmosphere all contribute to the complexity of the problem to be solved. Significant progress can be made with improved diagnostics based on the physical link and evolution between what measured in situ and its source regions on the Sun. The plasma composition and FIP fractionation are considered a good tracer for discriminating the wind source regions and the plasma propagation in the heliosphere. The main objective of this project is to provide strong constraints to the identification of the winds sources by exploiting joint measures from DKIST and Solar Orbiter of the plasma parameters (i.e. the FIP effect, flows) and magnetic field properties in different solar regions.

UC-65: Evolution of 3D Magnetic Configuration at Magnetic Flux Cancellation Sites (Masahito Kubo, National Astronomical Observatory of Japan)

The purpose of this project is to understand the disappearance of magnetic flux from the solar surface at magnetic flux cancellation sites. We investigate the motion of magnetic field lines formed by the flux cancelling process by using multi-line spectropolarimetic observations at high spatial and temporal resolution. Such study tells us whether submergence or emergence of magnetic field lines takes place at the magnetic flux cancellation sites.

UC-70: Magnetic Structure, Formation and Evolution of Active Region Filaments (Rebecca Centeno, High Altitude Observatory / NCAR)

Active region filaments are large concentrations of relatively cool and dense material that sit above magnetic polarity inversion lines. Instabilities in the magnetic structures that confine filaments can result in their eruption, in events often related to coronal mass ejections and flares. Thus, understanding the magnetic structure of filaments, their formation mechanisms and the conditions that lead to their eruption are the keys to improving our Space Weather forecasting abilities.

The observing requirements are stringent. The very magnetic nature of filaments calls for the measurement and interpretation of the full Stokes vector; the vertical span of the magnetic structures that hold them, rooted below the photosphere yet embedded in the corona, requires a multi-wavelength, multi-height observing approach; the small-scale magnetic shear in the narrow filament channels is still beyond the resolving power of the largest telescopes, and the mechanisms that lead to the magnetic rearrangement that trigger eruptions require high cadence observations.

For these reasons, the unprecedented high resolution, the high polarimetric sensitivity and the multi-wavelength capabilities of DKIST are needed to push forward our understanding of these phenomena.

UC-71: Structure, Dynamics, and Magnetic Environment of Filaments of Various Sizes (Navdeep Panesar, LMSAL/BAERI)

It is well known that the entire filament structure is made up of numerous threads of cool plasma that flows on the magnetic field lines. Recent observations from Hi-C have shown counter streaming in filaments, especially in filament spines, before their eruption but the source/origin of these flows from the photosphere is still not well understood. Is counter streaming common in all types of filaments e.g. polar crown filaments and minifilaments, or is it only in the active region filaments due to its high magnetic field strength? To better understand filament fine-scale structures and the origin of flows and their photospheric sources, DKIST should capture high-resolution magnetograms in combination with high-spatial and temporal resolution images in H-alpha and other chromospheric lines. In particular, in addition to studying the magnetic fine-scale structure of filament spines and barbs, we will explore the magnetic environment at the foot of barbs to understand how the flow in the filament spine is triggered.

UC-72: Observe Coronal and Chromospheric Jets in Polar Coronal Holes (Alphonse Sterling, NASA/MSFC)

Coronal jets are common in polar coronal holes (~60/day). We will study the formation mechanism of these jets using DKIST, with support from SDO, and optionally *Hinode* and IRIS. We will examine imaging data and photospheric and chromospheric magnetic field data of regions likely to produce jets, to test the formation mechanism of these features. The same data sets should also include spicules, to test whether their formation mechanism is similar to (or the same as) that of jets.

UC-73: On the Origin of Isolated Pores in the Quiet-Sun and Active-region Pores (Meetu Verma, Leibniz-Institute for Astrophysics Potsdam (AIP))

The goal of this Science Use Case is to comprehensively describe solar pores in terms of their flows and magnetic field properties. The need to understand the different mechanism responsible for the formation of quiet-Sun and active region pores motivate this work. The thin, dark lines, so-called "hairs" are often seen extending from the pores to the closest neighboring granules. What are the implications of such corrugated boundaries for the stability of flux tubes? Are they a first indication of penumbra formation? The results of this Science Use Case will be a first step towards a better understanding of pores and provide important information for numerical models. The high-resolution observations from DKIST will provide an opportunity to compare small-scale magnetic and flow fields in the vicinity of pores in different environments and at various stages of evolution. With DKIST we will be able to resolve features down to 35 km. Hence, enabling us to observe the fundamental building blocks of magnetic fields, i.e., individual flux tubes, and to examine the morphology and evolution of fine structures in and around pores. Quasi-simultaneous intensity maps, magnetograms, and dopplergrams will cover a much broader parameter space, thus providing even tighter boundary conditions for theoretical models. Observations in chromospheric lines are an additional resource provided by DKIST, which potentially links the photospheric properties of pores to the dynamics of the Sun's upper atmosphere.

UC-74: Emerging Flux: Current (de)Neutralization and Reconnection (Lucas A. Tarr, National Solar Observatory)

Flux emergence is a complex process that involves a restructuring of the emerging field and interaction between the emerging field and preexisting field in the corona. The restructuring of the field likely happens in the chromosphere where the emerging field must pass through ~9 vertical pressure scale heights. After passing through this region, the combined emerged field/preexisting field system must be in a state capable to producing eruptions. This use case focuses on the dynamic evolution of vertical currents above the photosphere during emergence, and how changes in their horizontal distribution both in time and with height are related to (a) self-reconnection of the emerging field, and (b) reconnection between the emerging field and surrounding, preexisting field. Both of these processes are related to the longstanding topic of current neutralization of active regions.

UC-75: Accumulation of Magnetic Twist in Eruptive Filaments in Chromosphere (Anna Malanushenko, High Altitude Observatory / NCAR)

The filaments which are seen erupting in some cases appear to have twist much bigger than 2-3 orders about an axis. This number of turns is thought to be, roughly, a threshold before a flux rope becomes unstable in the corona. Chromosphere is different and such amounts of twist can conceivably emerge, or accumulate during chromospheric evolution. There are also models that the twist accumulates during the eruption process itself, as the erupting rope reconnects with the neighboring structures.

The idea is to make use of unique capabilities of DKIST and track small-scale features and flows in compact filaments, in order to: (Q1) observe 'compressed' flux ropes before they erupt using high-res observations; (Q2) observe, using full vector magnetograms and Doppler velocities, the appearance of such flux ropes (emergence or otherwise) and determine how much twist they have at the time of appearance; (Q3) track small-scale features along filaments' lengths using high-cadence observations and determine through observations whether accumulation of twist happens during chromospheric evolution.

Eruptive flux ropes which have clear twisting structure, such as those in the attachments, are of particular interest. Joint observations with AIA would allow us to track the (un?)twisting of a flux rope during its eruption. At the time of planning the observations, AIA could be used to roughly determine ROI's which are then observed by DKIST for a given period of time (several hours a day?), for several objects, until sufficient statistics (especially of eruptive filaments) is gathered.

With regard to the wavelengths, this project's requirements are rather flexible, so long as the structures of interest can be observed. For a ROI determined through AIA, the optics setup available at DKIST at the time of the observation can be tested and used if appropriate. The desirable data are outlined above.

The PI's experience suggests that the flux ropes which have a clear twisted inner structure at eruption may have a compact chromospheric counterpart. In that case, the chromospheric FOV does not need to be large; the imaging observations should span several heights, and the vector-magnetic and Doppler data can be taken along slits across such filaments.

Aside from fundamental uses such as helicity accumulation and evolution in low atmosphere, this project will also be of immediate practical use for space weather studies. This outcome is similar to that of non-linear force-free modeling of energy and helicity accumulation in active regions, but those are limited to the low-beta corona and to field strengths found in active regions.

UC-76: Sub-Arcsec Magnetic Signatures of the Fine Coronal and Chromospheric Jet Activity (Nour E. Raouafi, The Johns Hopkins University Applied Physics Laboratory)

This Science Use Case targets the physical mechanisms at the origin of the fine coronal and chromospheric magnetic activity. The solar targets include (but not limited to) equatorial coronal holes, quiet sun, and plage areas. Solar structures that can be addressed by this SUC are coronal plumes and quiet sun. The frequency and preponderance of these events may provide important insights into the processes heating different coronal structures such plumes.

High-cadence and relatively high-resolution EUV observations from the Atmospheric Imaging Assembly (AIA) on the Solar Dynamic Observation (SDO) and to a less degree other instruments show a preponderance of small-scale, short-lived magnetic activity that may play a key role in the heating of different coronal structures. Coronal plumes are an excellent example where this activity in the form of small jets coined "jetlets" by Raouafi et al. (2014) are key to their formation and sustainability over lengthy periods of time.

We will analyze the details of magnetic activity leading to the formation and sustainability of coronal plumes observed in equatorial coronal holes using primarily DKIST, with support from SDO, *Hinode*, and IRIS. We will examine photospheric and chromospheric magnetic field and Dopplergram data of regions likely to produce tiny jets (e.g., jetlets), to test the formation mechanism of these features.

UC-77: Probing the Relationship between Surface Lightcurve Oscillations and High Altitude Coronal Reconnection (Adam Kobelski, West Virginia University)

Supra-arcade downflows (SADs) evident during long duration flaring events are a prime example of an indirect observation of magnetic reconnection in the corona. Capturing the creation of these phenomena at the point of reconnection is greatly complicated by low coronal signal. Therefore, to further strengthen the case relating SADs to reconnection outflows, it is necessary to look for additional correlations between them and other effects expected from individual reconnection events. One such candidate is the oscillating flare hard X-ray lightcurve signature (e.g., quasi-periodic pulsations (QPPs)), which may represent the reaction of the solar surface at the footpoints of reconnecting loops to accelerating particles. Finding a correlation between the timing of individual SAD detections with peaks in oscillating hard X-ray and chromospheric lightcurves would greatly enhance the connection between SADs and magnetic reconnection. Other relevant parameter correlations (such as wave amplitude and SAD velocity and/or rate) would also open exploratory space and would provide a clearer path toward measuring the rate of particle acceleration within retracting loops during flaring events.

UC-78: Reconnection Events in the Low Solar Atmosphere Driven by the Plasmoid Instability (Bart De Pontieu, Lockheed Martin Solar and Astrophysics Laboratory)

Magnetic reconnection is thought to drive a wide variety of dynamic phenomena in the solar atmosphere. Yet the detailed physical mechanisms driving reconnection in the solar atmosphere are not well known, in part because of the small spatial scales on which this process occurs. Here we propose to build on preliminary results using SST/CHROMIS and IRIS to identify the intermittency of magnetic reconnection and its association with the formation of plasmoids in so-called UV bursts in the low solar atmosphere. Recent CHROMIS images in the chromospheric Ca II K 3934Å line provide tantalizing evidence for the presence of plasmoids, by revealing highly dynamic and rapidly moving brightenings that are smaller than 0.2″ and that evolve on timescales of order seconds. With DKIST we aim to directly observe these plasmoids and study their relationship to the evolution of the magnetic field at a wide range of heights.

UC-79: Spectro-Polarimetric Detection of Propagating Alfvén Waves (Yukio Katsukawa, National Astronomical Observatory of Japan)

Recent high resolution observations have revealed that chromospheric structures, such as fibrils, spicules and prominences, often exhibit transverse and torsional oscillation, suggesting that Alfvenic waves potentially carry significant energy flux into the corona. The energy flux, i.e. Poynting flux, was usually estimated by assuming an Alfven velocity although it contains lots of uncertainty in magnetic fields and densities. If we can directly detect both magnetic and velocity fluctuation associated with such Alfvenic waves, we can directly quantify Poynting flux because the flux is proportional to ExB = Bx(vxB). By finding phase relationship between magnetic and velocity fluctuation, we could determine the wave is really propagating and carrying the energy. The high polarimetric sensitivity as well as spatial resolution of DKIST allows us to detect modulation of magnetic fields associated with Alfvenic waves directly, and to get the Poynting flux for the first time.

UC-80: Chromospheric and Photospheric Magnetic Field Evolution in Active Regions (Mark Linton, Naval Research Laboratory)

What is the magnetic structure of the active regions? Observing and / or modeling their magnetic structure is critical to understanding the energy content of active regions, and for predicting their potential to flare and erupt. There is currently significant effort being focused on reconstructing active region magnetic fields using photospheric vector magnetic field observations. These reconstructions are based on, for example, non-linear force free fields, magnetofrictional models, or magnetohydrodynamical simulations. A critical validation of these models, and a significant step forward in understanding active region magnetic structure and energy, would be comparison of the model magnetic fields with chromospheric and coronal vector magnetic fields measured by DKIST.

UC-81: Chromospheric Signatures of Active Region Microflares (David Mckenzie, NASA/MSFC)

Small-scale transient brightenings in active regions have been identified from coronal imagers (*Yohkoh*/SXT, *Hinode*/XRT, TRACE, Hi-C, e.g.) as microflares. High-cadence, high-resolution observations imply unresolved structure within the brightening loops on sub-arcsecond length scales, and time scales as short as 10s (Kobelski+2014). The microflares are found to be distributed throughout active regions, occurring as frequently as 50 per hour. This study investigates the chromospheric signatures of the energetic release in the microflares, and the relationship to magnetic footpoints in the photosphere.

UC-82: Photospheric Magnetic Energy Input and the Chromospheric and Coronal Response: Quiet Sun, Coronal Bright Points (Maria Kazachenko, University of Colorado, Boulder)

How is the energy that heats the Sun's outer atmosphere transported across the photosphere and processed through the chromosphere? The rate of transport of magnetic energy, the Poynting flux, can be estimated from the observed vector magnetic field evolution and the inverted electric fields (e.g., Fisher et al. 2012, Kazachenko et al. 2014). The properties of the photospheric Poynting flux, however, have not yet been thoroughly characterized due to the lack of vector magnetic field measurements outside strong field regions (Kazachenko et al. 2015, Welsch 2014) Unprecedented quality of vector magnetic field measurements from DKIST in the photosphere and the chromosphere suggests a promising way to address many scientific questions regarding energy transfer from the photosphere into regions above. How does the outer solar atmosphere respond to the injection of energy across the photosphere? How much of this magnetic energy reaches the chromosphere? On observable scales, can any correlation in space or time be detected between the input of energy at the photosphere and variations in emission in the chromosphere, transition region, and corona? Is injected energy dissipated immediately, or stored for some typical latency time? Do energy fluxes on observable scales possess any scaling that might enable extrapolation to unobservable scales?

With DKIST we propose to investigate the magnetic energy propagation from the photosphere above. We will do so by pairing out photospheric and chromospheric energy fluxes, estimated from vector magnetic field measurements from DKIST with observations of chromospheric (DKIST), transition region, and coronal emission observed by IRIS, *Hinode* and AIA.

UC-83: Flux Emergence Rates of Super-Small-Scale Magnetic Fields (Shin Toriumi, Japan Aerospace Exploration Agency)

Flux emergence rates show a power-law distribution over a wide range of orders of magnitude in flux from granular scales (10^{16} Mx) to sunspot scales (10^{23} Mx) (Thornton and Parnell 2011). Does this power law continue to even smaller scales? DKIST will observe the emerging magnetic fields in the photosphere with high spatial and temporal resolutions and explore the scales beyond granulation. The unique observation with DKIST will provide information of small-scale dynamo and flux emergence with unprecedented detail, answering the above-presented question.

UC-84: Resolving the Spatial and Temporal Evolution of Event-Driven Turbulence in the Chromosphere (Kevin Reardon, National Solar Observatory)

The passage of acoustic waves in the chromosphere is known to result in the creation of shocks and rapid deposition of energy into the coronal plasma. There is evidence that these shocks results in the onset of turbulent cascades that propagate that energy in space and frequency. This process may be important for chromospheric heating and mode conversion that might allow transmission of energy to higher layers of the solar atmosphere. With DKIST we can obtain observations of these events at sufficient spatial and temporal resolution to probe the details of this process in both individual and ensemble cases.

UC-85: The Cold Chromosphere: Mapping CO Spatial and Temporal Inhomogeneities (Sarah Jaeggli, National Solar Observatory)

The strongest lines of the CO fundamental vibration-rotation band (delta v=1, where v is the vibrational quantum number) reside in the infrared part of the spectrum around 4.6 um. These lines have been the subject of only a few observational studies, but state-of-the-art modeling has been developed to understand how they form, and what their presence means for the solar atmosphere.

Cryo-NIRSP on DKIST can conduct major discovery science using the CO fundamental band. Because of the limited time and spatial resolution of previous observations, the dynamical behavior of CO over the full range of solar phenomena has not been fully explored. We still do not have a good understanding of where and how lines of CO form, however they seem to probe a critical region in the solar atmosphere, where the photosphere couples to the chromosphere. This use case suggests only the first step in what should be a concerted campaign to observe CO under a range of conditions.

UC-86: Neutral Line Magnetic Context of Active Region Coronal Heating (David Falconer, University of Alabama, Huntsville)

UC-87: Fine-Structure of Macro-Spicules (Reza Rezaei, Insitituto de Astrofisica de Canarias)

Macro-spicules are slender bright structures in the solar chromosphere that extend over several ten Mm and often reach up to the corona. We want to resolve the internal fine-structure of macro-spicules and to study the variation of intensity enhancements inside them, e.g., oscillations or wave propagation along the major axis. This requires a high cadence and a high-resolution imaging setup to differentiate the thermal and flow properties of the macro-spicules from nearby normal spicules. High-cadence limb observations of macro-spicules in the core of strong chromospheric lines are possible with the DKIST, both because of its large aperture and high spatial resolution. This study will help to understand the driving mechanism for macro-spicules, the role of hydrodynamic and magnetic waves in their evolution and the impact of macro-spicules on the corona and the solar wind.

UC-88: Properties of the Solar Wind Source Regions Investigated by DKIST and Solar Orbiter (Daniele Spadaro, INAF, Osservatorio Astrofisico di Catania)

A detailed physical characterization of the solar wind source regions can be performed from near surface to about two solar radii above the limb, using several spectral bands (visible light, Lyα of H I and He II, in addition to spectra lines suitable for magnetic field determination). The magnetic field topology detected by DKIST can be related to the solar wind properties (plasma density, helium abundance, plasma outflow velocity) measured by the Solar Orbiter instruments Metis and EUI (FSI) in the inner heliosphere. The influence of the magnetic flux divergence (directly determined by DKIST and indirectly by Metis) on the wind expansion velocity in the source regions can be investigated. This science case can be categorized under the DKIST Research Area: Magnetic Connectivity, Mass and Energy Flows in the Solar Atmosphere. The corresponding Solar Orbiter science objective is Q1: What drives the solar wind and where does the heliospheric magnetic field originate?

UC-89: Tracking the Evolution of Corona Mass Ejections Plasma (Daniele Spadaro, INAF, Osservatorio Astrofisico di Catania)

Tracking the evolution of the coronal mass ejections plasma from the solar surface through the inner and outer corona, possibly through regions of the solar wind probed by PSP (TBC).
The relevant DKIST research area for these SUCs is Flares and Eruptive Activity. The corresponding SO science questions are Q1: What drives the solar wind and where does the heliospheric magnetic field originate? and Q2: How do solar transients drive heliospheric variability?

UC-90: Synoptic Coronal Observations in Support of PSP and Solar Orbiter (Gordon Petrie,National Solar Observatory)

Encounter missions such as the Parker Solar Probe and Solar Orbiter will benefit from as much knowledge of the physical conditions of the solar corona as possible in anticipation of each science window. This SUC describes the required coronal observations: cadences (daily), timing (one rotation in advance of the encounter window, ...), spectral lines (magnetic fields, abundances), FOV (polar, equatorial, global) needed to augment the joint PSP+SO+DKIST science.

UC-91: Coronal Magnetic Field at the Current Sheet Trailing CMEs (Katharine Reeves, Harvard-Smithsonian Center for Astrophysics)

CMEs eruption are known to have a trailing current sheet where reconnection occurs and that likely results in the post flare loops arcades. By doing off-limb spectroscopy and polarimetry of this region we can constrain the physics of the reconnection processes.

UC-92: Origin and role of Moving Magnetic Features in the evolution of sunspots (Francesca Zuccarello, University of Catania)

High-resolution magnetograms show the presence, around sunspots, of small-size magnetic elements, called moving magnetic features (MMF) that are seen to stem out from penumbra border and later on merge with the surrounding magnetic field. These magnetic patches seem to be related to the slow disaggregation of the magnetic flux tubes that were previously stuck together in sunspots. MMFs can be of different types, depending on the sign of magnetic polarity closer to the parent sunspots. Their interpretation is related to different configurations of the magnetic field (whether resembling a U-loop or a serpentine-like shape).

The MMFs observed so far have generally a size of few arcsec, but it is possible that higher spatial resolution observations, like those that will be available with DKIST, will reveal the presence of smaller structures and this finding would be important to verify whether they have a hierarchical subdivision and in this case how they contribute to the erosion/disappearance of sunspots.

The spectropolarimetric capabilities of DKIST instruments would allow us to detect the very first phase of detaching of MMFs from the penumbra or even from the umbra and verify whether both occur following a similar process. The capabilities of the VTF, characterized by rapid imaging spectrometry and Stokes imaging polarimetry will be fundamental in order to better characterize the magnetic properties of the MMFs and reveal the role that patches characterized by different magnetic polarities have in the umbra erosion. The imaging capabilities of the VBI and the high spatial, spectral resolution of DL-NIRSP could help us in detecting possible brightening at photospheric and chromospheric levels, that up to now have been observed only in few MMFs and therefore give some hints of the possibility that these brightening are related to small-scale reconnection processes occurring during the motion of these structures away from the parent spot.

UC-93: The Influence of Magnetic Field on the Properties of Convective Cells (Jan Jurcak, Astronomical Institute of the Czech Academy of Sciences)

The presence of magnetic field influences the shapes, sizes, and lifetimes of convective cells. There are a number of case studies showing the properties of convective cells in the presence of magnetic field. However, the dependence of convective cells evolution on the pre-existing magnetic field and vice versa the influence of the evolving convective cell on the magnetic field needs to be understood. The high spatial and temporal resolution of DKIST instruments DL-NIRSP and VTF will allow us to study the evolution of magnetic field vector during the lifetime of the convective cells and understood in greater detail the interplay between the magnetic and kinetic forces.

UC-94: Dependence of Heating of Active Region Coronal Loops on the Magnetic Setting of the Loop Feet (Sanjiv K. Tiwari, Lockheed Martin Solar and Astrophysics Laboratory)

In a recent work (Tiwari et al. 2017) we showed from SDO/AIA EUV observations and non-linear force-free field modeling of coronal magnetic field of two active regions that the brightness of an active-region coronal loop depends on the magnetic setting of the loop feet i.e., where in the photosphere both of the loop feet are rooted. Umbra-to-umbra loops were found to be the least heated. Sunspot-to-plage loops, penumbra-to-penumbra loops, or the loops rooted in a mixed-polarity flux at one or both of their feet were the brightest. We will verify the results of Tiwari et al. (2017) in high-resolution data of DKIST. In the past, coronal loops rooted in the regions of polarity inversion lines were found to be the hottest ones (Falconer et al. 1997, Chitta et al. 2017), in agreement with one category of the brightest loops in our observations. With DKIST we will investigate if all brightest loops are rooted in a mixed-polarity flux, at least at one of their feet, currently unresolved by HMI observations. We will also diagnose flow patterns using spectral observations from DKIST in the photosphere and chromosphere, combined with IRIS transition regions spectra.

UC-95: Observing Magnetic Structure and Evolution in the Lower Atmosphere Responsible for the Formation of Coronal Sigmoids in Solar Active Regions (Jie Zhang, George Mason University)

Sigmoidal structure in the coronal shown in X-ray and EUV observations are often found to be the precursor structure of a solar eruption that leads to CME and accompanying flare. The formation of sigmoids is a long-term process that spans for hours and days. During this period, significant changes of magnetic structure occur in the corona, for instance, transforming from an arcade field into a magnetic flux rope. Such changes shall be driven by magnetic process occurring in the underlying lower atmosphere, and very often, magnetic flux cancellation occurring cross a strong-gradient polarity inversion line in the source active region. Using advanced DKIST observations, this project is to study the expected dynamic magnetic changes in the photosphere and chromosphere in the polarity inversion line below a coronal sigmoid. Such changes, e.g., flux cancellation, magnetic reconnection, flux injection into the corona, and flux sub-mergence back to the sub-photospher, have not been well observed before, due to limited instrumental capability in the past. The extremely high spatial resolution and high sensitivity spectral-polarimetric diagnosis of magnetic field in multiple layers of DKIST allow us to investigate the key physical process that drives the formation of energetic magnetic configuration that generates CMEs and flares.

UC-96: Understanding the Origin of High Temperature Active Region Plasma (Harry Warren, Naval Research Laboratory)

Coronal heating is one of the central open problems in solar physics. This project will study the footpoints of high temperature (3-4 MK) loops that are found in the core of solar active regions. DKIST will provide critical new information on the photospheric motions that inject energy into the solar atmosphere, the magnetic field that stores and transports this energy, and the chromospheric response to the release of this energy. Many low-resolution studies of these footpoints have been made, but DKIST will be the first to provide observations of the photosphere and chromosphere at very high resolution and cadence. Further, these observations will be coordinated with space-based instrumentation such as *Hinode* EIS and XRT, IRIS, and SDO AIA that will provide simultaneous information on the higher-temperature emission. EIS, XRT, and AIA will provide the direct identification of the high temperature loops. EIS and AIA will provide information on the footpoints near 1 MK, where the contrast with the rest of the corona is highest. Finally, IRIS and AIA will provide information on the upper chromosphere and transition region. In combination, the DKIST and space-based observations will provide a complete description of these high temperature loops for the first time. We will use the observations to motivate 1D hydro and 3D MHD simulations of active regions loops. We will determine if the observed properties of the photosphere are consistent with the magnitude and variability of the emission observed in the corona.

UC-97: Prolonged Post-Reconnection Heating in Flare Loops (Jiong Qiu, Montana State University)

Magnetic reconnection releases energy in flare loops. The long duration (10+min) of flare emission in a flare loop or at its foot-point may not be entirely due to slow cooling, but may indicate continuous and prolonged heating in the flare loop, after the intense impulsive heating. It is not clear what are the mechanisms for the prolonged post-reconnection heating.

UC-98: Diagnosing Reconnection and Eruption from Coronal Dimming (Jiong Qiu, Montana State University)

Coronal dimming (transient coronal holes) maps locations where overlying coronal plasmas expand, leading to reduced coronal density and emissivity. This may be caused by either the eruption of a coronal structure or reconnection that opens up field lines. Observing dynamics and magnetic fields at the base of the coronal dimming, primarily using He I 10830 line (Harvey 2002) with other chromosphere lines, helps diagnose properties of reconnection or eruption in the corona and track the evolution of coronal structures from pre-eruption to eruption.

UC-99: Are Giant Tornadoes Sources of Large-Scale Vorticty or Flows along Twisted Magnetic Fields? (Eamon Scullion, Northumbria University)

Giant tornadoes have been observed for many decades. They appear in association with H-alpha barbs / magnetic dips in prominences and filaments, both on-disk and off-limb, as well as, in absorption within the EUV channels of the transition region and corona. They are named as tornadoes because they appear to evolve as a large-scale vortex, in the plane-of-sky, but the true nature of the vortical motions has not been confirmed. Furthermore, if they are indeed large-scale vortex motions does the coupling of plasma vorticity transpire from below (i.e. in the photosphere) or above (i.e. mass drainage from the prominence). They play a significant role in the evolution of eruptions and so they could be important for understanding the precursors to eruptions, leading to space weather events. Using DKIST, we aim to measure the properties of the magnetic vector field across the tornado funnel, radially projected at the limb, in order to detect signatures of rotation of the magnetic structures along the line of sight within the tornado. Spatially resolved inversions of the spectral profiles could also be used to interpret the flow fields in conjunction with the magnetic field vectors to understand how partially ionized plasma interacts with the magnetic fields in tornadoes. Giant tornado studies offer a fantastic opportunity to measure the nature twist of magnetic fields on large-scales as a function of height connecting all layers of the solar atmosphere.

UC-100: Magnetic Field Variations as Seismic Drivers (Juan Carlos Martinez Oliveros, Space Sciences Laboratory - University of California Berkeley)

Solar flares can excite seismic waves that propagate in the solar interior by providing an external impulse. The idea that a flare might do this was proposed by Wolff (1972) and developed by Kosovichev and Zharkova (1995). In 1998, Kosovichev and Zharkova detected for the first time a flare-induced seismic event, in the form of ripples expanding on the solar photosphere,this being the surface manifestation of an acoustic transient penetrating deep beneath the active region and refracting back to the surface thousands of km from the flare. They termed this phenomenon a "sunquake." Several mechanisms have been proposed to explain the generation of sunquakes: shocks, photospheric heating, penetrating particles, Lorentz forces, among others. Here we propose to observe variations of the photospheric and chromospheric magnetic field related to the generation and propagation of flare driven seismic events.

UC-101: Wave Dissipation along Magnetic Wave Guides (Samuel Grant, Queen's University Belfast)

The steepening of MHD waves into shock fronts provides an observable case of wave dissipation in the solar chromosphere. The density stratification of sunspots produces non-linear magneto-acoustic waves, commonly known as Umbral Flashes. However, there are a variety of physical situations within magnetic flux tubes that can lead to the steepening of MHD waves, including the elusive Alfvén wave. This observing campaign will provide an unprecedented insight into the magnetic structuring of flux tubes, allied with high temporal and spatial resolution spectral scans, that will allow for the identification of ideal locations for shock formation, and the necessary resolution to detect the signatures of shocks and assess their dissipative potential above the chromospheric temperature minimum.

UC-102: Detecting Ionization Fronts Due to Coronally Generated Waves (Lucas A. Tarr, National Solar Observatory)

Magnetic reconnection events drive Alfvénic waves that propagate outwards from the reconnection site along magnetic field lines. In nanoflares and flares, the reconnection occurs in the corona, so it is expected that the waves should propagate downwards to the chromosphere, where the increased density drastically increases their dissipation due to ion-neutral friction (ambipolar diffusion). Recent papers have predicted that heating due to Alfvénic waves in the chromosphere should produce asymmetries in chromospheric lines (Kerr et al. 2016) and an ionization front that propagates to ever-increasing depths in the chromosphere (Reep et al. 2018). We therefore propose to search for these signatures of Alfvénic wave heating in an active region, where the occurrence of nanoflares should be constantly driving waves.

UC-103: Acoustic Sources in the Photosphere (Mark Rast, University of Colorado, Boulder)

The aim is to directly assess the acoustic importance of dynamical processes in solar granulation: new downflow plume formation during granule fragmentation (exploding granules), sudden localized downflow amplification in intergranular lanes, and turbulent flow at the border between granules and intergranular lanes. We will observe sub-granular dynamics in regions of quiet Sun, and use high cadence intensity and velocity time series to characterize the excitation events in terms of their pressure, Doppler velocity, and continuum intensity signatures. These will be compared to the deduce properties of the helioseismic sources as determined from three-dimensional numerical simulations and helioseismic observations. An inversion for pressure fluctuations at the source sites is particularly challenging, but will direct determination of the acoustic source efficiency of the proposed mechanisms. The role of small scale magnetic field at the source sites will be assessed.

UC-104: Characterizing the Thermodynamic and Magnetic Structure of Spicules (Luc Rouppe van der Voort, University of Oslo)

Spicules are the main constituent of the solar chromosphere and are thought to be one of the main agents for the transport of mass and energy between the photosphere and the corona. Spicules pose a major challenge for present-day telescopes: they are very dynamic, evolve on short timescales, and show signs of substructure. The unprecedented diagnostic capabilities of DKIST will allow for a full characterisation of spicules which is necessary to distinguish between different driving mechanisms and establish the role of spicules in the global energy balance of the solar atmosphere. We aim to do this through spectropolarimetric inversions of the Ca II K, Ca II H, and Ca II 854.2 nm lines that can be observed strictly simultaneously at high spectral resolution and integrity with the ViSP instrument. The combination of these lines provides a powerful diagnostic to probe the atmosphere over the full depth from the photosphere to the chromosphere. DL-NIRSP will provide with context magnetic diagnostic of the deep photosphere through the Fe I 1565 nm line. We will target network regions at different observing angles on the disk. By observing spicules on the disk, it will be possible to isolate individual spicules over their full length and avoid the line-of-sight superposition that is an intrinsic problem towards the limb.

UC-105: Investigating Magnetic and Thermal Structures of Coronal Cavities (Suman Dhakal, George Mason University)

Coronal cavities are a large-scale structure that appears as a dark circular feature in the corona. It usually has a prominence at its base. The structure of coronal cavity is scientifically intriguing, since it appears to be similar to the structure of an erupting CME. It may contain twisted magnetic field. It may contain heated plasma in the core. The filament embedded in it is rather dynamic. The process of storing magnetic energy, pre-eruptive environment and the initiation of solar eruptions remain the central topics in solar physics. The high-spatial resolution and polarimetric accuracy of the DKIST will provide the unprecedented opportunity to understand the magnetic structures of both the cavity and the embedded filament. This will also help to understand the variation of the temperature and density along the cavity.

UC-106: The Interaction of Newly Emerging Magnetic Flux with Pre-Existing Magnetic Flux in Active Regions (Taylor Cox, George Mason University)

Magnetic flux emergence and cancellation is an influential factor in the formation of sheared arcades and/or flux ropes, that lead to solar flares and coronal mass ejections. This Use Case would use DKIST to scan a mature active region at or near the center of the solar disk when there is an emerging region in the active region. The observations are for magnetic field and temperature data from the photosphere and chromosphere. This data, taken at different heights over a period of time, will allow for the observation of flux emergence within the observed active region and of any magnetic developments that arise as a result of the interaction of the new emergence with the surrounding active region.

UC-107: Understanding the Cooling of Strands in Active Region Coronal Loops at High Resolution (Ignacio Ugarte-Urra, Naval Research Laboratory)

Recent spectroscopic observations of coronal loops with the Extreme-ultraviolet Imaging Spectrometer (EIS) on board *Hinode* have suggested that million degree loops are close to being resolved with existing coronal instrumentation (Brooks et al. 2012). Following that work, we propose to use sub-arcsecond diffraction limited coronal spectroscopic observations to estimate the cross-sectional size of loop strands and their densities to model and test that scenario. We will also investigate how the coherence of these single monolithic structures evolves, in their cooling to chromospheric temperatures, to produce potentially narrower strands.

UC-108: Detailed Spectroscopic Atudies of Ellerman Bombs (Peter Young, NASA Goddard Space Flight Center)

Ellerman bombs are suitable targets for studying how magnetic reconnection takes place in the stratified atmosphere. This study makes use of the unique spectroscopic capabilities offered by VISP and DL-NIRSP to make ultra-high cadence spectroscopic measurements of H-alpha and H-beta over a wide wavelength range combined with multi-height polarimetry from DL-NIRSP. The measurements will enable the reconnection dynamics to be mapped to the magnetic field evolution to an extent not previously attained.

UC-109: Mechanisms of Wave Propagation below the Acoustic Cutoff Frequency (Alfred De Wijn, High altitude Observatory)

Magneto-acoustic waves with frequencies below the acoustic cutoff still make it into the chromosphere and corona. What is the physical mechanism that allows this? One suggestion is that propagation is possible along inclined wave-guides. Another is that vertical propagation is possible after taking into account radiative losses that raise the cut-off frequency. The reality is that both of these mechanisms likely work but in different magnitudes in different cases. The DKIST suite of instrumentation enables more in-depth studies of wave propagation than previously possible due to the availability of spectroscopic and polarimetric diagnostics simultaneously in many wavelengths, at high resolution, and at high cadence.

UC-110: Investigating Thermal Non-Equilibrium with Coronal Rain (Emily Mason, Catholic University of America)

This use case investigates mass and energy transfer through the corona via coronal rain in helmet streamer closed loops. The origins of coronal rain are still somewhat undetermined, and due to the small scale of rain "blobs", events have been challenging to observe. The increased spatial resolution of DKIST will ameliorate this issue, and the ability to image in multiple wavelengths simultaneously will significantly contribute to our knowledge of coronal rain's main characteristics.

Thermal non-equilibrium is one explanation for coronal loop dynamics; if this explanation is correct, coronal rain should condense and precipitate to the solar surface at regular intervals, cascading to near photospheric temperatures on its descent. Therefore, this use case suggests a search in the broad inner portion of the legs of helmet streamers, as the largest and richest target for this type of condensation.

UC-111: Coronal Energy Release in a Kink Unstable Flux Rope (Ben Snow, University of Exeter)

A twisted flux rope can be unstable to the kink instability that can lead to eruptions. Energy release through small-scale current sheets occurs as the kink instability resolves, however no observational evidence for these events has yet been found, mainly due to limited spatial resolution of existing spectroscopic instruments. Recent forward modeling work of Snow et al. (2018) has demonstrated that the coronal lines accessible through the DL-NIRSP instrument of DKIST will allow the heating events to be diagnosed. We propose a target-of-opportunity active region limb observation to identify the energy release events.

UC-112: Magnetic Pores as Energetic Wave Conduits (Samuel Grant, Queen's University Belfast)

Magnetic pores exhibit preferential conditions for the formation and transmission of MHD wave modes from the solar surface into the chromosphere. They are more responsive to the dynamic motions of surrounding granules, leading to the generation of a plethora of MHD waves. There have been ample imaging studies of sausage modes in pores, including verification of their existence, propagation into the chromosphere, and definitions of their modes. What remains lacking is an intensive understanding of the magnetic structuring of the pores themselves, and investigating the chromospheric polarised signals of sausage modes. Such information would allow for wave models to be considerably constrained, and fully assess the energetics, damping and potential dissipation of the waves themselves in an unprecedented manner. The high resolution of the data products of DKIST also allow for the identification of previously unidentified higher order wave modes, such as the elusive 'fluting' mode.

UC-113: Microturbulence of Quiet-Sun Magnetic Fields Considering the Temporal Evolution of Hanle Polarization (Edgar Carlin, Instituto Ricerche Solari Locarno and Instituto de Astrofisica de Canarias)

Due to the Hanle sensitivity of SrI in 4607 A, the linear polarization emitted by the Sun in this spectral line has been proposed for investigating the weak and unresolved (microturbulent) magnetic fields of the solar photosphere in the context of the small-scale dynamo theory. However, there are discrepancies between calculations and observations in SrI 4607A, such as an apparent lack of spatial correlation between polarization amplitude and solar granulation. This situation demands more accurate observations (Signal to Noise (S/N) = 10^3 - 10^4) at disk center and at the high resolution of the intergranules (~50-100 km), where simulations suggest that most microturbulent magnetism is created. In addition, the temporal evolution of the signals should also be considered in order to identify/avoid cancellations of polarization that are induced by temporal variations in the polarizing mechanisms, as recently pointed out by investigations of chromospheric lines. With the sensitivity and resolution of DKIST we can understand the above-mentioned discrepancies because DKIST allows us to study wavelength, space and time with suitable resolution without sacrificing in excess the demanding S/N ratio that is required to detect linear polarization and Hanle effect away from the solar limb. Performing temporal series of Hanle polarization and measuring its value across granules and intergranules, we shall study the level of signal reduction due to cancellation effects and the spatio-temporal topology of microturbulent magnetic fields. To this aim, and as an additional interest that this project has, we shall try to verify the existence of Hanle Polarity Inversion Lines (HPIL) at disk center. The HPILs stand out in maps of resolved non-null polarization as grooves of null polarization.

Their detection would imply the first direct measurement of resolved quiet-Sun magnetic field lines by mere polarization imaging.

UC-115: Temperature, Density and Composition of the Solar Corona and the Solar Wind from Joint DKIST and Solar Orbiter Observations (Andrzej Fludra, STFC Rutherford Appleton Laboratory)

We will use joint observations of Solar Orbiter SPICE EUV spectrometer and DKIST Cryo-NIRSP to derive temperature and density distribution with height above the limb in polar coronal holes, and the composition of the solar wind plasma. Temperature and density, combined with a solar wind model, will be used to calculate the ionization fractions of elements along the open magnetic field lines, and to compare them with line intensities observed by SPICE and ion fractions measured by Solar Orbiter SWA/HIS. We will also derive outflow velocity maps and FIP maps of elements observed by SPICE and compare them to in situ abundance measurements. This study will provide constraints on the fast solar wind models and locate the sources of the fast solar wind.

UC-116: Chromospheric Jets in the Sunspot Umbra and Penumbra (Luc Rouppe van der Voort, University of Oslo)

Penumbral and umbral microjets are an impulsive kind of jet that rapidly evolve on small spatial and temporal scales. They provide a unique window on the fundamental mechanism of magnetic reconnection in the strong field environment of the sunspot atmosphere. The unprecedented diagnostic capabilities of DKIST will allow us for the first time to fully characterise the magnetic and thermodynamic structure and evolution of these microjets. We aim to do this through spectropolarimetric inversions of the Ca II K, Ca II K, and Ca II 854.2 nm lines that can be observed strictly simultaneously at high spectral resolution and integrity with the ViSP instrument. The combination of these lines provides a powerful diagnostic to probe the atmosphere over the full depth from the photosphere to the chromosphere. DL-NIRSP will provide with context magnetic diagnostic of the deep photosphere through the Fe I 1565 nm line.

UC-117: Do Non-Magnetic Photospheric Bright Points Exist? (Eamon Scullion, Northumbria University)

Recently, advanced 3D radiative hydrodynamic simulations have shown that structures akin to intergranular magnetic bright points in the photosphere can exist as intensity enhancements in G-band and continuum images but without corresponding magnetic field signatures. Synthesized G-band images show that these small-scale brightenings are co-located with regions of strong vertical vorticity in the flow field of the granular downdrafts. They are predicted to be detectable, however they have not been observed either due to them being an artefact of numerical modelling, or because their simulated sizes are close to the DKIST diffraction limited resolution at 400 nm. Due to their small size and non-magnetic nature, they are distinguishable from magnetic bright points and other granular brightenings. Strong vortex motions at the smallest scales could yield new insights into the nature of a local surface dynamo and as a generator for waves into the atmosphere above. The existence of non-magnetic bright points would be a major result for studies of the solar photosphere.

UC-118: The Formation of Penumbral Filaments (Rolf Schlichenmaier, Leibniz Institute for Solar Physics/KIS)

The energy transport within large-scale magnetic structures like sunspots is a challenge to our understanding of radiative MHD. Since recently we know that the vertical component of the magnetic field is crucial for distinguishing the umbral and penumbral mode of magneto-convective energy transport (Jurcak et al 2018). It has been observed that penumbral filaments form out of umbral areas (Jurcak et al. 2015). While the umbra is characterized by close-to-vertical magnetic fields, penumbral filaments feature close-to-horizontal magnetic fields. Hence, during the penumbra formation, vertical magnetic field is transformed into horizontal ones. It is not known how this transition takes place. Shimizu et al. (2011) and Romano et al. (2014) present observational evidence of a penumbra in the chromosphere before it is seen in the photosphere. This indicates that close-to-vertical field lines start to become horizontal in the chromosphere and then fall down to photospheric layers (Bello González et al. 2017). Yet, it remains unclear how the low plasma-beta regime is capable to initiate the penumbral mode of convection in the high plasma-beta regime of the photosphere. Therefore, it is crucial to understand how individual penumbral filaments form as the field lines fall through the photosphere. Our ideal target is a penumbra that forms from a proto-spot. However, transient filaments also form frequently at the boundary of pores. We expect that such transient filaments also show the corresponding fundamental penumbral signatures.

Why do we need DKIST for this? The individual penumbral filaments form on scales smaller than 0.08 arcsec (Schlichenmaier et al 2016), hence DKIST is needed close to its diffraction limit. Moreover, we need to reconstruct the depth-dependent magnetic and velocity fields with a time cadence of 20sec. For this, inversions invoking two spatial components, each being depth dependent, need to be performed. This requires spectro-polarimetric observations of a few spectral lines at spectral resolution exceeding 150 000. VTF (Ca IR narrow band context images; Fe I 7090, Fe I 5434) and ViSP (Fe I 6173; Na I 5896) would be used simultaneously.

UC-119: Fine-Structure and Evolution of the Convective Collapse Process (Catherine Fischer, Leibniz Institute for Solar Physics/KIS)

Previously ignored, we now know that the quiet-sun magnetic fields outside of sunspots are omnipresent and cover 99% of the solar surface at any given time. They are not only responsible for the energies required to maintain the hot corona but are also for example the main contributor to the solar UV irradiance variability influencing our climate on earth. We propose to study the process that generates the kilogauss quiet-Sun magnetic field population. This process, the so-called convective collapse, is a very dynamic process with sudden changes in, for example, densities, magnetic field strength and velocities happening in seconds. The onset of the process and the conspicuous oscillations seen in the physical parameters in the magnetic element are open questions in the description of this fundamental process. To identify moreover the oscillation modes, we need to measure the small-scale changes in the diameter of these magnetic elements, and need to go below 50 km in spatial resolution such as we will be able to obtain with DKIST. The suggested science use case will contribute to understanding and characterizing the evolution of this kiloGauss magnetic field population, from formation to destruction. This is crucial in the calculation of the overall magnetic flux budget and estimating their contribution to the energy transport in the solar atmosphere.

UC-120: Linear Polarization in Small Regions of Kilogauss Fields: Detection and Causation (Erica Lastufka, FHNW/ETH Zürich)

Strong kilogauss concentrations of vertical magnetic fields have long been observed in the quiet Sun. However, they remain elusive features to study, because polarimetry is photon starved at the diffraction limit. DKIST's Visible Spectropolarimeter (ViSP) is designed to reach 0.07" at 630 nm. For the first time, kilogauss concentrations tens of kilometers in scale are accessible for examination. Our scientific goal is to search the full Stokes spectra for signs of horizontal radiative transfer occurring in and around strong vertical magnetic field concentrations. Performing full radiative transfer calculations on a simulated atmosphere predicts asymmetric intensity profiles and non-zero linear polarization, contrary to the simple LTE approximation often applied to the photosphere. Observational confirmation or contradiction of these characteristics and how frequently they manifest would invite us to re-examine assumptions about the quiet Sun photosphere.

UC-121: How Quiet is the Quiet Sun? Hanle Imaging in Molecular Lines Can Finally Provide the Answer (Lucia Kleint, Leibniz Institute for Solar Physics/KIS)

DKIST will play a decisive role in revealing and evaluating the hidden energy reservoir of the Sun – magnetic fields which are not spatially resolved, even at the highest resolution. Such turbulent fields cannot be seen in Zeeman imaging due to signal cancellation and are only visible via the Hanle effect. By imaging the Hanle effect surface distribution, we can learn about the origin of these entangled fields. The measurement requires a sensitivity of 10^{-4} in Q/I within the lifetime of granulation (less than five minutes). Current measurements have to be averaged spatially (>100") and temporally (>10 minutes) to reach this sensitivity and therefore such measurements will only be possible with the photon collecting power of DKIST. Hanle effect measurements in molecular lines provide most unambiguous estimates of the entangled field strength, because they are based on the differential Hanle effect by utilizing different spectral lines belonging to the same molecule and, therefore, are basically model independent. This is in contrast to the Hanle effect in atomic lines, which requires the knowledge of the zero-field polarization deduced from models. Spatial imaging of the Hanle effect will also clarify why atomic and molecular Hanle measurements so far yield different turbulent field strengths (~100 G vs. 10-60 G). By obtaining synoptic measurements of spatially unresolved magnetic field traces during the course of the solar cycle, for example with monthly measurements, we can also learn about the interplay of the local and global dynamo on the Sun and whether the entangled fields are continuously generated by a local dynamo or are remnants of the global dynamo activity. We propose to carry out regular spatially resolved Q/I measurements of the scattering polarization at different position angles near the solar limb in several molecular and atomic spectral lines (e.g., C_2 around 5141 A, Cr I at 5206 A). If the spatial Hanle effect is independent of the solar latitude and of the cycle phase, this would imply the existence of a local dynamo on very small spatial scales.

UC-122: The Origin of White-Light Flares (Paulo Simoes, Universidade Presbiteriana Mackenzie, Sao Paulo)

The formation mechanism of the optical continuum, or white-light, during solar flares has not yet been confirmed observationally. The two main candidate mechanisms are blackbody radiation from a flare-heated photosphere and H recombination continuum in the chromosphere. Past observations lacked the required spectral coverage, spatial and temporal resolutions to constrain the models. We propose that with flare observations with DKIST, covering both the optical and infrared ranges, combined with radiative hydrodynamic simulations, we will be able to settle the question of the origin of the white-light flares. The infrared emission, recently shown to emerge from chromospheric free-free radiation, will set the necessary constraints to out modelling efforts and remove the ambiguity in identifying the origin of the white-light emission.

UC-123: An Observational Test for the Electron Beam Heating Hypothesis in Solar Flares (Paulo Simoes, Universidade Presbiteriana Mackenzie, Sao Paulo)

One of the fundamental concepts in the current standard model of solar flares is the transport of flare energy by accelerated electrons. The presence of high-energy electrons in the flaring chromosphere has been established beyond any doubt, via their hard X-ray signatures, however, the energy transport by these electrons has never been unambiguously confirmed by observations. We propose solar flare observations in the infrared with DKIST that would allow us to test the electron beam heating hypothesis. It has been shown that the infrared emission in flares is a good proxy for chromospheric heating, and thus, for energy deposition. By measuring time-delays between conjugate footpoints, and comparing such timings with the timescales of the formation of the radiation from models, we can establish limits for the timescales of the energy transport and, consequently, verify the role of the electron beams in the standard model.

UC-124: 3D Dynamic Structure of the Sunspot Umbra (Svetlana Berdyugina, Leibniz Institute for Solar Physics/KIS)

DKIST will image the Sun at multiple wavelengths with unprecedented spatial (xy) resolution, down to 20km x 20km. We aim to match this resolution in the vertical (z) and obtain the first 3D high-resolution structure and dynamics of sunspot umbra and umbral dots, in terms of their magnetic field, temperature, pressure, and velocity. To achieve this goal, we propose spectropolarimetric imaging of the sunspot umbra in hundreds of carefully selected atomic and molecular lines formed at a fine grid of heights in the sunspot atmosphere and simultaneous inversions of their Stokes profiles. Observing umbra with maximum cadence to measure all Stokes parameters in these lines will allow monitoring temporal evolution of the finest structure of the background dark umbra, network of umbral dots, and adjacent penumbral filaments. Hence, for the first time we will be able to see true dynamics of magneto-convection at the strongest magnetic field on the Sun, providing a coherent picture of the heat transport in the sunspot umbrae. This has further implications for long-term studies of the solar activity.

UC-125: The Magnetohydrodynamic Fine Structure of Faculae (Oskar Steiner, Leibniz Institute for Solar Physics/KIS)

Faculae are very prominent features on the white light solar disk and are fundamental to solar irradiance and stellar photometric variability. While facular areas live for days and weeks, individual faculae show a highly dynamic fine structure with a lifetime of minutes and less. We intend to observe this fine structure at the highest possible temporal and spatial resolution. In particular, we want to find out if the bright/dark striation or the "dark bands", which both are typical fine structure elements of faculae, have a corresponding imprint in the magnetic field and if their movement can be traced in the magnetic field. Faculae offer the unique opportunity of observing photospheric magnetic flux concentrations from a lateral direction. This makes it potentially possible to directly observe different types of magnetohydrodynamic waves and mode conversion in the photosphere. For these to discover, however, we need high spatial resolution combined with high cadence and high polarimetric sensitivity. We believe that DKIST, with its unique set of instruments, is the right tool to discover new substructure and magneto-acoustic waves of solar faculae.

UC-126: Wave Propagation in Magnetic Structures and Quiet Sun Regions at High Spatial and Temporal Resolutions (Ana Cristina Cadavid, California State University Northridge)

Progress has been made in understanding the propagation of magnetoacoustic waves from photospheric heights to the chromosphere from both the theoretical and observational points of view. Of particular interest has been to interpret the presence of propagating, evanescent or standing waves in the context of the transmission or conversion of the magnetoacoustic modes as they transition through the region where the Alfvén and sound speeds are equal. Recent results indicate that the small scale magnetic field in the quiet Sun can affect the phase differences in the oscillations at different heights. Other work has indicated the importance of the high frequency signals when the energy flux contributed by acoustic waves to power the chromosphere. Given DKIST's coordinated instruments, high spatial resolution, and temporal cadence, we propose to investigate properties of magnetoacoustic in a wide frequency range in quiet Sun and network regions, using quasi contemporaneous photospheric intensity and chromospheric intensity and velocity signals in the context of a high resolution magnetic field.

UC-127: Horizontal Magnetic Internetwork Fields (Sanja Danilovic, ISP, Stockholm University)

Recent numerical models suggest that the quietest regions harbor enough magnetic and kinetic energy to sustain solar corona. The spectropolarimetic observations, however, do not always agree with the models. Depending on the spectral and spatial resolution of the instruments, as well as polarimetric sensitivity, the retrieved properties of the internetwork magnetic field differ substantially. Additionally, forward modeling also points to the fact that the diagnostics used in these studies might not always trace the horizontal magnetic field in the same way, which makes the problem more complex. One way of resolving the apparent dispute is scanning through different spectral regions with the instrumental and seeing differences minimized.

UC-128: Coupling between Chromospheric and Photospheric Flows in Arch Filament Systems (Christoph Kuckein, Leibniz Institut für Astrophysik Potsdam)

Supersonic downflows are often detected in spectra of the chromosphere at the footpoints of filaments or arch filament systems (AFSs) ($v > 10$ km/s). However, the same downflows are not easily detected below in the photosphere of the Sun. It is likely that a shock, produced due to changes of the density while the plasma descends along different layers of the atmosphere, decelerates the plasma. Emission of chromospheric lines, indicating signs of heating, would provide evidence of these shocks.

Tracking supersonic flows in filaments or AFSs, from the chromosphere to the photosphere, is only possible recording simultaneously a large number of different wavelengths. In addition, these supersonic flows are often masked with two components within the same resolution element. Therefore, DKIST provides a unique possibility to carry out such a study, since it combines many instruments capable of spectroscopy, with large combinations of different wavelengths, and has an unprecedented high spatial resolution. The goal is to track the plasma while it flows down along the legs of filaments and AFSs with the best possible temporal and spatial resolution and determine at which height the supersonic downflows become subsonic. In addition, we intend to unveil the mechanism which produces the strong deceleration of the plasma.

The knowledge gained from this study can be applied to other solar features which also present supersonic velocities in the chromosphere and will lay the foundations for a second campaign including polarimetry.

UC-129: Characterization of Solar and Stellar atmospheres through UV and Visible Measurements of Solar Surface Magnetism (Serena Criscuoli, National Solar Observatory)

We plan to employ observations with DKSIT in the IR, Visible and NUV with coordinated observations with IRIS in the UV, to characterize the spectra of different magnetic features observed on the Sun. The purpose is to validate existing atmosphere models and radiative transfer codes employed for solar irradiance reconstructions. We will investigate also the Visible and IR spectral features that are best correlated with UV variability. These results will be used to calibrate the UV spectra of cool stars, which are of extreme importance in the study of climate and habitability on extrasolar planets. This work is timely as far-UV spectroscopy of cool stars will no longer be available after the retirement of the Hubble Space Telescope.

UC130: The Mode Coupling Signal in the Chromosphere (Wang Yikang, The University of Tokyo)

Acoustic wave, derived by non-linear mode coupling from Alfvén wave, is a possible mechanism for chromosphere heating in network region. To make an observational confirmation, it is necessary to observe transverse Alfvénic wave and longitudinal acoustic wave simultaneously. DKIST is thought to be necessary for such observation.

UC-131: Inferring the Magnetic Field 3D Topology of Chromospheric Features (Carlos Quintero Noda, Instituto de Astrofsica de Canarias)

The solar surface is covered by small-scale magnetic fields rooted on photospheric network concentrations that expand into the chromosphere and beyond. In recent years, we have developed more and more detailed theoretical models with elaborated cartoons as the one showed by Wedemeyer-Bohm et al. (2009) or 3D simulations like those presented on Carlsson et al. (2016) or Iijima and Yokoyama (2017). Unfortunately, there is essentially no observational support or constraint for those models beyond photospheric layers. This is because there are just a few observations of chromospheric lines with polarimetry in the quiet Sun, and in all the cases, the signal-to-noise (S/N) ratio is not high enough to detect linear, or sometimes circular, polarization signals (e.g., Pietarila et al. 2007). This property impedes inferring the magnetic field topology, which would help us understanding the magnetic field configuration of the quiet solar atmosphere and also help to improve the current theoretical models.

UC-132: Shock Waves Involving Spicules (Akiko Tei, Kyoto University)

UC-133: The Process of Formation, Evolution, and Eruption of the Flux Rope (Yusuke Kawabata, ISAS/JAXA)

Sheared or twisted magnetic fields (flux rope) containing free energy play an important role in the explosive phenomena, i.e., solar flares and CMEs (coronal mass ejections). Emergence, shear, and/or rotational motion in the photosphere are thought to contribute to the formation and evolution of the flux rope. Although the evidences of such motions were observed in the photosphere, magnetic field response in the chromosphere has not been observed yet. We propose the multi-wavelength spectropolarimetric observations with high SNR for at least three days (three maps per day) and investigate the magnetic field response in the chromosphere to the photospheric motion.

UC-134: Spectropolarimetry of Quiet Sun Ellerman Bomb-Like Brightenings (Gregal Vissers, Institute for Solar Physics, Stockholm University)

Recent observations have revealed reconnection jets in the quiet Sun with properties similar to active region Ellerman bombs (EBs), yet smaller in size, shorter-lived and with lower intensity contrasts. DKIST is particularly well-suited to investigate these events, as they are observed at the limit of what current high-resolution observing facilities can resolve. This study will combine high-cadence, multiline spectroscopy from ViSP with polarimetry from DL-NIRSP to analyze their fine structure morphology and dynamics, as well as the magnetic field topology in which they occur.

UC-135: Origin and Dynamics of Strong Polar Magnetic Fields (Shin Toriumi, Japan Aerospace Exploration Agency)

Previous observations showed that patchy unipolar magnetic concentrations are distributed over the entire polar regions and that their intrinsic field strength are over 1 kG. The origin of such strong fields, however, remains unclear. Utilizing the high-sensitivity, high-resolution spectropolarimetric capability of DKIST, we reveal the formation process of the polar kG patches and their evolutions.

UC-136: Small-Scale Flux Emergence and Its Associating Dynamic Phenomena (Takahito Sakaue, Kwasan and Hida Observatories, Kyoto University)

UC-137: Heating and Jets in Plage Regions (Reizaburo Kitai, Ritsumeikan University)

Study of plage atmosphere is the target of our CSP. Heating of the chromosphere is under debate (Waves/Reconnection). And the relation between heating and the dynamic fibril is not cleared yet. We plan to solve the evolutionary scenario of plage atmosphere heating by observing granular field, photospheric magnetic field and ejection of dynamic jets.

UC-138: Multi-Height Magnetic Field Measurement of Filament Channels and Filaments (Yoichiro Hanaoka, National Astronomical Observatory of Japan)

Solar filaments are considered to be formed in flux ropes above polarity inversion lines. The magnetic field structure around a filament is complicated, and it is not known well how such a magnetic field structure is produced. Multi-height measurements of the magnetic field, including the chromosphere of the filament channels and the filaments, are crucially important to investigate the magnetic field in and around the filaments. We propose to track the evolution of the magnetic field of filament channels and filaments, from before the formation of the filaments and also until their eruption observing a couple of chromospheric and photospheric absorption lines, which show the magnetic field at the different heights.

UC-139: Role of Chromospheric Swirls on the Spicule Formation (Haruhisa Iijima, ISEE, Nagoya University)

The swirls are ubiquitously observed in the solar photosphere and chromosphere. The Alfvén wave produced by the torsional motion transport large amount of energy to the upper layer and contributes the formation of spicules. The high-precision polarimetry with the high spatial/temporal resolution of DKIST allows us to reveal the role of chromospheric swirls on the spicules and upper solar atmosphere.

UC-140: How the Horizontal Convective Flow Drives MHD Waves (Takayoshi Oba, ISAS/JAXA)

DKIST with unprecedented high spatial resolution would first see how the photospheric convective flow drive MHD waves propagating from the photosphere to the upper layers. One of the key physical quantities is horizontal flow fields in interacting vertically-standing flux tubes. However, horizontal flow field is difficult to be captured because LOS fields is aligned with the horizontal direction at only limb observation, in which the foreshortening degradation crucially makes it difficult to spatially resolve intergranular lanes and magnetic flux tubes there. DKIST could provide really high spatial resolution enough to resolve those flux tubes even at the limb observation. The polarimetric observations for the photosphere and chromosphere with DKIST would identify which kind of the flow pattern drives MHD waves and actually affects chromospheric dynamics.

UC-141: Coronal Magnetometry Constraints on Alfvén Wave Damping in the Corona (Tom Schad, National Solar Observatory)

Spectroscopic evidence for Alfvén wave damping in the solar corona was provided by Gupta (2017), using off-limb multi-spectral measurements of nonthermal line widths from EIS/*Hinode*. The damping lengths were found to vary from region to region, and it has been suggested that temperature-dependent damping may play some role. As the Alfvén wave energy flux density is a function of the magnetic field strength, measurements of the magnetic field for various regions, and especially its height dependence, is an important constraint on the wave damping length. In past measurements, the magnetic field was assumed to be constant along a flux tube, but recent measurements by Schad (2016) using He I show that this is not a good assumption. DKIST provides for the first time the opportunity to measure the magnetic field along such structures.

We propose to use DKIST and EIS/*Hinode* in coordination to measure the Alfvén wave damping length for multiple active regions, to begin to constrain the dependences of damping on thermal and magnetic structure. In addition, we will use HAO/COMP data from Mauna Loa for context and to help understand the Alfvén wave amplitude.

UC-142: How to Make a Magnetic Field Stronger Than a Sunspot Umbra? (Joten Okamoto, National Astronomical Observatory of Japan)

Here we propose an observation of sunspots to reveal a mechanism to generate a very-strong magnetic field which is stronger than that in the umbra. Generally, the strongest magnetic field in each sunspot is located in the dark umbra in most cases. A typical field strength in sunspots is around 3,000 G. On the other hand, some exceptions also have been found in complex sunspots with bright regions such as light bridges that separate opposite-polarity umbrae, for instance with a strength of 4,300 G. Recently, we found a sunspot with a field strength of 6,250 G in a similar location. Considering the spatial and temporal evolution of the vector magnetic field and the Doppler velocity in the bright region observed with the *Hinode* satellite (only 6301.5 and 6302.5 A), we suggested a mechanism that this strong field region was generated as a result of compression of one umbra pushed by the outward flow from the other umbra (Evershed flow), like the subduction of the Earth's crust in plate tectonics. We also had a statistical analysis of sunspot field strength, and found that stronger fields outside umbrae have three important features: redshift, horizontal flow, and close to polarity-inversion line. This SUC is to observe such a region with these three features with DKIST for confirming this proposed mechanism. Spectropolarimetric measurements will give us important information about the physical quantities of the focused region with multiple wavelengths beyond what *Hinode* did. Filtergraphs can help us to understand the dynamics of the interaction between umbrae and horizontal flows. The combination of these observations will provide a new insight to understand how to make a stronger field in sunspots.

UC-143: Turbulent Flows Associated with Flares (Shinsuke Imada, Nagoya University)

Magnetic reconnection is thought to be a driver of solar flare. Standard magnetic reconnection theory predicts reconnection rate that is too slow to explain observed reconnection events in the solar corona. Some theoretical studies suggested that turbulence or small magnetic islands in the reconnecting current sheet are important. To clarify the fast magnetic reconnection process, observing the turbulent flows associate with flare is essential. High cadence velocity field measurement in the offlimb by DL-NIRSP is required. Coordinated observation with *Hinode*/EIS is also helpful.

UC-144: Understanding the Energy and Mass Transfer Mechanisms in Magnetic Flux Tubes from the Photosphere through the Corona: On the Origin of Chromospheric Jets and their Heating (Yoshinori Suematsu, National Astronomical Observatory of Japan)

Recent observations with *Hinode*, IRIS and ground-based observatories of high temporal and spatial resolution have revealed that jet-like structures are ubiquitous in the solar chromosphere. They are likely to play an important role in maintaining the energy balance of the local chromosphere and the mass balance in the corona. On the other hand, the formation mechanism of small-scale jets such as spicules remains unsolved, although it is no doubt that they root at photospheric magnetic elements. Many models have been proposed to explain their formation. It is likely that a key mechanism is a strong slow shock formation in the chromosphere, irrespective of its original energy sources, e.g., a p-mode acoustic wave leakage into the chromosphere, MHD waves including torsional Alfvén waves launched in the photosphere, or magnetic reconnection in the lower chromosphere. Fine structure and footpoint height of the jets should suggest the driving mechanisms. With DKIST, we will obtain observations of the chromospheric jets at sufficient spatial and temporal resolution to probe the details of the process.

UC-145: Origin of Coronal Line Broadening and Hidden Dynamics (Kiyoshi Ichimoto, Kyoto University)

It is known that the profiles of coronal emission lines are well fit with a Gaussian and have excess broadening compared to that expected from the thermal width by ~20km/sec. The origin of the excess broadening is attributed to the 'turbulent motion', the nature of which is unknown. In past, those data were obtained with a long (~1 min) exposure and low spatial resolution (several arcsec). DKIST has photon collecting power 256 times higher than 25-cm coronagraph (used in Norikura). Deviation of coronal line profiles from a Gaussian, and its spatial and temporal variations will be investigated at high spatial and temporal resolutions. This study aims to search and identify the coronal waves and intermittent plasma flows possibly caused by small scale energy releases.

UC-146: Spicule Velocity Field and Magnetic Connectivity to Corona (Masaki Yoshida, SOKENDAI/NOAJ)

UC-147: Magnetic Origins of Microflares (Toshifumi Shimizu, ISAS/JAXA)

Microflares, small transient energy release events, have been investigated to understand the magnetic origins by examining high spatial and temporal resolution series of photospheric magnetograms. Past studies with *Hinode* XRT-SOT/FG (Kano et al. 2010) and *Yohkoh*-LaPalma/SOUP (Shimizu et al. 2002) revealed emergence and cancellation as important photospheric activities to the occurrence of microflares. However, no apparent counterpart in photospheric magnetograms can be identified in about half of examined microflares. They may show multiple numbers of brightening coronal loop structures and multiple numbers of chromospheric footpoints. This project is to investigate the magnetic origins of such microflares by coordinating *Hinode*/XRT, *Hinode*/SP with DKIST instruments. New addition of chromospheric magnetic field and spectroscopic information would give new insight into the magnetic origins of these microflares.

UC-148: Supersonic Flows of Condensation and Their Mass Supply For Prominence (Takafumi Kaneko, Nagoya University)

We observe the flows from the corona to prominence driven by radiative condensation. Radiative condensation for prominence formation was detected only by multi-wavelength EUV images of SDO/AIA, while no spectroscopic observations detected the condensation flows. It is expected the condensation flows are present in the narrow transition region between prominence and the corona and they are multi-thermal. In our numerical simulations, supersonic condensation flows transiently intrude into prominence body, hence, the condensation flows and internal turbulent flows can be distinguished from each other. Based on the knowledge from numerical modeling and the spectroscopic observation of DKIST with high resolution, we can detect the condensation flows and derive mass flux toward prominence. The results will give significant impact on understanding mass cycle among the chromosphere, prominences, and the corona.

UC-149: Investigating Magnetic Structure and Dynamics of Coronal Cloud Prominences (Huang Yuwei, Kyoto University)

In comparison with channel prominences, coronal cloud prominences are generally much fainter that without longer exposure they would not be regarded as a part of large cloud prominence. As a result, relatively few events have been recorded and studied. One of the major questions is what kind of magnetic field configuration supports these prominences and it is suggested that coronal cloud prominences are trapped along separatrix surfaces between coronal loop systems. With DKIST Cryo-NIRSP, not only large amout of photons can be collected by the 4m aperture telescope even with short exposure time, the ambient magnetic field configuration can also be measured. This study aims to search the basic properties of coronal cloud prominences.

UC-150: Coordinated Observations of Ellerman Bombs with DKIST and ALMA (Jeongwoo Lee, New Jersey Institute of Technology)

We have a proposal approved for observing Ellerman Bombs (EBs) with the Atacama Large Millimeter/submillimeter Array (ALMA) maybe around April in 2018, and will analyze the ALMA data together with H-alpha and Ca II 8542 spectra to be measured with the Fast Imaging Solar Spectrograph (FISS) at Big Bear Solar Observatory. In future, we hope to use this experience to have another ALMA observation coordinated with the DKIST observation. From the ALMA observation, we expect to detect the temperature excess as well as oscillations and waves of EBs themselves and the surrounding atmosphere. We will analyze spectral line profiles of the chromospheric lines obtained from DKIST for information of local heating in the chromosphere responsible for causing EBs. This study may help understanding the role of EB in releasing magnetic energy in the solar chromosphere. Since EBs are so ubiquitous and frequently occurring, this coordinated observation should be able to detect sufficient number of them within the time scale of a few hours needed for co-observations with ALMA and DKIST.

UC-151: Polar Magnetic Fields from Two Vantage Points: Joint Observations with Solar Orbiter (Andreas Lagg, Max Planck Institute for Solar System Research)

The progress in understanding the operation of the solar dynamo depends on how well we understand differential rotation and the meridional flows near the poles of the Sun. However, because of the lack of out-of-the-ecliptic observations, the near-polar flow fields remain poorly mapped, as does the differential rotation at high latitudes (see Beck 2000; Thompson et al. 2003). The meridional flow, in particular, the very foundation of the flux transport dynamo, is not well characterized above ~50° latitude; it is not even certain that it consists of only one cell in each hemisphere. The return flow, believed to occur at the base of the convection zone, is entirely undetermined save for the requirement of mass conservation. All these flows must be better constrained observationally in order to help solve the puzzle of the solar cycle and to advance our understanding of the operation of the solar dynamo (and, more broadly, of stellar dynamos generally). Solar Orbiter will measure or infer local and convective flows, rotation, and meridional circulation in the photosphere and in the subsurface convection zone at all heliographic latitudes including, during the later stages of the nominal mission, at the critical near-polar latitudes. Solar Orbiter will reveal the patterns of differential rotation, the geometry of the meridional flow, the structure of subduction areas around the poles where the solar plasma dives back into the Sun, and the properties of convection cells below the solar surface. This will be achieved through correlation tracking of small features, direct imaging of Doppler shifts, and helioseismic observations (including the first from a high-latitude vantage point). By monitoring the temporal variations over the course of the mission, it will be possible to deduce solar cycle variations in the flows. DKIST will ideally complement this study: the second vantage point will allow for unambiguous magnetic field measurements. The high spatial and temporal resolution will add valuable information to the PHI vector magnetograms. DKIST measurements at multiple spectral lines will constrain the atmospheric stratification and allow for a seamless connection to the PHI measurements.

UC-152: Helicity Mapping for Dynamo Studies (Also in Coordination with Solar Orbiter High-Latitude Phase) (Andreas Lagg, Max Planck Institute for Solar System Research)

The magnetic helicity being a conserved quantity plays an important role for the solar dynamo and its connection to heliosphere. Particularly important is to know how the helicity is distributed as a function of latitude. Low latitude measurements have already been done using space-based and ground-based telescopes, however, with the exception of Ulysses, the high latitudes have not been accessible. The high spatial resolution of DKIST will allow for an unprecedented level of detail especially for the high-latitude measurements. Coordinated observations with Solar Orbiter in its extended mission phase (latitudes up to 33 degrees), provide a unique opportunity to measure the magnetic helicity at high latitudes and near the poles.

UC-153: Stereoscopic Magnetic Field Measurements: Joint Observations with Solar Orbiter/PHI (Andreas Lagg, Max Planck Institute for Solar System Research)

Combining magnetic field observations from two vantage points is unique and only possible with a space mission on a different trajectory around the Sun than Earth. The determination of the magnetic field vector from such a combined data set will deliver unambiguous magnetic field maps, even for very complex magnetic field topologies like in pre-flare current sheets or delta spots. In addition, it will simplify the determination of the atmospheric stratification on a geometrical height scale, allowing, e.g., for detailed studies of mass flux balance.

In addition, stereoscopy will provide valuable input for the highly sensitive Hanle diagnostics provided by DKIST. DKIST can carry out highly sensitive Hanle diagnostics of solar limb magnetic structures. These measurements can be calibrated only if simultaneous high resolution photometric and Zeeman measurements are carried out from a much less inclined vantage point.

UC-154: Searching for Flare Current Sheet Instabilities with DKIST and Solar Orbiter (Sarah Matthews, UCL-MSSL)

In the standard eruptive flare model the current sheet created by the rising magnetic flux rope is believed to be the site of the magnetic reconnection and the associated energy dissipation that powers the flare and accelerates the CME. The current sheet itself is predicted to be only 10s of metres thick, making it difficult to observe directly with current instrumentation, although there have been observations reported of the heated region surrounding the sheet, and of the behaviour of the substructure within flare ribbons that have been linked to current sheet dynamics. The purpose of this proposed study is to make use of DKIST and Solar Orbiter quadrature observations to simultaneously study the dynamics of the flare ribbons and current sheets in order to search for signatures of instabilities within the current sheet during the reconnection process, and their impact on flare/CME evolution.

UC-155: Coronal Prominence Cavity Systems with DKIST-Solar Orbiter Joint Observations (Susanna Parenti, Institut d'Astrophysique Spatiale)

Coronal prominence-cavity systems are regions of stored magnetic energy, that often erupt in CME. DKIST provides unique observations of circular polarization and high-temporal-cadence linear polarization, as well as polarimetric measurements of the prominence. In conjunction with SolO observations these may be used to reconstruct the 3D magnetic field of the system, particularly when SolO is at a sufficiently large angle from the Sun-Earth line to be able to provide a cotemporal photospheric magnetic boundary condition beneath the prominence-cavity system. In addition, the joint observations allow us to analyze the magnetic-thermal connections of prominence and cavity in three dimensions.

UC-156: Plasma Dynamics and Inner Structure of Coronal Plumes (Nour E. Raouafi, The Johns Hopkins University Applied Physics Laboratory)

Coronal plumes are enigmatic structures. The energy source that sustain plumes for days (and some cases weeks) is not completely understood. What is missing to gain insight into this is the detailed structures of the magnetic field at the footpoints of these structures as well as the plasma properties in the corona and solar wind.

Joint observations from DKIST, Parker Solar Probe, and Solar Orbiter will help us understand better the evolution of these prominent structures and consequently have insights into the coronal heating problem in general.

UC-157: Waves and Turbulences in the Nascent Solar Wind with Solar Orbiter and Parker Solar Probe (Yuan-Kuen Ko, Naval Research Laboratory)

We propose to measure wave and turbulence properties in the solar wind when it is just formed in the inner corona to shed light into the different formation mechanisms of the fast and slow solar wind. The intensity, line-of-sight speed and line width fluctuations of coronal lines from DKIST Cryo-NIRSP at the base of the coronal hole and coronal hole boundary will be combined with the electron density (or visible light brightness) and LyA intensity fluctuations at higher altitudes with SO/Metis to infer wave and turbulence properties in the fast and slow solar wind. Linear polarization of coronal lines from Cryo-NIRSP will also be used to infer wave properties from the dynamic fluctuation in the plane-of-sky direction of the magnetic field. These properties will be compared with the solar wind properties measured in situ.

UC-158: Understanding the Line-of-Sight Integration in Coronal Observations (Valentin Martinez Pillet, National Solar Observatory)

Off-limb Coronal observations through optically thin regions average structures differently depending on the magnetic configuration and thermal properties of the loops along the line-of-sight. Combined observations between DKIST (Cryo-NIRSP) and Solar Orbiter (EUI and PHI) offer a unique opportunity to calibrate the effects of the line-of-sight averaging.

UC-159: Stereoscopic Observations of Loops and Magnetic Fields (Harry Warren, Naval Research Laboratory)

Loops are the building blocks of the solar atmosphere. Since magnetic fields are most easily measured in the photosphere, the modeling of loops relies on extrapolations of vector photospheric field measurements. Observations of both loops and magnetic fields, however, are generally taken from a single vantage point, making their interpretation ambiguous. We propose to carry out coordinated observations with DKIST, SDO, and Solar Orbiter to observe both coronal loops and magnetic fields from multiple vantage points. We will use DKIST and SO/Phi to measure the field properties from the different lines of sight and constrain magnetic field extrapolations. We will use SDO/AIA along with SO/EUI and SO/SPICE to measure loop properties in three dimensions. Finally, we will match and compare the field lines computed from the extrapolation to the three dimensional geometry of the observed loops.

UC-160: What is the Magnetic Flux in Coronal Holes? (John Linker, Predictive Science Inc.)

The magnetic flux in coronal holes (as determined with 5 different types of magnetograms) appears to be about a factor of two less than the interplanetary magnetic flux (Linker et al. ApJ 2017). While there are a number of possibilities for explaining this deficit, a key question is whether present observatory magnetograms systematically underestimate the magnetic flux. The goal of this observation to use DKIST's unique sensitivity and resolution to determine the magnetic flux in a portion of a near-equatorial coronal hole and compare with simultaneous HMI, VSM, and GONG observations.

UC-161: Stereoscopy of polar magnetic fields (Luis Bellot Rubio, Instituto de Astrofisica de Andalucia)

The magnetism of the polar region is poorly understood. This is due to strong projection effects, which reduce both the amplitude of the polarization signals and the effective spatial resolution of the observations. Another serious problem is the 180 deg azimuth ambiguity affecting Zeeman measurements. Near the limb, such an ambiguity implies that even the polarity of the field is uncertain. While indirect methods have been devised to find the true field azimuth, the fact is that vector magnetic fields have never been measured unambiguously in the polar region. The only way to solve this problem is to use stereoscopic measurements. Such observations can be provided by Solar Orbiter and DKIST.

UC-162: DKIST and Solar Orbiter Observations for Understanding Upflowing Plasma on the Sun: Limb Observations for DKIST, Quadrature for SO (Louise Harra, PMOD / WRC)

Solar Orbiter will provide unique observations from the remote sensing and in situ instruments. We can take advantage of the different viewpoints. In particular, the quadrature situations will allow 3D spectroscopy in different regions of the atmosphere. This will assist in removing the 180-degree ambiguity in the magnetic field measurements, will allow multi-directional spectroscopy using DKIST and SO-SPICE (and IRIS, *Hinode*/EIS if still operational), and stereoscopy with the imagers. The different views at the disk and limb simultaneously will allow us to probe the magnetic field and dynamics in an active region on the disk and measure the active region expansion at the limb at the same time. It will allow us to measure the magnetic fields and dynamics on the disk, and then observe, for example, spicules at the limb simultaneously. If an active region is not present, coronal hole or streamer belt is a good alternative.

UC-163: Investigation of the Chromospheric Arch-Filament Systems (Rahul Sharma, University of Alcalá)

Here, we propose to investigate the dynamic evolution of the chromospheric arch-filament systems (AFS) in multi-wavelength observations, for both, on-disk and limb regions. Since their first observations in Skylab-era, these short, low-lying, loop-like features are routinely observed in both, ground- and space-based observations, of the solar chromosphere. These structures play a critical part in the longstanding puzzle associated with the temperature profile at the solar interface region and in the past were linked with small-scale magnetic flux emergence, magnetic reconnection (e.g., Ellerman bombs), high Doppler velocities and jet-like features. However, still there is a lack of understanding of the evolution of AFS in association with the above mentioned observables, along with many of the elementary questions regarding their morphology. The key aim of this proposal to exploit the state-of-the-art DKIST imaging-spectropolarimetry capabilities to investigate the evolution (kinetic/thermal) of these structures and the associated phenomenon.

UC-164: The Physical Nature of Spicules (Phil Judge, High Altitude Observatory/NCAR)

The seeing-free platform of Hinode revealed curious properties of "spicules" as seen with Ca II H filter measurements. They extend across the solar limb with no apparent intervening chromosphere. Judge and Carlsson (2010) explained this in terms of different contributions to the broad filter signal as a function of wavelength across the line profiles. In a series of papers, Judge and associates have suggested that some spicules are projections of sheet-like structures. DKIST can potentially refute these pictures, helping us to understand the physical nature of spicules, the role they might play in coronal physics, and whether they correspond, at times, to tube- or sheet-like structures.

UC-165: Tracking Chromospheric Shocks in Solar Flares (Malcolm Druett, Stockholm University)

The ability to track shocks in solar flares as they propagate down through the atmosphere will greatly enrich understanding of flare energy delivery and the associated atmospheric dynamics.
The DKIST/ViSP instrument enables us to track these shocks using simultaneous, high-cadence spectral observations of H-alpha, H-beta and H-gamma, with context and spectro-polarimetric data provided by DKIST/DL-NIRSP in Ca 8542.

Using these data, we will deliver measurements of the velocity profiles of chromospheric shocks in the impulsive phase of solar flares; this will also constrain emission such as the heights and speeds of chromospheric white light sources due to recombination in the Balmer continuum. Additionally, these observations will test whether such shocks can be responsible for the seismic responses detected in these flares using photospheric HMI data from SDO and chromospheric data from Ca 8542 using DL-NIRSP.

UC-166: Sunspot Shock Wave Tracking and Plasma Beta Mapping (David Jess, Queen's University Belfast)

Previous research has documented the ubiquitous presence of non-linear shocks that are introduced by upwardly propagating magneto-acoustic waves in sunspot umbral atmospheres. In recent years, extensive analyses have been undertaken to examine the effect of these shocks on the surrounding magnetically-dominated plasma, with recent slit-based spectro-polarimetry suggesting how energetic shock waves can provide full vector fluctuations in the chromospheric umbral magnetic field. Here, we wish to utilise a plethora of DKIST instrumentation, including VBI, DL-NIRSP and ViSP, to examine the effect magneto-acoustic wave steepening has on the multi-level sunspot atmosphere spanning the photosphere to upper chromosphere. We will employ these multi-line spectro-polarimetric observations to search for upward **and** downward feedback resulting from the shocking of the umbral plasma, both in terms of temperature enhancements and magnetic field perturbations. Furthermore, by combining the high-precision spectro-polarimetric observations with modern inversion routines, we will accurately compute the magnetic/plasma pressure equipartition regions spanning the photosphere to chromosphere, and use these high-resolution boundaries to search for the efficient coupling between magneto-acoustic and elliptically polarised Alfvén modes, which can also steepen to form fast mode shocks in the lower solar atmosphere.

UC-167: Picoflares: Mode Coupling and Wave Generation (Stephane Regnier, Northumbria University)

Picoflares are (if they exist) the observable part of energy release of te order of 10^{21} erg. It is anticipated that picoflares are mostly either generated by wave mode interactions or generates fast mode waves during the reconnection process. According to Aschwanden (2000), the range of phsical properties are well defined, for instance the temperature range is between .25 and 0.5 MK. Picoflares considered here are located in the quiet Sun where the magnetic field is highly tangled and is recycled in few minutes.

DKIST is providing a unique opportunity to investigate the existence of picoflares by:

- resolving the vector magnetic field in the quiet-Sun photosphere. Typically using VTF Fe I line;
- scanning the chromosphere to access the density and emission of these picoflares. Typically using the ViSP density sensitive lines;
- obtaining high-cadence images of the chromosphere to study wave propagation. Tyypically using VBI filters.

UC-168: Wave Generation, Propagation, Conversion, and Dissipation in the Quiet Sun (James McAteer, New Mexico State University)

Small scale network bright points at the junctions of supergranular cells may be a conduit for transferring kinetic energy from the photosphere into thermal heating in the chromosphere. Magnetic field accumulates at these junctions making these bright points into distinct vertical features (flux tubes) protruding from the photosphere into the chromosphere.

Granular buffeting at the photosphere (few km/s) shuffle the footpoints, setting up kink-mode (transverse) waves, that propagate up into the lower chromosphere at sub-sonic speeds, and with an oscillation frequency of 1-2 mHz. These waves slow down as they propagate upwards, until they couple, and transfer energy, to longitudinal waves propagating at the same speed. These longitudunal waves have a characteristic frequency at twice that of the original transverse waves. As longitudinal waves, these then steepen as they propagate upwards, and shock therby heating the ambient chromospheric plasma.

DKIST (combination of VBI and VTF) will provide four observational tests of this mechanism: horizontal footpoint shuffling at a few km/s; the existence of low and high frequency wavetrains; a subsonic wave propagation velocity; increased heating in the vicinity of the waves. Critically, only DKIST can supply these data at the combined spatial, temporal, and spectral resolution required to track individual wavetrain events.

UC-169: Waves and Resonances in the Chromospheric Cavity above Sunspots (Gert Botha, Northumbria University)

UC-170: MHD Oscillations in Coronal Rain (Petra Kohutova, University of Oslo; University of Warwick)

Coronal rain consisting of down-falling cool plasma condensations is a phenomenon occurring in footpoint-heated coronal loops as a result of thermal instability. Recent high resolution observations have shown that coronal rain is much more common than previously thought, suggesting its important role in the chromosphere-corona mass cycle. Coronal rain condensations are coupled to the magnetic field lines in the loop and therefore can be observed to track the oscillatory motion of the loop. Small amplitude transverse oscillations showing no observable damping are commonly observed in both coronal rain and hot coronal loops seen in AIA 171. The main objective of this proposal is to obtain fast-cadence high-resolution observations of such oscillations. The evolution of the oscillation parameters during the whole duration of the loop thermal cycle will be used to deduce the fraction of the loop plasma mass that becomes thermally unstable using seismological techniques. Comparing this estimate with the total mass of condensations estimated using direct methods will tell us how much of the coronal rain mass (if any) remains unresolved. This provides constraints on the fundamental spatial scales of coronal rain and on fine-scale structure of coronal loops. Overall fraction of the thermally unstable plasma can be used to determine how localised is the heating of the observed coronal loop. High resolution observations of footpoints of the oscillating coronal loop will also enable us to determine which excitation mechanism is responsible for small amplitude transverse loop oscillations ubiquitous in the solar corona.

UC-171: The Evolution of Eruptive Instabilities in the Solar Atmosphere (David Long, UCL, Mullard Space Science Laboratory)

Solar filaments are elongated structures consisting of cool chromospheric material suspended in and thermally isolated from the hot surrounding solar corona. This material typically collects in the dips in the magnetic field, thought to be associated with twisted magnetic field lines that form magnetic flux ropes. Filaments can remain stable for extended periods of time, in some cases lasting for several solar rotations before erupting into the heliosphere. However, the processes leading to the onset of this instability are not well understood. The aim of this science use case is to use the high temporal and spatial resolution of DKIST and its ability to measure magnetic field across a range of heights in the solar atmosphere to study the interaction between plasma motion and magnetic field evolution prior to the eruption of a solar filament/prominence.

UC-172: Observational Signatures of Alfvén Waves in Chromosphere and Corona (Mahboubeh Asgari-Targhi, Harvard-Smithsonian Center for Astrophyiscs)

UC-173: Wave Generation and Propagation in Coronal Loops (Arcades) (Rekha Jain, University of Sheffield)

The AIA/SDO revealed large-amplitude, flare-induced and low-amplitude, decayless oscillations in solar coronal arcades. The large amplitude oscillations appear to propagate in a 3D waveguide of arcades especially the ones off the limb. Hindman and Jain (2015) have explained them as fast MHD waves, where magnetic pressure and tension both play an important role and are triggered by different drivers. DKIST can potentially confirm or negate this picture, enabling us to understand the nature of these oscillations, where these oscillations originate, propagate and reflect, the role they might play in coronal physics, and what is the geometry and the spatial extent of the waveguides where these oscillations reside in solar coronal arcades.

UC-174: Transverse Wave Induced Kelvin-Helmholtz Rolls in the Solar Atmosphere: Coronal Loops (Patrick Antolin, Northumbria University)

The inhomogeneous solar corona is continuously disturbed by transverse MHD waves. In the inhomogeneous environment of coronal flux tubes, these waves are subject to resonant absorption, a physical mechanism of mode conversion in which the wave energy is transferred to the transition boundary layers at the edge between these flux tubes and the ambient corona. Recently, a large amount of numerical and theoretical work has shown that transverse MHD waves also trigger the Kelvin-Helmholtz instability (KHI) due to the velocity shear flows across the boundary layer. These vortices, known as TWIKH Rolls for Transveerse Wave Induced Kelvin-Helmholtz Rolls, are able to explain observations of strand morphology of coronal loop substructure, the characteristic broad DEMs of loops and may provide an efficient means of energy conversion through the turbulent cascade and also through magnetic reconnection between the KHI vortices. However, the TWIKH rolls in coronal loops remain to be discovered. With the guidance from published forward modelling results from the numerical experiments we build a science use case that maximises the detection of the TWIKH rolls in the solar corona with DKIST.

UC-175: MHD Wave Energy Budget (Ineke De Moortel, University of St. Andrews)

By using a series of coronal measurements of an off-limb loop system with Cryo-NIRSP, we will study the evolution of the MHD wave energy budget in the coronal loops. By constructing power-maps at different atmospheric temperatures (using appropriate wavelength observations) and at different positions along the loops, it is possible to establish at which rate both high and low-frequency power is lost in the solar atmosphere. This will allow us to test whether the damping of the observed transverse motions is indeed frequency-dependent, as suggested by theoretical modelling. By examining how the power is distributed over the frequency range, we can verify whether only lower-frequency perturbations reach higher into the solar atmosphere (as theory predicts) or whether additional processes are altering this predicted frequency distribution. This analysis of the power spectrum and energy budget will permit us to determine whether the observed, ubiquitous wave motions do indeed contribute to the coronal energy budget. DKIST will give high-resolution, high cadence data with spectral information and the averaged magnetic field.

UC-176: Understanding the Formation Mechanism behind Chromospheric Fan-Shaped Jets (Aaron Reid, Queen's University Belfast)

Fan-shaped jets can be observed in chromospheric lines, and appear dark in SDO coronal lines. They are thought to be formed via shearing reconnection between horizontal and vertical magnetic fields in the photosphere, at umbral boundaries. It has recently been shown that these jets may have connections to running penumbral waves.

This Use Case aims to directly observe the link between running penumbral waves to the shearing reconnection resulting in these chromospheric jets.

UC-177: Magneto-acoustic to Alfvén Mode Coupling between the Photosphere and Chromosphere (Damian Christian, California State University Northridge)

We propose using DKIST observations to identify how pressure oscillations in the photosphere propagate into the upper solar atmosphere and may undergo mode conversion.

We will search for this "reverse" mode-coupling (Jess et al. 2012), where pressure oscillations, detected in small-scale photospheric magnetic bright points, generate kink waves in the Sun's outer atmosphere with transverse velocities approaching the local sound speed. The high resolution of the DKIST is needed to quantify the smallest magnetic elements in the photosphere and subsequent propagation into the chromosphere. We will use the high resolution images taken with VBI in G-band and Ca II K, the ViSP in two lines at 517 and 525 nm, and velocities in Na, H-alpha, and Ca 8542 with the VTF to locate and quantify the wave properties. We will compare our observations with advanced two-dimensional magnetohydrodynamic simulations, to model the wave properties.

UC-178: Propagation of Swirls from the Photosphere to the Chromosphere (Jiajia Liu, The University of Sheffield)

Swirling motions in the solar atmosphere have been widely observed in recent years and suggested to play a key role in channeling energy from the photosphere into the chromosphere and corona. Statistic studies of solar photospheric intensity/magnetic swirls and chromospheric swirls, based on unbiased (compared to human eyes) auomated detection methods are highly needed to study: 1) how solar photospheric intensity swirls and magnetic swirls are related; and 2) how photospheric swirls propagate into the chromosphere and contribute to the local heating. In this SUC, we propose to perform swirl detections and analysis using the robust ASDA tool (Liu et al. 2018) developed by us on the high spatial and temporal resolution DKIST observations to find answers for the above questions.

UC-179: Formation, Propagation and Dissipation of the High-Frequency Waves in the Fast-Evolving Chromospheric Events (Juie Shetye, University of Warwick)

Solar chromosphere serves as an interlacing layer between the photosphere and the corona and is covered with a plethora of events such as spicules, fibrils, mottles, and swirls. These events are known to be associated with various different types of MHD waves and oscillations. The aim of this project is to identify isolated and clear examples of chromospheric events with different wave signatures. These observations serve as an input to state-of-the-art simulations developed for understanding heating mechanisms. We need high-cadence spectral and spectropolarimetric observations, that can be inverted to give a clearer understanding of the plasma dynamics.

UC-180: Transverse Waves in Small-Scale Magnetic Structures (Shahin Jafarzadeh, University of Oslo)

MHD waves are one of the prime candidates that have been proposed as agents for the transport of energy and momentum into the upper solar atmosphere. We aim at detection of such weaves in small-scale structures, such as small magnetic elements and chromospheric fibrillar structures, by combining observations simultaneously recorded at several atmospheric heights. These will allow us to directly trace the propagation of MHD waves, particularly, transverse waves, in the solar atmosphere all the way from the base of magnetic flux concentrations in the solar photosphere out into the upper chromosphere and beyond.

UC-181: Wave Transmission through Penumbral Fine Structure (Shaun Bloomfield, Northumbria University)

UC-182: Kelvin-Helmholtz Instability and Non-Thermal Broadening in Chromospheric Fine-Scale Structures (David Kuridze, Aberystwyth University)

Recent theoretical studies suggest that the Kelvin-Helmholtz Instability (KHI) could be a viable mechanism for the observed fast heating associated with the locations of the chromospheric jets. KHI can be observed directly in the chromospheric fine-scale structures via e.g., detections of vortex-like features at their boundaries. However, characteristic spatial scales of KHI vortices to be $\sim 20-50$ km are below the limit the spatial resolution of modern ground-based telescopes, which makes the KHI vortices extremely difficult to resolve. The KHI could also lead to enhanced MHD turbulence near the jets boundaries, which may result in spectral line broadening due to small-scale, unresolved velocity-fields and non-thermal heating. From theory we expect variation of Doppler width along the small-scale chromospheric jets due to the KHI could be less than ~ 3 km/s. These observational goals can be achieved with several DIKIST instruments.

UC-183: Torsional Alfvén Waves in the Chromosphere (Robertus Erdelyi, University of Sheffield)

Torsional Alfvén Waves (TAWs) associated with localised magnetic structures in the solar atmosphere are widely hypothesised to play a key role in channeling energy from the photosphere into the upper atmosphere. We propose to run an observing programme to detect the presence and propagation of TAWs simultaneously in line widths (QWHM, FWHM and TQWHM) oscillations and magnetic field observations at a range of different layers of the solar atmosphere in and above MBPs. We aim to conclude about TAW propagation and their roles in channeling energy from the photosphere in the the chromosphere and above.

Key data products required include: high-resolution and cadence e.g., Ca II 8542 A full-Stokes data from VTF, high resolution and high-cadence imaging from VBI, and full-Stokes parameter measurements from DL-NIRSP.

UC-184: MHD Waves in Chromospheric Fibrillar Structures (Shahin Jafarzadeh, Institute of Theoretical Astrophysics, University of Oslo)

UC-185: Convection-Driven Ubiquitous Coronal Waves (Markus J. Aschwanden, Lockheed Martin, Solar and Astrophysics Laboratory)

The scientific goal of this SUC is to test whether the vortex motion of sub-photospheric convection explains the exciter mechanism of ubiquitous (kink-mode transverse) oscillations of coronal loops. The spatial scale of sub-photospheric vortices correspond to the granular structure (L ~ 1000 km), the time scale or period corresponds to the life time of granules (typically ~7 min), and the speed is expected to be of order 0.3 km/s, as measured from the rms velocity with CoMP by Tomczyk et al. The required measurements include a time sequence of high-resolution magnetograms B(x,y,t), and Dopplershift measurements of coronal loops. The kinematic motion [x(t), y(t), z(t)] of magnetic elements can be directly obtained from the decomposition of magnetograms into unipolar magnetic charges as provided by the VCA-NLFFF code (Vertical-Currrent Approximation nonlinear force-free field code; Aschwanden 2016). Transverse motion x(t),y(t) is directly measured in LOS magnetograms, while the vertical motion z(t) is obtained from the relative variation of the width w(t) as defined by a divergence-free potential (or non-potential) force-free field (or the conservation of the magnetic flux).

In a first experiment we measure magnetograms at disk center and coronal loop oscillations above the limb. In a second experiment we try to measure both subphotospheric vortex motion (from magnetograms) and loop oscillations of the same loops, located about 45 deg from disk center (where magnetic field modeling is still feasible).

Magnetic field measurements can be obtained with VTF (Fe I line 6302.5 A), or the Fe I 15,650 A with DL-NIRSP, and multi-object multi-frame blind deconvolution method (MOMFBD).

The Doppler shift of coronal loop oscillations (or transverse motions) can be measured with Cryo-NIRSP Si IX (3935 A), perhaps together with the two Fe XIII (10747 and 10797 A) lines to obtain electron densities from the line ratios.

UC-186: Oscillations and Flows in Coronal Fan Loops at the Limb (Peter Young, NASA Goddard Space Flight Center)

Fan loops have temperatures of around 1 MK, and are large structures typically rooted in plage and sunspots. Observations with the TRACE 171 channel demonstrated they exhibited upwards propagating intensity disturbances that were interpreted as fast magnetosonic waves. Periods typically range from 3 to 10 minutes.

UC-187: Sources of the Slow Solar Wind: Reconnection and Flows at Active Region Boundaries (Huw Morgan, Aberystwyth University)

The boundaries between active regions and neighboring open field are thought to be a source of the slow solar wind. This study uses multiple instruments to observe such a region off the limb. We hope to (i) identify and track 'blobs' propagating outwards along the open field, thus contributing to the slow wind, (ii) make the first direction observations of the reconnective events that may form these blobs, (iii) characterise the nature of the plasma along the active-region/open field boundaries, and attempt to isolate the characteristics of the propagating blobs, and (iv) establish whether there is co-existing quiescent steady flow co-existing as a background along the open field, in addition to the irregular blobby flow.

UC-188: Rapid Fluctuations in the Lower Solar Atmosphere (Damian Christian, California State University, Northridge)

UC-189: The Signatures of Tether Cutting Reconnection in the Lower Solar Atmosphere (Christopher Nelson, QUB/University of Sheffield)

The evolution of the photospheric and chromospheric magnetic fields during the formation of large scale eruptions in complex Active Regions is extremely dynamic. Tether cutting reconnection can take place between sheared arcades, forming twisted magnetic flux ropes which are unstable to a range of magnetohydrodynamic instabilities, leading to both successful and failed eruptions. As the newly formed large loops expand outwards into the corona, the small-scale loops in the centre of the Active Region can quickly submerge to the regions below the solar photosphere. The spectral signatures of this magnetic field evolution should be varied, potentially including small-scale bursts, convective collapse, and bi-directional flows. The high-resolution imaging and spectro-polarimetric accuracy provided by the suite of instruments available with DKIST will allow us to accurately identify the signatures of tether cutting reconnection throughout the lower solar atmosphere, allowing us to advance our understanding of the build-up of twist in the solar atmosphere.

UC-190: Identification and Initial Characterisation of Molecular Lines in Sunspots (Huw Morgan, Aberystwyth University)

Accurate estimates of a sunspot's magnetic field are key to understanding the processes of how the solar magnetic field emerges into, and effects, the solar atmosphere. As DKIST becomes operational, it is imperative that sunspot molecular lines can be identified and used as part of the standard data analysis. This case aims to identify molecular lines in various DKIST sunspot spectra and assess their suitability for future diagnostics. This work will use existing published linelists and other new/improved molecular linelists from the ExoMol project.

UC-191: Small-scale Horizontal Fields in the Lower Solar Atmosphere (Mihalis Mathioudakis, Queen's University Belfast)

The magnetic field of the solar surface has a huge influence on solar phenomena, and thus developing our understanding of this field on the smallest scales is a crucial science goal. While the vertical component of the photospheric magnetic field, which is relatively strong, has been studied extensively, the relatively weaker small-scale transverse field warrants more thorough investigation. The Zeeman effect is blind as a diagnostic to mixed-polarity fields within the resolution limit. However, the Hanle effect, since opposite polarity fields contribute with the same sign to this depolarisation phenomenon, is suitable as a diagnostic for tangled, weak horizontal fields. This Science Use Case is concerned with the study of the turbulent magnetic field in the photosphere. The observing proposal has been designed to, first, take advantage of the unprecedented spatial resolution provided by DL-NIRSP to evaluate the transverse field using Zeeman diagnostics in the far-infrared and, second, exploit the unparalleled polarimetric sensitivity offered by the ViSP to probe the magnitude and time-evolution of this horizontal field using Hanle-based diagnostics in the visible.

UC-192: The Formation of Shocks in Sunspot Atmospheres Due to Down-Flowing Material (Christopher Nelson, QUB/University of Sheffield)

Recent observations (Nelson et al. 2017) have shown the presence of localised shocks at the foot-points of dynamic fibrils in sunspot atmospheres. Whether these events are formed outside of umbral flashes due to the modulation of upwardly-propagating waves by the fine-scale structuring in the sunspot atmospheres (which means the shock at that location occurs before or after the flash) or due to the shocking of down-flowing material during the evolution of dynamic fibrils is still to be determined. These events, named Small-Scale Umbral Brightenings (SSUBs) by Nelson et al., are short-lived (lifetimes of less than one minute) and have small spatial extents (semi-major axes shorter than 1") meaning extremely high resolution data are required in order to detect them. This makes DKIST the primary telescope in the world for SSUB studies. The aim of this SUC is to combine high-resolution imaging data (sampled by the VBI instrument) with inverted atmospheric properties (inferred from DL-NIRSP data) in order to identify the actual formation mechanism of SSUBs.

UC-193: Vortex Characterisation, Waves and Heating (Nitin Yadav, Max Planck Institute for Solar System Research)

The solar surface is populated with magnetic structures of kilogauss field strength and a wide range of spatial sizes. With recent progress in our understanding of Sun, small-scale structures and small-scale heating events are believed to be the main contributors in heating of the outer atmosphere that have not been fully explored due to the limited spatial and temporal resolution. These magnetic elements couple different solar atmospheric layers and provide conduits for wave propagation and allows the channeling of energy and momentum to higher layers. Recently, Requerey et al. (2018) demonstrated that a magnetic flux tube becomes stable when captured by vortex flow. Vortex flows are ubiquitous over a large range of temporal and spatial sales having diameters ranging from a few hundred kilometers (highest possible resolution) up to several Megameters and lasting from few seconds (highest possible cadence) up to several hours. They are strongly coupled with magnetic flux tubes which are wave guides for the propagation of MHD waves generated in the solar interior through the upper layers.

The actual connection between small-scale photospheric vortices and large scale tornadoes in upper layers is yet elusive and needs to be explored in more detail. Also, to apprehend how much wave energy finally reaches the different layers in solar atmosphere through vortices, is extremely challenging because of the multi-scale nature and complex dynamics of vortices. This can possibly be done by unprecedented high spatial, temporal and spectral resolution of DKIST using simultaneous multi-wavelength observations in different solar atmospheric layers. We intend to make high-resolution measurements of the magnetic field connectivity from deep photosphere to upper chromosphere by observing multiple spectral lines simultaneously and using state-of-the-art inversion techniques.

Moreover, by extracting the magnetic field connectivity and small-scale (<200 km diameter on photosphere) vortex signatures in active region, we investigate the correlation between them and investigate if all vortices align along the field lines and during all their lifetime or not? Also, plage being magnetically dominated region, supports various MHD wave-modes that are believed to be most important candidate for chromospheric heating. Making use of unprecedented resolution of DKIST, we want to explore the relationship between vortices and wave-excitation.

High-resolution 3D radiative-MHD simulations show that small-scale vortex features are locally denser and hotter structures aligned along the magnetic field lines. These structures haven't been observed yet due to lack of required resolution. Simultaneous spectropolarimetric observations in the photosphere and chromosphere will provide further information on the temperature and density stratification of these structures.

UC-194: Off-limb Line Widths, Alfvén Waves and Ion-Cyclotron Heating (Gerry Doyle, Armagh Observatory & Planetarium)

Wave- and turbulence-driven models of coronal heating and solar wind acceleration show that energy is carried to larger heights via plasma waves. Emission-line profiles can be used to infer many of the initial properties. The two main types of wave in the solar corona are Alfvén waves and slow magnetosonic waves. Alfvén waves are transverse waves and can be observed spectroscopically through non-thermal line broadening perpendicular to the magnetic field. Here, we propose to observe out to 300 arcsec with DL-NIRSP in a polar coronal hole and at the equatorial region.

UC-195: Flare Evaporation and Linkage to Electron Beams (Gerry Doyle, Armagh Observatory & Planetarium)

Solar flares are observed as emission enhancements across the entire electromagnetic spectrum, from radio to γ-ray wavelengths. For decades, the chromospheric response to flares has been investigated using Hα filtergrams. Flaring sites observed in Hα show spectacular phenomena such as filament (prominence) eruptions and flare ribbons (bright regions in the chromosphere along the magnetic neutral line). Hα kernels are very bright and compact emission sources embedded in these flare ribbons. They are believed to be the locations of high-energetic particle precipitation. Spectroscopic analysis of the solar chromosphere in the Hα line provides crucial information for understanding the impact of the energy release during solar flares on the lower atmosphere. In many cases, the complex evolution of the Hα line profiles suggests that possibly several heating mechanisms are at work in this ribbon. The proposed DKIST observations at highest spatial resolution will provide the details on the localized energy submissions of the energetic particles at the small-scales in the solar chromospheric flare ribbons. The consequences will be unveiled regarding the differential bunch of the energetic particles, and their interactions with the structured/random density fields in the flare ribbons.

Many of the current instruments are only able to measure up to ~50 km/s, however with DKIST/ViSP, however, we can go above -/+ 200 km/s. Here we wish to observe locations of flare kernels in Hα and Ca II 8542 with ViSP, plus H β images with VBI in the anticipation of detecting high-velocity flows during the impulsive phase of a flare. As mentioned above, this will itself be a signature of non-uniform/multiple heating scenarios of the flare kernels, as well as different possible interactions of energetic particles with the inhomogeneous atmosphere of these kernels. Fine details of the horizontal as well as vertical spread of the emissions and flows will be observed, thereby changing completely the scenario of single beam heating and uniform ambient atmosphere. Moreover, the other plasma dynamics, highly inhomogeneous outflows/evaporation; non-uniform sun-quakes etc. will also be possibly observed. The new observations will also put rigid constraints on the existing particle acceleration models and their interaction with the solar chromosphere.

UC-196: Dynamics and Energetics of Sequential Small Scale Flare Brightenings (Michael S. Kirk, Goddard Space Flight Center / CUoA)

During the impulsive phases of many flares, there is often a significant number of compact areas, spatially separated from the evolving flare ribbon, observed in the chromosphere. These compact areas brighten sequentially, radially away from the site of the ribbons and are known as sequential chromospheric brightenings (SCBs).
Previous studies with ISOON and SDO showed that these SCBs are distinctly different from flare kernels in their temporal characteristics of intensity, Doppler structure, duration, and location properties.

Whereas flare kernels exhibit redshifts, remain bright long after the impulse, and have typical lateral propagation speeds of ~0.2 km s^{-1} (maximum speed of 2.3 km s^{-1}) over a mean distance of 5000 km along the ribbon, SCBs are observed with coincident negative, positive, or both negative and positive Doppler shifts of a few km s^{-1}, precedes peak flare intensity by ≈12 minutes, decay ≈1 hr later are are found to propagate laterally away from flare center in clusters at 45 km s^{-1} or 117 km s^{-1} over 30000 km or more.

These distinguishing characteristics are limited by the nature of existing observations (only 2-3 points along the spectral line, 2 arcsec resolution, 1 minute cadence) have resulted in SCBs being grouped into various types. Only DKIST can provide the full spectral scan at the small spatial resolution and high cadence required to fully understand these dynamics, and determine the magnetic field strength inside these features.

UC-197: Pulsations in the Chromosphere Generated by Flares (Lyndsay Fletcher, University of Glasgow)

Recent observations with space-based instruments in the UV (SDO/AIA 1600A, Ly-alpha, Ly-C) show enhanced power in pulsations at the 3-minute chromospheric oscillation period, occurring during a solar flare (Milligan et al 2017). This is centred at the location of the chromospheric brightening in a solar flare. The purpose of this use case is to investigate whether these signals are present in other spectral lines, and if so how (i) the intensity signal strength varies between the line core and the line wings, as an indication of the power in pulsations as a function of height and (ii) whether there are changes in the line centroid wavelength, which would help identify possible drivers for the pulsations.

UC-198: Black Light Flares and Continuum Dimming (Graham Kerr, NASA GSFC)

UC-200: Identifying the Flare Driving Mechanism from the Induced Velocity Structure (Stephen Bradshaw, Rice University)

UC-201: Flare-related Magnetic Changes: Vector Magnetogram Imaging of the Photosphere and Chromosphere (Gordon Petrie, National Solar Observatory)

Significant change in the magnetic structure of the solar atmosphere occurs during flares. Though flares are coronal magnetic phenomena, quantitative measurements of magnetic changes come almost exclusively from the photosphere, and the coronal changes are usually studied via extrapolated models for the coronal field and/or from coronal EUV emission patterns. In this SUC we will use DKIST's ViSP, VTF and DL-NIRSP instruments to observe magnetically sensitive photospheric and chromospheric spectral lines with full-Stokes polarimetry from each instrument, and thereby derive matching high-resolution, high-cadence series of photospheric and chromospheric vector magnetograms combining the high temporal cadence of VTF and DL-NIRSP, the larger FOV of ViSP and VTF and the higher spectral resolution of ViSP and DL-NIRSP. This unique data set will have multiple applications. We will derive several non-potentiality parameters (twist, shear, free-energy proxies) using the proposed photospheric and chromospheric vector magnetograms from DKIST, when required complemented with other ground-based instruments e.g., DST, GST, GREGOR, VTT, and track the changes in these parameters before, during and after small flares. This includes estimating the changing Lorentz forces and magnetic shear and tilt at the different atmospheric subdomains. We will determine the relationship between the changes in these parameters from subdomain to subdomain, and comparing the height-dependence of the magnetic changes during eruptive as opposed to non-eruptive flaring fields.

UC-202: Magnetic Energy Deposition in Flare Chromospheres (Jaime de la Cruz Rodriguez, Institute for Solar Physics, Stockholm University)

During flares, the magnetic field is expected to reconnect to a lower energy state, releasing large amounts of magnetic energy in short time scales into the solar atmosphere. The latter heats the photosphere and the chromosphere while very rapid changes are observed in the overall structure of the active region. Our goals are to study how this chromospheric heating occurs and how energy is transported towards the photosphere, from an observational perspective.

UC-203: Physical Conditions at the Current Sheet Trailing CMEs (Katharine Reeves, Harvard-Smithsonian Center for Astrophyiscs)

In the decay phase of long duration flares, turbulent flows are observed in the current sheet region between the flare arcade and the erupting plasmoid. We propose to measure coronal magnetic fields and plasma properties in this region during the decay phase of an eruption.

UC-204: Community Flare Program (Disk) (Stephen Bradshaw, Rice University)

The high-resolution, polarimetric, and multi-wavelength capabilities of DKIST are eagerly awaited to advance our understanding of many aspects of the flare phenomenon – as testified by the over 30 flare-related Use Cases submitted to date. However, the intrinsic intermittency of flares – highly localized in space and time – makes it difficult to properly plan observations, unless one can run a dedicated program and tolerate a certain amount of "idle" time. Given the expected high-volume of requests for DKIST observing time, it is very plausible that flare proposals might not be granted high priority in the early stages of its operation, because of this risk.

We detail here a "community" flare proposal, i.e., a multi-purpose observing program discussed and agreed upon by several members of the community during the CSP Workshop on flares, held in Houston in May 2018. Specifically, we detail observations for flares expected to develop on disk. A separate Use Case will detail a community program for limb observations.

The general idea of the proposal is that of devising a program that can address several of the most sought-after characteristics of modern flares' observations, while being reasonably easy to rapidly implement at the telescope should a Target of Opportunity arise. The main logic behind the proposal is that of adopting the "default" distribution of light among instruments, as envisioned by the project. As this mode is foreseen as the most common one, it will allow the attendant astronomers to respond to the Target of Opportunity calls without having to use precious time to reconfigure the instruments. If necessary and desired, we are available to work with the project to define other multi-purpose programs that can use different light distribution modes.

Within the constraints posed by the chosen distribution of light, we then aim to employ as many diagnostics as possible, and to target phenomena that DKIST can uniquely address, like high precision measurement of chromospheric magnetic fields in flaring regions, or extreme high cadence and spatial resolution evolution of the flare kernels.

It would be desirable to have coordinated observations with IRIS, and an HXR imager like STIX from Solar Orbiter.

UC-205: Changing Coronal Magnetic Fields Over Limb Active Regions with ViSP and DL-NIRSP (Phil Judge, High Altitude Observatory/NCAR)

This Science Use Case is focussed on magnetic (not thermal) changes over active regions. Various combinations of ViSP and DL-NIRSP configurations are built to observe one chromospheric line and two coronal lines per instrument. The 637.0 nm nonpolarizable line is included to assess polarization calibration and cross talk. The FOV is about 1 arcmin square. Each scan is 1/2 hour so it could be repeated to build up magnetic changes with 1/2 hour sampling rate. Other sequences should be used to study thermal evolution (see UC 206).

UC-206: Changing Coronal Magnetic Fields over Limb Active Regions with Cryo-NiRSP (Phil Judge, High Altitude Observatory/NCAR)

This Science Use Case is focussed on magnetic (not thermal) changes over active regions, using the most sensitive line accessible to first-light instruments. Cryo-NiRSP has advantages over the other shorter-wavelength instruments that are exploited: observations can extend under poor seeing conditions and magnetic sensitivity is larger. The proposed FOV is 1 arcmin (radially) by 4 arcmin (tangentially to limb) using the wide slit. Each scan is 1/2 hour so it could be repeated to build up magnetic changes with 1/2 hour sampling rate. He I context images would be useful to link context images and coronal line observations to other data. Scans can extend to 2 (radial) x4 (tangential) arcmin for a slower cadence or with under-sampling using 1 arcsec raster steps.

UC-207: A Search for Electrostatic Shocks in the Low Solar Corona (Adam Kowalski, University of Colorado / National Solar Observatory)

Linear polarization may be detectable with the DKIST in high order Paschen lines of hydrogen due to macroscopic electric fields transverse to the line-of-sight. The electrograph technique is described in Moran and Foukal 1991 Sol. Phys., and a parallel electric field of 35 V/cm was detected in a small flare kernel (in Paschen-18) in Foukal and Behr 1995 Sol. Phys.). We propose to follow up on this pioneering detection and use the ViSP to detect electric macrofields in impulsive-phase flaring plasma.

Specifically, we seek to detect double-layers (see article by Andersson and Ergun in Auroral Phenomenology and Magnetospheric Processes: Earth and Other Planets), also sometimes called electrostatic shocks, that are expected to result from high-density electron beams streaming through the corona in the impulsive phase of solar flares (Lee and Buchner 2008). Although many in number and microscopic in scale, a series of double layers produce a dramatic net potential drop (Li, Drake, and Swisdak 2014), and maybe there will be a net polarization signature as well. Double layers have been observed in the Earth's aurora (e.g., Ergun et al. 2001, Phys. Rev. Lett.), and we propose for the first detection in the Sun's corona, possibly opening a new regime of electrographic studies of the Sun. Electric macrofields in the corona in the impulsive phase of flares would show that: 1) flare electrons are accelerated in the corona; 2) the electron beams have a very high flux density (as suggested by recent observations of Krucker et al. 2011, for example); 3) a return current is produced; and 4) the role of double-layers in particle acceleration in the Sun and other stars would need to be further considered.

The Paschen 18 line will be targeted with ViSP as well as well Paschen 10 and Paschen 13 + Ca II. To infer the electric field-induced polarization in these lines, we will plot ½ (I+Q) and ½ (I-Q) (Casini and Foukal 1996, Sol. Phys.). A major uncertainty lies in whether double layers occur in cool enough material so as to be detected in hydrogen lines (ostensibly, the Paschen lines are hotter than the Balmer lines but are still rather cool). We will position our slit over an active region, perpendicular to the limb so as to observe the transverse (parallel to B) electric fields. Sit-and-stare observations are crucial in case the formation of double layers is fleeting over a short time during the impulsive phase. In the case of null detections during a flare, these ViSP observations will still be very interesting by comparing the broadening of the hydrogen lines due to electric microfield distribution in the flare chromosphere directly to radiative-hydrodynamic models.

UC-208: Modulation of Basal Flux and Quiet Sun Magnetism with Solar Cycle (Reza Rezaei, Instituto de Astrofísica de Canarias)

The relative share of magnetic flux from decaying active regions and local dynamo action in quiet Sun regions is still an open question. Despite improvements in the spatial resolution and signal-to-noise ratio, we have not yet reached the sensitivity to detect variations in the weak quiet Sun magnetic fields with the solar cycle. Therefore the basal flux, the minimum chromospheric emission in quiet Sun regions, will be modulated by the amount of magnetic flux and is an indirect tracer of magnetic field variations. We propose a synoptic observing program of the chromospheric emission in the quiet Sun to elaborate on a possible cyclic trend in the basal flux, and hence the quiet Sun magnetic field. As a byproduct, we also trace long-term trends in solar magnetic activity and monitor the same quantities such as the H- and K-index that are used in night-time observations to characterize chromospheric activity of other stars. Simultaneous measurements of photospheric magnetic fields with the best currently available sensitivity and precision will be used to corroborate the results.

UC-209: DKIST Prominence Cavity Study (Kévin Dalmasse, IRAP France)

Coronal prominence-cavity systems are regions of stored magnetic energy, that often erupt in CMEs. DKIST provides unique observations of circular polarization and high temporal and spatial resolution linear polarization, as well as polarimetric measurements of the prominence.

This enables direct measurement of line-of-sight oriented magnetic field strength and diagnosis of magnetic topologies.

UC-210: Prominence-Corona Connectivity and Dynamics (Shadia Habbal, Institute for Astronomy, University of Hawaiʻi)

Total solar eclipse observations have been consistently providing images of the dynamic connectivity between the fine scale structures within a prominence and the overlying and surrounding coronal structures, which form the base of streamers. Missing from the eclipse observations is information regarding the coronal magnetic field. The goal of this science case is to explore this dynamic connectivity via multi-wavelength imaging and spectro-polarimetric observations, covering chromospheric to coronal lines. Line widths are also very important for the dynamics within the prominence-coronal plasma, whether line broadening or Doppler shifts.

UC-211: DKIST Pseudostreamer Study: Magnetic Topology, Plasma Properties, Magnetic Reconnection (Mari Paz Miralles, Harvard-Smithsonian Center for Astrophysics)

The role of magnetic topology in determining plasma conditions of the solar atmosphere is still unknown. We will use high-resolution DKIST Cryo-NIRSP instrument to quantify the solar atmosphere, in particular pseudostreamers. Spectroscopic observations from Cryo-NIRSP will look at flows, density, temperature, and ion abundances (low/high-FIP emission lines in the corona off-limb, and ionization fractions), while spectropolarimetric observations will look at magnetic strength, orientation, and topology. These measurements will be compared to predictions of magnetic expansion factors and flow velocities based on models. In additions, due to their topology, pseudostreamers have been suggested as ideally suited for magnetic reconnection. We will be searching for magnetic reconnection signatures and compare to model predictions.

UC-212: Magnetic and Thermodynamic Evolution in Post-Flare Loops at the Limb (Lyndsay Fletcher, University of Glasgow)

As the magnetic field relaxes following a flare reconnection event in the solar corona, the magnetic field 'dipolarises' from a cusp-like structure to a lower energy configuration, and the plasma that it entrains cools down. This process can take hours, depending on the strength of the flare. The evolution of the hot plasma can be deduced from EUV imaging and spectroscopy; the evolution of the magnetic field is as yet unknown. We propose to use DKIST spectroscopy and spectropolarimetry to characterise the slow evolution of the post-flare loop system in a suitable flare at the solar limb.

UC-213: Magnetic Topology of Pseudostreamers (Laurel Rachmeler, Marshall Space Flight Center)

Combinations of measurements with Cryo-NIRSP to determine the static magnetic structure of pseudostreamers whose cusp height is on the order of 1.1 to 1.3 solar radiii. Uses polarization measurements in a slit raster and context images. This set of measurements can be used to answer multiple science questions, or be used as a contextual component of other science use cases.

UC-214: Magnetic Field Structures Associated with Suppression of the Thermal Conduction (Tetsu Anan, National Solar Observatory)

Thermal conduction controls thermal structures in the solar corona, e.g., solar flares, coronal loop structures (Yokoyama & Shibata 1997; Bradshaw et al. 2019). The thermal conductivity has been derived from particle collisions as the Spitzer conductivity. However, some observations of the solar corona show some evidence of the conductivity suppressed below the Spitzer conductivity (Imada et al. 2015, Wang et al. 2015). Turbulent magnetic field (Biann et al. 2016), global structure of the magnetic reconnection (Imada et al. 2015), and plasma waves (Wang et al. 2015) have been suggested as the causes of the suppression. We are going to investigate arelation between turbulent magnetic fields and suppression of the conductivity using the Cryo-NIRSP of the DKIST.

UC-215: CME Diagnostics in the Inner Corona (Enrico Landi, University of Michigan)

We seek to determine the thermal evolution and chemical composition of all types of plasmas involved in the CME, with particular interest in the evolution of the CME core. Results will be modeled using an ionization code to compare resulting charge state composition with in situ measurements – where available – or Solar Orbiter.

UC-216: What is the Relationship between Alfvénic Waves and Density Fluctuations in the Corona (Michael Hahn, Columbia University)

The purpose of this Science Use Case is to understand the relationship between Alfvénic waves and density fluctuations in the corona. Both Alfvén waves and density fluctuations have been observed in the corona and it is likely that these density fluctuations are compressive wave modes. The interactions of these types of waves are likely important for coronal heating. For example, Alfvén waves may damp partially by generating compressive waves via parametric instability. Conversely, density fluctuations promote the reflection of Alfvén waves thereby generating sunward propagating Alfven waves that interact with the outward directed waves and producing turbulence. This turbulence mediates the transfer of energy from the wave fields to particle kinetic energy. Here, we propose observations to understand the connections between these types of waves. We will observe the power spectral distribution of wave energy in both Alfvén and compressive waves in coronal holes and the quiet Sun and quantify their wavelengths and periods as a function of height. The objectives are first, to determine whether the density fluctuations are consistent with being generated by the parametric instability of Alfvén waves; second, to quantify the reflection of Alfvén waves from the density fluctuations; and third, to measure the wavelengths, periods, amplitudes, and other data that are needed in order to constrain wave-driven models of coronal heating.

UC-217: Densities and Non-Maxwellian Electron Distributions in AR (Giulio Del Zanna, University of Cambridge)

The main scientific aim is to measure the density distribution in an off-limb active region by combining simultaneous observations with the DKIST forbidden lines and the allowed transitions observed with *Hinode* EIS. The secondary aim is to constrain the electron temperatures using the line ratios. The third aim is to put constraints on the possible presence of non-Maxwellian distributions. The fourth aim is to measure the non-thermal widths of the DKIST lines, using the electron temperatures (and assuming that the ion temperatures are the same).

UC-218: Discovering the Coolest Sun (Svetlana Berdyugina, Leibniz Institute for Solar Physics/KIS)

We propose to discover and characterize the coolest regions on the Sun using the CO NIR bands. The CO molecule has a high dissociation potential and a very high temperature and pressure sensitivity. Hence, it can be found in cool regions within the photosphere, chromosphere and corona, and it can be employed to probe the finest structure and dynamics of those yet unexplored regions in the upper solar atmosphere.

We will employ the CO 4.6-4.7 µm lines observed with the Cryo-NIRSP spectropolarimeter and context imager. We request the CO 4.7 filters on both instruments, and H-alpha filter on the context imager (or access to VBI via new dichroic).

These observations may be coordinated with ALMA.

Targets:

- On-disk: center-to-limb, quiet Sun, plages, sunspots, filaments.
- Off-limb: spicules, prominences, quiet corona, CMEs.
- Sungrazing comets.

Outcomes:

- Temperature maps -> model-independent, using rotational excitation energy.
- Doppler maps (oscillations, flows).
- Oxygen isotope ratio -> origin of the cool matter in the corona.
- Anisotropy maps (polarimetry).
- (Q,U) <-> V cross-talk calibration.

UC-219: Fine-Scale Coronal Dynamics by High-Cadence DKIST Observations (Hirohisa Hara, National Astronomical Observatory of Japan)

This is a study for searching small-scale events with a short life time of less than 1 min, which will be associated with the coronal heating. The followings are the primary science questions to be answered:

- What kind of dynamics occurs in the corona in association with the heating processes?
- Can we find a small-scale (<1") event with a short (< a few secs/tens of secs) time scale?
- Can we find high-frequency waves in the corona and what is the origin if there is? Magnetic reconnection is a candidate.
- What kind of magnetic structures are associated with coronal dynamics?

UC-221: In Search of Acoustic Episodes in the Photosphere and Above (Alina Donea, Monash University)

A major issue in the physics of seismic emission in quiet sun is the degree to which the emission from a particular location is episodic. The intension is to image sources of seismic emission in the photosphere and link their location to the chromosphere, and link their location to local thermal and magnetic properties of the sun. Particular interest is in observing the neighbouring zones of quiet sun surrounding penumbrae of active regions, where we have reported enhanced seismic emission haloes at high frequencies 6mHz and above. Acoustic glories are present in haloes but also are identified in surrounding plages and sometimes complex supergranular structures.

UC-222: Coronal and Solar Wind Diagnostics below 3000 A (Enrico Landi, University of Michigan)

The spectral range between 3000 and 3800 A is rich with coronal lines that allow a wealth of plasma diagnostic opportunities. This SUC explores such diagnostic potential, to investigate the plasma temperature and density of the solar corona, as well as the evolution of the wind charge state distribution in polar coronal holes.

UC-223: Siphon Fow in Hot Flare Loops (Hugh Hudson, University of Glasgow)

In addition to evaporation flow (injecting mass into a coronal loop) and coronal rain (removing same) there should be essentially horizontal flows along the loops reflecting any footpoint asymmetry, e.g. in field intensity. DKIST can observe these flows in flare loops appearing above the limb, using traditional and IR lines with high formation temperatures, e.g., the Ca XV yellow line. Such flows should occur both in the impulsive and gradual phases of a flare.

UC-224: Evolution and Properties of Small Photospheric Magnetic Fragments (Eric Priest, University of St. Andrews)

How much small-scale magnetic flux is there at DKIST resolution in the very quiet Sun, in unipolar regions and in active regions? What are the properties of that flux in terms of appearance, evolution, fragmentation, coalescence and cancellation?

UC-225: Guide Field and Acceleration Efficiency in Flare Reconnection (Rick Wilder, University of Colorado Boulder)

Fermi acceleration of energetic ions and electrons can occur during magnetic reconnection (Drake et al., 2006). Recently, it has been suggested that this process is more efficient for anti-parallel reconnection than for reconnection with a guide field. Our objective is to verify the hypothesis that fermi acceleration of energetic particles by magnetic reconnection is more efficient at high magnetic shear (e.g., anti-parallel magnetic reconnection). This will require observations of the corona on the limb to determine the guide field, as well as observations of x-rays from spacecraft to determine the acceleration and density of energetic particles.

UC-226: Magnetic Falloff above Potentially Eruptive Active Regions and Prominences (Katharine Reeves, Harvard-Smithsonian Center for Astrophysics)

For eruptions triggered by the helical kink instability or the torus instability, the fall of of the magnetic field as a function of height (the decay index) is an important parameter. This observation will survey the magnetic field as a function of height above potentially eruptive active regions or prominences on the east limb in order to measure the decay index.

UC-227: Elongation of Ribbons in Two-Ribbon Flares (Paul Cassak, West Virginia University)

Ribbons in two-ribbon flares separate from each other in time as the reconnection process above it proceeds. At the same time, typically the ribbons elongate along the polarity inversion line. This is associated with the reconnection process spreading in the direction perpendicular to the plane of reconnection. This spreading and elongating has gotten much less attention than the separation of the ribbons, but it is important not just for solar flares – it is also relevant for prominence eruptions, solar wind reconnection, dayside magnetospheric reconnection, and magnetotail reconnection. This study is to investigate the speed and directionality of the ribbon elongation.

UC-228: Magnetic Mapping of Photospheric Flux Elements through the Chromosphere (Dana Longcope, Montana State University)

Magnetic flux in the photosphere is observed to be concentrated into small tubes of kilogauss field strength, surrounded by regions of much weaker field. The large plasma pressure there is capable of confining these tubes.

Some or all of this flux is believed to pass through the chromosphere into the corona where it is believed to be far more uniformly distributed because of the much smaller plasma pressure available for confinement. In passing between these layers the field must expand horizontally. The layer of this expansion, called the magnetic canopy, is a critical component in many models of the solar magnetic field. DKIST will be able to observe the magnetic structure of this layer in unprecedented detail.

UC-229: Non-ideal Dynamics in Cancellation and Emergence (Brian Welsch, University of Wisconsin / Green Bay)

Observations suggest that magnetic diffusivity plays a role in some episodes of flux cancellation and flux emergence. DKIST's combination of high spatial resolution and high sensitivity should enable estimation of the magnitude of magnetic diffusivity in some cancellation and emergence events. We shall analyze near-disk-center magnetic and spectral observations, made in photospheric and chromospheric lines, of a few episodes of either cancellation or emergence in isolated bipoles, to better constrain non-ideal aspects of their evolution.

UC-230: Granule Temperature Sampling (Hugh Hudson, University of Glasgow)

Newborn granules consist of pristine subphotospheric gas and could reveal its thermodynamic properties. DKIST brings multiple resources at the highest resolution to make precise measurements of irradiance, line equivalent widths, and color temperature of this material. The spatial distribution of these measures may reflect interior flows involved with structures otherwise only visible by helioseismic techniques. There are many interesting systematic limitations of such a program, including the p-modes, embedded magnetism, seeing, etc.; we propose initial observations that characterize these limitations. If successful at a level of 0.1 K, we would propose synoptic observations.

UC-231: Seeking On-Disk Continuum and Coronal Line Emission during the Impulsive Phase of Flares (Sarah Jaeggli, National Solar Observatory)

All flares produce continuum emission and enhancement in photospheric, chromospheric, and coronal lines. Large X-class flares produce continuum that can be easily distinguished above the photospheric continuum at visible wavelengths, but the photospheric continuum becomes increasingly weak at longer wavelengths making it possible to detect the continuum emission even from modest C-class flares in the thermal infrared. In addition, heating during a flare can make coronal lines hundred of times stronger than they are in the quiet-Sun and it may be possible to detect them against the photosphere on-disk. This program would make use of the imaging and spectroscopic capabilities of DKIST's infrared instruments to conduct exploratory observations of active regions during periods with non-ideal conditions for other observations.

UC-232: Do Existing Fast Dynamo Simulations Explain Observed Small-Scale Solar Surface Fields? (Robert Rosner, University of Chicago)

A number of weakly compressible MHD convection simulations have shown suggestive similarity of sweeping magnetic fields into intercell boundaries to what is commonly observed in granular flows in the Quiet Sun. The question is: Can one practically disentangle the surface dynamics modeled by these simulations (including the fast/turbulent dynamo effects) from what is going on at larger scales and deeper layers? To put it most coarsely: Can one practically separate the global magnetic dynamo problem from what is seen at small scales at the surface? Answering this question might well help us constrain the global magnetic dynamo process(es).

UC-233: Cancellation of Flux and Chromospheric Heating (Eric Priest, University of St. Andrews)

Recent observations from IMAX on Sunrise at 0.15 arcsec have shown that flux cancellation is much more common than previously realised, and that it occurs at the footpoints of chromospheric and coronal loops. This has led to the proposal of a new “Cancellation Nanoflare Model for Solar Chromospheric and Coronal Heating” by Priest, Chitta and Syntelis (ApJ L, submitted). DKIST offers a wonderful opportunity to examine flux cancellation in unprecedented detail, as well as its effect on driving reconnection and heating in the overlying atmosphere, in the Quiet Sun, in unipolar regions and in active regions.

The flux interaction distance is d_0=6(F_19 / B_1)^0.5 Mm, with flux F_19 in units of 10^19 Mx and the overlying field B_1 in units of 10G. It gives the distance apart when oppositely directed photospheric fragments start to drive reconnection in the overlying atmosphere and also roughly the maximum height of the reconnection process. For small flux sources of say 10^17Mx in a weak field of say 10G it gives d_0=0.6Mm, but for large sources of say 10^20 Mx in a strong field of 100G it gives d_0=6Mm.

UC-234: Detection of Ion-Neutral Drifts to Prove the Ambipolar Effect in Weakly Ionized Plasma (Yukio Katsukawa, National Astronomical Observatory of Japan)

The ambipolar effect can play an important role in dissipation of magnetic fields in weakly ionized plasma seen not only in the solar chromosphere but also in astrophysical plasmas. The ambipolar effect is a strong candidate to cause "fast" magnetic reconnection in the chromosphere by thinning of a current sheet caused by escape of neutral species from a current sheet. The direct indication of the ambipolar effect is to measure non-zero drift velocities between ions and neutrals. The unprecedented spatial and temporal resolution of DKIST as well as spectroscopic capability of multiple species have potential to access the regime where the ambipolar effect is prominent.

UC-235: Mapping the Helium Corona with DKIST and Parker Solar Probe (Justin Kasper, University of Michigan)

UC-236: Resolving Fine Scale Structure in the Solar Corona (Kevin Reardon, National Solar Observatory)

The fine-scale structuring of the solar coronal plasma may be closely related to the injection and dissipation of energy into the corona. The scale and distribution of such structures could help clarify the mechanisms that create density and temperature variations in the coronal plasma. This may be related to the connectivity with multiple photospheric footprints and their driving. This proposal will attempt to achieve observations that achieve high spatial resolution information on the solar corona.

UC-240: Elemental Coronal Flux Tubes (Valentin Martinez Pillet, National Solar Observatory)

The magnetic field of the photosphere is highly fragmented in the form of distinct kG flux tubes. They have a characteristic strength of 1500 G and characteristic scale ("diameter") of 150 km, although recent magnetoconvection simulations suggest that the cross sections may be highly distorted. The tubes expand in the low-beta corona to a diameter of roughly 800 km in active regions, where the coronal field strength is roughly 50 G. A typical coronal loop (emission structure seen in an image) contains the flux equivalent of approximately ten kG flux tubes, while an entire active region contains of the order of 100,000 kG tubes.

Processes in the corona, such as magnetic reconnection, quasi-ideal instabilities, and turbulence fragment the tubes into still smaller structures. They are topologically distinct and therefore constitute the true elemental structures of the corona. We refer to them as elemental coronal flux tubes (ECFTs). The boundaries between ECFTs are separatrix surfaces, which invariably become current sheets in response to the incessant driving of the footpoints. This means there is a discontinuous change in magnetic field direction across the boundaries. The discontinuity should extend all the way down to the photosphere.

The size ECFTs is not known. The objective of this study is to determine their size by mapping the transverse magnetic field across individual kG flux tubes in the photosphere and chromosphere. Each kG tube will contain several ECFTs that can be distinguished by an abrupt change in the transverse field. We expect a "web" of sharp gradients. To accomplish this objective, we require transverse field measurements with the highest possible spatial resolution (25 km). Accuracy in the measured transverse field should be 5-10% of the vertical field strength: 75-150 G in the photosphere and 15-30 G in the chromosphere. Temporal resolution is not critical.

UC-241: Type II Spicules (Kevin Reardon, National Solar Observatory)

Several years ago, it was discovered that many spicules are heated as they rise. Most of the ejected material is heated to ~0.1 MK, but the tip may be heated to much higher temperatures.

The 0.1 MK material falls back to the surface, while the tip material continues to rise into the corona. These were given the name “type II” spicules to distinguish them from more common classical spicules (type I) that rise and fall at chromospheric temperatures (0.01 MK), without heating.

It has long be recognized that emission from the Sun temperatures less than about 0.1 MK is much brighter than can be explained by conventional loop models (hot corona and thin transition region). It was proposed that this excess emission comes from “cool loops.” However, cool loops are necessarily short and low lying, and therefore can only exist in regions of highly mixed magnetic polarity, i.e., the quiet Sun. Another explanation is needed for active regions. We suggest that the cool emission in active regions, and possibly also the quiet Sun, is due primarily to type II spicules.

We have attempted to measure the brightness profile of individual type II spicules (brightness as a function of distance along the spicule axis) using IRIS slit jaw observations of Si IV (1394) at the limb. When combined with an estimate of their number density (number per unit area across the solar surface), we can determine whether spicules are in fact the primary source of the observed cool emission. Unfortunately, it is extremely difficult to identify the lower parts of spicules at the limb because of line-of-sight overlap confusion. We do not even know how close to the surface they extend. Their total brightness is therefore highly uncertain.

Our objectives are to study the lower parts of type II spicules and to determine their number density. We will accomplish this by using disk observations, where there is much less overlap ambiguity. We will use He II lines to observe plasma that has been heated to ~0.04 MK. We will also study colder emissions that have much better signal to noise. By measuring where the rising cold material disappears during the rise phase, we will infer the lowest height of the warm (Si IV emitting) plasma. By observing whether cool material reappears as the spicule falls, we infer whether the material remained hot during the entire descent.

Type II spicules are thin features, so we require a high spatial resolution. They have velocities of 50-100 km/s, so a vertical resolution of 100 km requires a temporal resolution of 1-2 s.

UC-242: Alfvén Wave Turbulence Heating of the Corona and Chromosphere (Mahboubeh Asgari-Targhi, Harvard-Smithsonian Center for Astrophysics)

The origin of coronal and chromospheric heating is currently being debated. One idea proposes the convective flows in the photosphere slowly displace magnetic footpoints and quasi-statically stress the field. The field suddenly reconnects and heats the plasma when a critical level of stress is achieved. This is often called “nanoflare” heating. Another idea proposes that convective flows change direction with sufficiently high frequency to generate Alfvén waves. Counter propagating waves from different ends of a loop interact to produce MHD turbulence, which dissipates the waves and heats the plasma. The waves are assumed to be generated within (internal to) kG magnetic flux concentrations in the photosphere, commonly called “kG flux tubes.”

We propose to look for evidence of these waves by measuring the motion (oscillatory displacement) of intensity and/or magnetic features in the photosphere and chromosphere. Since kG flux tubes have a characteristic scale (diameter) of roughly 150 km in the photosphere, the correlation length of the motions must be <150 km. This is the maximum size of the intensity/magnetic features. In order to have waves in the corona, instead of quasi-static evolution, the wave period must be < 60 s. (For a typical coronal Alfven speed of 2000 km/s, the wavelength of a 60 s wave is 120,000 km.) The driver velocity in the photosphere is estimated to be 1.5 km/s, which implies a displacement amplitude of < 90 km.

The flux tubes flare out in the chromosphere, and the corresponding wave parameters are (lower to upper chromosphere): correlation length < 650-800 km, fluctuation velocity = 10-20 km/s, displacement < 600-1200 km. The wave period is the same (< 60 s). These values are based on Fontenla Model P for faculae and bright plage, as reported in van Ballegooijen et al. (2011).

UC-243: Monitoring of turbulent field during the solar cycle (Alfred De Wijn, High Altitude Observatory/NCAR)

Weak magnetic field is thought to be ubiquitously present in the quiet sun. Traditional Zeeman diagnostics are blind to this field because it has mixed polarity on scales much smaller than can be resolved. Using Hanle diagnostics, Trujillo Bueno et al. (2004) inferred a field strength of approximately 130 G. I propose to monitor this "turbulent magnetic field" during a solar cycle. The absence of variation in the turbulent magnetic field could be evidence for a local origin of this field.

UC-244: Subsurface and Surface Meridional/zonal Flows at High Latitudes with Application of Local Helioseismology Techniques to DKIST Observations (Sanjay Gosain, National Solar Observatory)

With increasing angular resolution application of local helioseismology techniques (LHT) and local correlation technique (LCT) becomes possible at much higher latitudes. As an example with SDO HMI (0.5"/pixel), the meridional and zonal flows are routinely recovered up to ~75 degrees. With DKIST, filtergrams, dopplergrams and magnetograms can be obtained at a resolution of ~0.02 arcsec resolution with high cadence of up to 60 arcsec FOV (larger with mosaicking). During the March and September months, the solar poles present good views and application of LHT and LCT becomes even more applicable to high latitudes (reaching >90 degrees) and a few days of observations during these epochs would provide crucial insights into the nature of meridional and zonal flows close to solar poles. We propose to take advantage of new cutting-edge observations from DKIST to discover large-scale flows near the solar poles and its variation during one full solar cycle. Current telescopes such as GST, DST, and GREGOR can not address these problems.

UC-245: Dynamics of the Near-Surface Shear Layer Using High-Resolution DKIST Observation (Sushanta Tripathy, National Solar Observatory)

In the proposed work, our major goal is to determine the dynamics of the near-surface shear layer using the high-wavenumber solar oscillation modes. In particular, we will focus on these particular topics: (i) characterize the variations of the subsurface shear flow with latitude and time with the progression of the solar cycle, (ii) examine the evolution of the sub-surface dynamics of the shear layer associated with quiet and active regions to assess the conditions below the surface, (iii) study the differences between the northern and southern hemispheres of the sun, which reflect the differences in magnetic activity between the two hemisphere and (iv) analyze the differences beneath the quiet sun in the presence of coronal holes.

UC-246: Assessing Solar Open Magnetic Flux from the Surface Up (Xudong Sun, University of Hawaiʻi)

The solar open magnetic flux originates from coronal holes (CHs), where magnetic elements of a single polarity dominate the photosphere landscape. These elements are a few arc seconds across with kilogauss field and moderate filling factor (Tsuneta et al. 2008). The total flux budget, estimated from moderate-resolution magnetographs, falls far below the in situ measurement at 1 AU (Linker et al. 2018); it also differs significantly between observatories (Riley et al. 2014). This program will observe a large number of on-disk magnetic elements using multiple photospheric and chromospheric lines, as well as near-limb coronal field above CHs. Parker Solar Probe (PSP) and Solar Orbiter (SO) will provide complementary near-Sun in situ measurements. The high resolution and sensitivity of DKIST are expected to minimize several known systematic biases and help reconcile the discrepancy between in situ and remote sensing methods.

UC-247: Properties of Small-Scale Photospheric Magnetic Structures over the Solar Cycle (Courtney Peck, CIRES University of Colorado Boulder)

High-resolution 3D MHD simulations show the presence of small-scale magnetic structures in quiet regions of the solar photosphere. These magnetic structures remain unresolved by current instruments, and therefore changes in the size and contrast distribution of these structures with the solar cycle are unknown. As a result, the contribution of these small-scale magnetic structures over the solar cycle to inferred irradiance trends remains uncertain. In this proposed synoptic observation, we aim to determine the small-scale magnetic structure size distribution and contrast as a function of solar cycle using G-band observations with VBI. Simultaneous spectropolarimetric observations in the photosphere with VTF will provide further information on the magnetic flux densities and temperature stratifications of these structures to further constrain their radiative output.

UC-248: Synoptic Magnetic Vector Field Measurements for Filaments (Gordon Petrie, National Solar Observatory)

Solar filaments are relatively cool, dense plasma structures in the chromosphere, supported against gravity by twisted and sheared magnetic fields. The free magnetic energies associated with their highly non-potential fields give filaments a very significant role in space weather phenomena. Filaments form and erupt both within and outside active regions and are often associated with geoeffective CMEs. Filaments also participate in the global magnetic cycle, including the transport of magnetic helicity, the rush to the poles and the polar field reversal. Despite their importance to solar magnetism and to solar effects on Earth, filament magnetic fields are measured only rarely and generally not systematically. Because such measurements are lacking, existing models of filament eruptions are usually derived by mimicking the general appearance of observed filaments in intensity images. This Use Case will collect filament magnetic field measurements on a regular basis using the DKIST's Cryo-NIRP instrument, together with maps of the underlying surface magnetic field. This will give models of filament eruptions a more solid empirical basis, and inform models of filament formation and studies of cycle-dependent magnetic helicity patterns.

UC-249: Study of the Lifetime, Size, and Flux Distributions of Magnetic Elements in the Polar Crowns (Andrés Muñoz-Jaramillo, Southwest Research Institute, Boulder)

The polar crowns are one of the unknown and uncharted frontiers in solar physics. This means that we don't have measurements of the characteristic time-scales and spatial scales of relevance for studying and understanding the evolution of the polar magnetic fields. The purpose of this study is perform a detailed analysis of polar magnetic flux elements at difference cadences to better inform the instrumental requirements (cadence and resolution) of any subsequent studies of the polar magnetic fields (normal or synoptic).

UC-250: Helicity as the Ultimate Test to the Surface Dynamo Problem (Alexei Pevtsov, National Solar Observatory)

It is widely accepted that large-scale magnetic structures on the Sun, such as active regions, are the product of a dynamo situated at or near the base of the convection zone. The intermixed, small-scale photospheric magnetic field could be generated by a second dynamo operating at or near the solar surface. Since the deep-seated and near-surface dynamos are driven by flows of different sizes operating on different time scales, the magnetic fields generated by these two dynamos should be quantitatively different. In particular, there are well-studied helical trends in the large-scale magnetic which could be imprinted on them by the deep, slow flows of the dynamo which generates them; these helical trends would be absent from a field generated by a surface dynamo. We propose that observations of magnetic/current helicity at very small scales can be used to establish the role of the second, surface dynamo on the Sun.

UC-251: Subsurface Structure and Dynamics of Solar Filaments (Kiran Jain, National Solar Observatory)

Solar filaments are long-lived, relatively cool and dense structure formed inside and outside the active regions. These mainly lie along the main neutral line and form a chain-like pattern at high-latitudes in each hemisphere, known as polar crowns. They are considered as one of the major drivers of global magnetic field. While some filaments erupt, some of them are long-lived in a quiescent stage. Models of filament formation suggest the existence of surface plasma flows and some evidence has been provided in a case study. Therefore, it is important to carry out a statistical study of the subsurface structure and flow pattern beneath the filaments to understand their characteristics. Continuous high-cadence and high-resolution observations from DKIST for several hours, in conjunction with high-resolution ring analysis, will allow us to investigate the dynamics and structure of filaments in subsurface shear layer.

UC-252: Observing the Coolest Regions of a Sunspot (Smitha Narayanamurthy, Max Planck Institute for Solar System Research)

The Ti lines at 2.2 μm, due to their large Landé g-factor and long wavelength, are highly Zeeman sensitive. In addition, they are also temperature sensitive due to their low excitation and ionization potentials. They are formed only in cool plasma with $T \leq 5000$ K, making them ideal for the observation of the cool sunspot umbra without any contamination from the surrounding penumbra or the quiet Sun. While the other lines commonly used for sunspot observations such as Fe I 6301 Å and 6302 Å (e.g., by *Hinode* SOT/SP) are affected by molecular blends in the umbra, the Ti lines are quite clean. These lines were observed using the NSO McMath-Pierce telescope on Kitt Peak in the 90's and since have been seldom used for sunspot observations, partly due to the lack of instruments that can observe at these wavelengths. Now with the Cryo-NIRSP instrument at the DKIST facility, it may be possible to record the full Stokes profiles of these lines.

UC-253: Mercury Nov 11, 2019 Solar Transit Spectroscopy (Carl Schmidt, Boston University)

Mercury has a non-spherical, seasonal atmosphere coupled to its surface and dynamic magnetosphere. Characterizing this unique atmosphere is interesting, yet studies to date remain relatively primitive, both because traditional astronomical techniques fail due to solar proximity and because NASA's MESSENGER orbiter carried only a single point spectrometer. Absorption techniques during rare solar transits have offered the highest spatial, temporal and spectral resolution. Only Na has been measured in absorption (e.g., Fig 1), but K and Ca atomic resonance lines may be within DKIST's reach. Each is predicted to have different properties associated with its source. Doppler structure of Ca emission in Keck HiRES data remains unexplained. Alkalis can best characterize sources by solar wind precipitation, analogous to aurorae, by using variations in distribution, line width and atmospheric scale heights. Additionally, scaling from lunar measurements would predict a denser and more extended dust cloud on Mercury's leading hemisphere, and one potentially detectable in a broadband absorption column. The data set is also an invaluable analogue to transiting exoplanets, of which there are at least 20 exhibiting the alkali absorption features we target here. Together, these pack a many valuable experimental possibilities into a short-lived and rare event.

UC-254: Observing Spatially Unresolved Coronal Structure High above the Limb in the Quiet Sun and Coronal Holes (Richard Frazin, University of Michigan)

A two-week (ie, 1/2 of a Carrington rotation) sequence of above-limb spectral images of the corona enables tomographic 3D reconstruction of the emissivity of the spectral line. The method works well in structures that are temporally stable such as coronal holes and quiet Sun. When performed with multiple spectral lines, various quantities can be obtained in each volume element. These quantities include low-order information such as elemental abundances, density and mean temperature, as well as high-order information such as local differential emission measure, filling factors, and temperature-density correlations. These high-order quantities are the result of spatially unresolved, inhomogeneous flux-tubes that thread the tomographic volume element. These empirical quantities will provide a stringent set of constraints for coronal models. This project would be best served with a synoptic sequence of above-limb images in the Si IX 3934 nm and Fe XIII 1074.7 nm bands. Stokes parameters are not needed. I think it would easiest to collect the needed observations with the Context Imager, since rastering faint spectral lines is bound to be slow. The context images would need to be tiled out to 1.3-1.5 Rs to allow tomography. These data would be nicely complemented by EUV images routinely measured by AIA on SDO, narrow-band off-limb images from UCoMP (MLSO), and white-light coronagraphic images from K-Cor (MLSO). The Fe XIII images would allow cross-calibration with the UCoMP (MLSO) images at the same wavelength. Simultaneous slit spectroscopy in various coronal lines could be done in order to provide complimentary information. Tomographic analysis would be applied to each image type separately. Once this is done, we will have emissivities from many image types in each volume element of the tomographic grid. In each volume element, this would allow us to determine: abundances of Si and Fe, temperature mean and stdev, density mean and stdev (from which you can calculate the filling factor = <n^2>/<n>^2), correlation of temperature and density.

UC-255: Exploring the Properties of the Chromospheric Turbulent Cascade (Momchil Molnar, University of Colorado, Boulder)

We propose to extend the previous work by Reardon and et al. (2008), to measure the high-frequency RMS velocity in chromospheric diagnostics such as Hydrogen Balmer alpha (H-alpha) and Ca II 8542 Å. These observations will constrain the heating contribution to the quiet chromosphere from high frequency waves. This will also allow us to further characterize better the turbulent properties of the chromosphere and for the first time attempt to disambiguate between different MHD waves in the chromosphere using the polarimetric capabilities of DKIST. We propose to use VTF and VISP to obtain high cadence datasets with full polarimetry in Na D I 5986 Å, Fe I 6301 Å and Fe I 6301 Å and with VTF in H-alpha and Ca II 8542 Å. We require excellent seeing conditions for the execution of this proposal.

UC-256: The Propagation and Dissipation Characteristics of Slow Magneto-Acoustic Waves in a Sunspot Umbra (Krishna Prasad Sayamanthula, Queen's University Belfast)

The ubiquitous acoustic waves and oscillations present in the photosphere can be channelled into the outer layers of the solar atmosphere via magnetic fields. Upon interaction with magnetic fields, the acoustic perturbations become converted into the slow and the fast magnetohydrodynamic wave modes, of which the slow mode waves continue to propagate along the magnetic field. It has been shown that the umbral flashes, running penumbral waves, and the propagating coronal disturbances observed in sunspots are different manifestations of these wave perturbations. The high thermal conduction and other (some still unknown) dissipative processes in the solar corona, are known to cause rapid decay and eventual disappearance of the slow waves. However, in a recent study, a significant damping is observed in these oscillations in the lower atmospheric layers. The observed damping is likely due to a combination of dissipative processes (e.g., radiative losses, shock dissipation) and non-dissipative processes (e.g., reflection, mode conversion). In order to assess their true dissipation and develop a comprehensive understanding on their propagation across the solar atmosphere, we now need full spectral information at multiple positions along the propagation path of these waves. To achieve this goal, we will make use of the multi-wavelength and ultra-high resolution capabilities of DKIST in combination with the existing space-based telescopes such as IRIS and *Hinode*.

UC-257: Magnetic Field Evolution from the Photosphere to the Corona of a Large Active Region Complex (Lauren Doyle, Armagh Observatory and Planetarium)

The connection between the Sun's magnetic field and solar activity has been well established. Similarly, it is generally accepted the more complex the active region and sunspot configurations, there is an increased chance of flaring and the possibility of releasing a higher energy flare. By monitoring active regions on the Sun and extracting their magnetic field properties we can better understand the conditions needed for such high energy flares. In stellar physics, flares have been observed from solar-like and very low mass stars for many decades with observational evidence suggesting magnetic fields drive them. However, obtaining magnetograms of these stars is almost near impossible and so, the mechanisms for flare generation are still largely unknown. In order to gain an insight into the magnetic topologies and properties needed for high energy flares on these stars, we need to utilise the wealth of information which DKIST can provide.

UC-258: Wave Physics with Cryo-NIRSP (James McAteer, New Mexico State University)

UC-259: Oscillation of Filament Threads (Shuo Wang, New Mexico State University)

Solar filaments are composed of dynamic threads with width of ~ 0.2 arcsec. Motions of threads include oscillations in line-of-sight direction in Dopplergram, counter-streaming motion along thread direction, and sway motions in the direction perpendicular to thread on the CCD plane. We propose to use VTF to observe H-alpha for Dopplergram to find oscillations, and DL-NIRSP at 1083.0 nm to obtain magnetic fields information of the filament. Both active region filaments and quiescent filaments are of interest.

UC-260: Exploring Photospheric Center-to-Limb Doppler Velocity Variations with Height (Aleczander Herczeg, New Mexico State University)

Time-distance helioseismology allows for the mapping of flows in the outer ~30% of the Sun; namely, the meridional flow. This flow is a low velocity (~15 m/s) surface flow moving plasma and magnetic field from the equator to the poles, as well as a flow at the base of the convection zone returning plasma to the equator from the poles. Accurate measurements of the meridional flow profile are important for constraining models of the solar dynamo to predict activity cycles and understand the processes that build up magnetic fields at the tachocline. These time-distance measurements have been plagued by a systematic effect that, to first order, mimics a flow radially outward from the center of the disk. At high latitudes, this spurious "flow" can be an order of magnitude larger than the true meridional flow, introducing large uncertainties to the results. The current method for removing this effect is a simple subtraction method that does not rely on any physical understanding of the phenomenon, which is unsatisfactory. Additionally, this effect varies significantly and can even change sign depending on the observable used to measure it or the frequency of the waves being considered. In order to obtain accurate measurements of the meridional flow using the time-distance method, it is critical to understand the cause of this center-to-limb effect. As this effect has been considered a surface phenomenon, measurements of variations or correlations from the disk center to the limb will be made targeting specific spectral lines that probe different heights in the photosphere. From this data, trends or anomalies in the Doppler velocity signal as a function of line formation height will be studied to identify potential physical causes of this center-to-limb effect.

UC-261: The Magnetic Rayleigh-Taylor Instability in Quiescent Prominences (Thomas Rees-Crockford, Northumbria University)

The magnetic Rayleigh-Taylor Instability (RTI) allows insight into the temporal and spatial evolution of the magnetic fields and structures. The RTI is caused by the interaction of a relatively more dense fluid being accelerated through a relatively less dense fluid. Applying this to the solar atmosphere, the comparatively high density plasma of a prominence falling through the low density corona under gravity provides a source of material for the instability. The ability to resolve the fine detail of individual falling spikes and rising plumes of the two fluids interacting is a key part of the study of the instability, and why observations of the RTI are limited.

DKIST will allow us to observe this evolution not only in great detail and at sufficiently short cadence, but also in several important wavelengths that each provide key insights into the underlying magnetohydrodynamics.

UC-262: Transverse Wave Induced Kevin-Helmholtz Rolls in the Solar Atmosphere: Spicules (Patrick Antolin, Northumbria University)

Transverse MHD waves such as the kink wave and the torsional Alfvén wave are ubiquitous in the solar corona and are a major candidate for coronal heating. A large number of recent numerical studies indicate that dynamic instabilities associated to these waves, such as the Kelvin-Helmholtz instability (KHI), should be common, and that they could help to dissipate the wave energy. In the case of the kink wave, the mechanism of resonant absorption provides an additional energy source to the KHI, facilitating its detectability. Spicules are jet-like chromospheric structures protruding into the corona that usually exhibit strong transverse swaying and torsional motions, highly suggestive of transverse MHD waves. In a recent study, 3D MHD numerical models combined with radiative transfer indicate that Kelvin-Helmholtz rolls associated with transverse MHD waves (so-called TWIKH rolls) can explain several of the observed features in spicules: coherent strand-like structure in intensity, strong chromospheric intensity variations, Doppler velocities and line widths at high resolution, and ragged Doppler shift sign changes at maximum displacement accompanied by increased line widths. Supported by forward modelling, we here propose a DKIST science use case that aims at directly detecting the formation of TWIKH rolls, and better constrain the role of the KHI and resonant absorption in the heating of the spicule plasma and of its fate in the overlying corona.

UC-263: Height Dependence of the Photospheric Magnetic Field as Inferred from Inversions (Ryan Hofmann, University of Colorado, Boulder)

Magnetic field extrapolations are a crucial method to understand the magnetic topologies in the solar atmosphere. Such extrapolations are much more reliable if the input magnetic field is measured at a height in the atmosphere where the fields are primarily force-free. Otherwise, ad hoc corrections must be applied to account for plasma forces on the field. Therefore, it of significant importance to know at what heights the force-free approximation can be reliably applied. Previous efforts to address this question have been carried out by Metcalf et al. (1995), Tiwari (2012), and Liu et al. (2015) but the results remain inconclusive. Only Metcalf et al. used magnetic field measurements in the upper photosphere (using Na I 5896 Å) in order to characterize the magnetic field with height through the bulk of the photosphere.

We plan to observe multiple lines simultaneously and apply modern inversion techniques to more robustly measure the components of the vector magnetic field over a wider range of heights than has previously been determined. Analysis by Zhang et al (2017) suggests that this can only be achieved with the high signal-to-noise provided by the DKIST aperture. We will then use our results to determine the heights at which the force-free approximation is valid. This knowledge may guide future efforts to make routine vector field measurements higher in the atmosphere as the basis of more robust coronal field extrapolations.

UC-264: Study of Pseudo-Shocks in the Fine-Structured Sunspot Penumbra (Abhishek Kumar Srivastava, Dept. of Physics, Indian Institute of Technology)

Recently discovered pseudo-shocks (Srivastava et al., 2018) in the chromosphere/TR are a potentially new energy source which may power the Sun's active corona. The proposed study will use DKIST to search statistically for the presence of plasma ejecta possessing the pseudo-shocks above sunspot penumbra. The high resolution and high temporal multi-line imaging observations will be done by VBI-blue respectively in G-band 430 nm; blue continuum 450 nm; and Ca II K 393 nm in order to constrain the sunspot penumbra starting from the photosphere to the chromosphere. The VBI-blue (45" x 45") will cover the sunspot penumbra and its outer part, along with part of the umbra-penumbra boundary. We will also use the IR beam splitter configuration of DL-NIRSP with Ca II (854.2 nm), and Fe I (1565 nm) in a continuous polarimetric mode. The resolution mode f/24, 0.08" sampling will be used to observe a field of view slightly smaller than the VBI-blue field-of-view at high cadence. The DL-NIRSP observations will provide the information on I, V, and magnetic fields through Stokes profiles in the region of interest. Finally, we choose "Intensity mode" of the ViSP in three lines Fe I (617.3 nm); Mg I (517.3 nm), and Na D line (589 nm) in order to constrain the spectral line profiles at different heights above the observed sunspot penumbra. The proposed sequences will observe the multi-height/multi-temperature view of the sunspot penumbral region, and will also provide information on velocity and magnetic field structures between the photosphere and chromosphere, in order to understand the dynamics of the pseudo-shocks. The sunspot region should be towards the limb near the equator so that we could observe the plasma ejecta almost perpendicular to our LOS providing information on the evolution of the pseudo-shocks. The sweeping of the mass would be observed, and we will have the correlated analyses between density (thus intensity) enhancements, and their possible relations with the velocity and/or magnetic field variations that are not likely in the pseudo-shocks. The detailed observations on their detection will serve on refining our existing model, and help to understand their role in the overlying atmosphere above the sunspot.

UC-265: Statistical Search of the Wave Propagation in the Fine-Structured Flux-Tubes above the Plage Region (Abhishek Kumar Srivastava, Dept. of Physics, Indian Institute of Technology)

Plages are areas of high magnetic field concentrations on the Sun, which may be generally considered as the foot-points of numerous strongly magnetized magnetic flux tubes rooted in this region. If such finely structured and highly magnetized flux tubes could be observed at very high-resolution using DKIST, then new information will be gained on the waves and plasma dynamics within it. We will use high spatial (~20 km) and high temporal resolution observations (12-25 s) of the plage region near the solar disk for at least 1 hour in multiple observational modes, e.g., VBI-blue; DL-NIRSP; ViSP. It is expected that we will be able to resolve the tiny magnetic field concentrations in the plage region, and would be able to reconstruct the overlying magnetic field and nature of the magnetic fields. A statistical search will be made concerning the significant oscillations in these fine structured flux-tubes enabling a study of the wave propagation. The role of inhomogeniety, strength of the magnetic field, their inclination etc, will be studied in the context of wave propagation. In conclusion, the role of waves in terms of their energy transport in these fine structured flux tubes will be explored. Therefore the non-uniform heating aspects of the overlying TR and inner corona will be understood as the properties of the wave propagation will be different in the various finely structured flux tubes rooted in the plage region.

UC-266: Magnetic Fields in Limb Spicules with VTF (Nitin Yadav, Max Planck Institute for Solar System Research)

The solar chromosphere is an intricately structured and dynamic layer (~2 Mm) lying between the relatively cooler solar photosphere and the intensely heated transition region and solar corona. The chromosphere draws notably great research interests as the magnetic energy generated in the photosphere, heats the chromosphere and is channeled through the chromosphere before heating the plasma to coronal temperatures. Observations show that the chromosphere is highly dynamic with ubiquitous fine-scale structures. These structures are visible as dark mottles on quiet sun, as spicules on the limb and as elongated fibrils in the vicinity of magnetic network and active regions in chromospheric diagnostics. Due to their ubiquity, investigating the formation and evolution of these structures is crucial to the understanding of the chromospheric dynamics.

Despite their importance and ample observations, their origin, physical parameters, association with the magnetic field and their role in chromospheric heating is still unclear. Several models have been proposed to account for the origin of spicules viz. leakage of p-mode into the chromosphere, torsional Alfven waves or magnetic reconnection. However, the exact formation mechanism still remains unresolved due to insufficient spatial and temporal resolution. Vortices/swirls present an alternative physical hypothesis for the spicule formation that is worth investigation. Vortex motions have been observed over a wide range of spatial and temporal scales in recent years and are supposed to play an important role in energy and mass transport from the photosphere to the higher layers. Moreover, there are simulations and observational evidences which indicates the association of vortex/rotational motions with spicules.

The aim of this SUC would be to use the unprecedented imaging-spectropolarimetry capabilities of DKIST, to investigate if vortex motion is a necessary ingredient for the formation of spicules. If not, statistically what fraction of spicules are co-existent with vortices/swirls and vice-versa. We also aim to look for magnetoacoustic waves and shock signatures in spicules as magnetoacoustic shocks have been suggested as a possible driver of spicules in literature.

UC-267: On the Formation of Coronal Rain and the Tracing of Fundamental Processes in Coronal Loops (Patrick Antolin, Northumbria University)

Coronal rain is the main observable characteristic of thermal instability in the solar corona and is a common phenomenon of active regions. This recently rediscovered phenomenon constitutes a major coronal heating constraint due to its strong link to the spatiotemporal properties of the coronal heating mechanism in coronal loops. Furthermore, thanks to its cold temperature relative to the hot coronal background, it allows to trace at high resolution the coronal magnetic field and to capture physical processes in action, such as MHD waves and magnetic reconnection. One of the most puzzling features of coronal rain is its morphology: clumpy and multi-stranded. A few theories have been put forward to explain it, including the yet unobserved MHD entropy mode and the occurrence of Kelvin-Helmholtz and Rayleigh-Taylor instabilities. The formation of rain suggests the formation of fundamental magnetic strands in coronal loops, whose existence is a major debate. We here provide a DKIST science use case specifically tailored to capture the cooling of plasma from coronal down to chromospheric temperatures, the recombination process and the formation of coronal rain at the needed spatial, temporal and spectral resolution to solve these various major puzzles. Furthermore, we use DKIST at its highest capabilities in order to trace coronal heating mechanisms in action.

UC-268/269: How Far Off-Limb Can We Detect Type-II Spicules? Probing for Coronal Impact (Vasco Henriques, Rosseland Centre for Solar Physics, Institute of Theoretical Astrophysics, University of Oslo)

Type II spicules on-disk counterparts were demonstrated to have an impact on quiet Sun corona by Henriques et al. (2016), leading to intensity enhancements with the same lifetime and overlapping locations on AIA bandpasses FE IX 171 and He II 304. While a few striking events were published, including multiple frames showing multiple events of type II spicule counterparts leading to both 304 and 171 signatures (of which the best example is highlighted in Kuridze et al. 2016) the proof was statistical. Crucially, for this project, the same technique can be attempted in other low coronal signal contexts.

Signatures of off-disk type II spicules in AIA 304 were first detected by Pereira et al. (2014), who also find, together with Skogsrud et al. (2015), using IRIS data, that after fading from Ca II H filtergrams, spicules continue to evolve and show a downward phase in filtergrams sampling higher temperatures. This suggests rapid heating and that signatures following type II spicules should be investigate in the corona.

The vertical extent up to which the chromospheric emission itself can be detected remains unclear due to the scarcity of published attempts. Pereira et al. (2012) found a maximum extension of off limb type II spicules of 8 Mm with *Hinode*'s SOT Ca II H 0.1 nm filter. In order to know more about how much the quiet corona is impacted by the ever present type II spicules, knowing how far the cold material can extend should be explored with new telescopes and instruments, especially with narrower bandpasses, reducing the effects of straylight, and higher apertures that can simultaneously provide sufficient signal and resolution of these fine-scale short-lived features. Off limb observations sampling the lifetimes of type II spicules at chromospheric channels are rare, and attempts at matching these with coronal channels have only be performed with AIA which barely samples their lifetime (10 second cadences whereas type II spicules live for 50s and will evolve spatially).

UC-270: Electric Microfields in Solar Flares: The Broadening of Hydrogen Lines and Comparison to dMe Flare Spectra (Adam Kowalski, University of Colorado / National Solar Observatory)

The broadening of the hydrogen lines constrains the charge density and optical depth in the flaring chromosphere of the Sun. However, current solar instrumentation does not have the ability to constrain the broadening using the wings of the lines. New RHD models predict extreme broadening of the hydrogen lines due to the evolution of chromospheric condensations, but these models cannot be rigorously tested with current or archival data. A grid of high electron beam flux models has recently been calculated with the RADYN and RH codes, and accurate broadening methods are now included in these new models. We propose for high spectral resolution observations of flare kernels at DKIST's highest possible temporal and spatial resolutions to determine the mechanism that broadens the hydrogen lines in solar flares. These observations will constrain the maximum charge density attained in solar flare chromospheric condensations – is it a few x 1e13 cm-3 or as high as 5e14 cm-3? VISP wavelength windows provide enough coverage in the wings of the hydrogen lines to compare to the expected broadening in current models. The DKIST/VISP spectra will be compared to the optical spectral measurements of dMe flares for the first time. Our VISP observations employ two different setups: 1) H-gamma, H-epsilon+CaIIH, and 4170 continuum; and 2) H-alpha, Pa18, and Pa13+CaII. We aim to observe at least five flares with each setup and will coordinate with EOVSA, IRIS (if available), the DST (if available), and future proposed hard X-ray missions.

UC-272: Filament Magnetic Field for Space Weather Effects (Aparna Venkataramanasastry, Georgia State University)

The direction of the axial magnetic field of chromospheric filaments can be effectively used as a predictor for events that can have severe space weather impacts. Marubashi et al. (2015) and a statistical survey by the author of this use-case (in preparation) have shown a direct correlation between the interplanetary magnetic field (IMF) Bz at L1 and the direction of the axial magnetic field of the filaments on the Sun that caused the Earth-bound CMEs. The latter study involves obtaining the poloidal component of the axial field and the former uses flux rope fitting to obtain the axis. DKIST Spectropolarimetric observations will prove useful to improve the accuracy of such studies which will help better prediction of the location and magnitude of impact at the magnetosphere.

UC-273: Magnetic Field Gradients in the Lower Solar Atmosphere (Stephane Regnier, Northumbria University)

The physics of the photosphere and chromosphere is highly dependent on the amount of free magnetic energy stored in these layers. One mechanism to store magnetic energy is the existence of strong electric currents twisted and braiding the magnetic field. Currently, only the vertical component of the current density can be derived from the vector magnetic field. We propose a new modus operandi that will lead to the derivation of the full current density vector in the photosphere using the Fe I lines at 630.15 and 630.25 nm.

UC-274: Evolution of Plasma Properties Due to the Interaction of Magnetic Flux Tubes (Serena Criscuoli, National Solar Observatory)

The evolution of the magnetic field and plasma properties generated by the interaction of opposite polarity magnetic structures has been the subject of several investigations. Nonetheless, theoretical models predict that both plasma and magnetic field properties should vary even at sights of interaction of same-polarity features. Such phenomena have been rarely observed before, most likely because in the lower layers of the solar atmosphere they occur at spatial scales not resolved with current instrumentation.

UC-275: Investigating the Dynamics and Magnetic Transient Events in Solar Plages (Lakshmi Pradeep Chitta, Max Planck Institute for Solar System Research)

Plages in active regions are formed by a dense collection of unipolar magnetic field concentrations extending several tens of arcsec on the solar surface. They are the footpoints of bright chromospheric emission underlying coronal moss or fan-type loops. In support of earlier studies from Hinode, recent high-resolution observations from the Swedish 1-m Solar Telescope revealed pervasive small-scale transient events of magnetic flux emergence and cancellation in plages. Such transients could play an important role in the overlying chromospheric and coronal dynamics. The case for magnetic transients is strengthened by 3D radiation MHD simulations that exhibit flux emergence and cancellation down to the spatial scales accessible by the DKIST (~30 km).

We propose to exploit the capabilities of DKIST (in terms of its high spatial and temporal resolution), to investigate the impact of photospheric magnetic transients in plages on the chromosphere and corona. We will request coordination with IRIS for these observations.

UC-276: Coronal Magnetic Field of Active Region: A Combined DKIST and Radio View (Dale Gary, New Jersey Institute of Technology)

Radio spectral observations of gyroresonance emission provide direct measurement of the coronal magnetic field corresponding to harmonics of the gyrofrequency f = sf_B_MHz = 2.6 sB, where s is typically 3 for conditions in the active region corona. EOVSA's 1-18 GHz frequency range corresponds to a magnetic field range of 128 - 2300 G, i.e., strong field regions in active regions. This coordinated observation of off-limb emission will provide a direct comparison of coronal fields from radio measurements and Zeeman measurements of IR spectral lines. The two measurements are complementary, arising from completely different physical mechanisms and weighted differently in terms of where in the region the measurements are most sensitive. When possible, Jansky Very Large Array (VLA) observations will be used to provide additional microwave observations over the same 1-18 GHz range of frequencies.

UC-278: Investigation of Time-Dependent Phenomena in Pseudostreamers (Nathalia Alzate, Goddard Space Flight Center)

The solar wind contains signatures of the physical processes that heat the corona and accelerate the wind. Density variability is observed in the slow solar wind in the form of blobs and puffs and are tracers of solar wind formation. This variability is continuously produced in the highly dynamic streamer belt and pseudostreamers. The aim of this study is to trace the roots of the slow solar wind in pseudostreamers by taking advantage of the synergy between DKIST and space-based observatories. We aim to relate large-scale pseudostreamer activity to the lower atmosphere by correlating their coronal signatures to changes in the magnetic field topology. Specifically, we hope to (i) trace blobs down to the solar surface, (ii) observe changes in the chromosphere related to these structures, and (iii) establish whether or not systematic redshifts in UV lines are related to them.

UC-279: Sun-Grazing Comets as Probes to the Solar Corona (Wei Liu, Lockheed Martin Solar and Astrophysics Laboratory)

Comets are among the most pristine bodies within the solar system and can give critical clues for its formation and the origin of life on Earth. Sun-grazing comets, those with perihelion distances of less than a few solar radii, are extremely valuable. The intense solar radiation during their close perihelion passage can evaporate thick layers of near-surface material and thus expose their otherwise invisible, pristine interiors. Their high-speed intrusion into the million-degree hot, magnetized solar corona and, in extreme case, plunging into the solar interior, make them nature-made probes to the Sun, which is inaccessible to man-made instruments. Recent serendipitous detection and subsequent coordinated observing campaigns of sun-grazing comets by space missions and ground-based facilities have opened a new interdisciplinary subject for both solar and cometary sciences. A wide range of new phenomena, including the interaction of the cometary material with the coronal mass and magnetic field, are yet to be explored or discovered. DKIST, as the next generation solar telescope, will play a unique role in observing Sun-grazing comets and the solar atmosphere in which they travel, thus advancing both solar and cometary sciences in the decades to come.

UC-280: Thermal Instability and Magnetic Reconnection at Preferential Topological Locations (Wei Liu, Lockheed Martin Solar and Astrophysics Laboratory)

Thermal instability by radiative cooling is key to understanding the return flow of the chromosphere-corona mass cycle and the fundamental question of coronal heating. Such mysterious cooling condensations have recently been detected preferentially at certain topological location such as null points, where magnetic reconnection occurs and can potentially produce favorable conditions to trigger run-away radiative cooling. DKIST, with its superior spectral and spatiotemporal coverage and resolution, together with its unprecedented capability of measuring the coronal magnetic field, will play a unique role in solving the mystery of thermal instability preferentially developing at such special topological locations.

UC-284: Signatures of Interchange Reconnection in the Low Corona (Emily Mason, Catholic University of America)

Interchange reconnection (IR) is one of the foremost candidate mechanisms for slow solar wind creation, and it could also provide a significant energy deposition contribution to coronal heating. Despite this, a rigorous and observationally-derived IR frequency estimate has not yet been developed for the Sun either generally, or with respect to specific phenomena (i.e., active regions). This use case uses targets of opportunity in the form of null-point topologies on coronal hole borders, where the open/closed boundary provides highly favorable conditions for IR. Unique observational hallmarks of IR have been hard to find in the past, but using the spectropolarimetric instrumentation and high spatiotemporal cadence of DKIST, we plan to make direct observations of IR and find such hallmarks.

UC-285: Chromospheric Swirls and Their Interaction with Waves (Juie Shetye, University of Warwick)

UC-286: Type II Spicules and Solar Wind Transients (Jeongwoo Lee, New Jersey Institute of Technology)

Small-scale dynamics in the solar chromosphere are believed to play an important role in the energy balance and structuring of the corona as well as the mass transport in the solar wind, which is thus of interest to upcoming in-situ observations by Parker Solar Probe (PSP). Type II spicules at the solar limb are of particular interest in this regard because they show fast upward motion, rapid heating, and large vertical extent dominating the interface between the chromosphere and the corona. It has also been established that these jet-like structures have their on-disk counterpart in the large upward velocities identified in the blue wings of chromospheric spectra, so-called chromospheric rapid blueshifted excursions (RBEs). An urgent scientific question is whether type II spicules are related to any solar wind features to be detected by PSP. We also want to study which mechanism drives type II spicules among the candidate mechanisms including magnetic reconnection, Alfven waves, and field squeezing due to small-scale flux emergence. We propose to observe type II spicules at the limb using DKIST in collaboration with BBSO/GST and PSP, because such observations will help us to understand how heating and mass loading occur in the corona, and determine whether coronal jets are related to transients in solar wind.

UC-287: Measuring Coronal Vector Magnetic Field through Wave Observations and Spectropolarimetry (Hui Tian, Peking University)

Understanding the processes responsible for heating the solar corona to over 1 million Kelvin, as well as unveiling the mechanisms of various solar eruptions, are among the most important tasks in solar physics. The key to accomplish these tasks lies on precise measurements of the coronal magnetic field, since the magnetic field serves as the primary energy source of the solar corona. However, measurements of the coronal vector magnetic field are still unavailable. We propose to measure the coronal vector magnetic field through a combination of plane-of-sky (POS) magnetic field measurements based on coronal wave observations and line-of-sight (LOS) magnetic field measurements from spectropolarimetry. With an unprecedented high spatial resolution and sufficient signal-to-noise ratio (S/N), DKIST allows us to measure the coronal vector magnetic field for the first time.

UC-288: Coupling between the Photosphere and Upper Atmosphere in Light Bridges (Hui Tian, Peking University)

Many sunspots are divided by light bridges (LBs) into several parts. It is believed that light bridges are manifestations of magnetoconvection in sunspots. There are several types of substructures in light bridges, such as central dark lanes and dark knots. Meanwhile, observations of light bridges have revealed highly dynamic structures such as surges or jets in the chromosphere and transition region, which likely result from leakage of (magneto) acoustic waves or magnetic reconnection. The relationship between the small-scale photospheric structures and the dynamic chromospheric/TR phenomena in light bridges is still unknown. These small-scale structures and fast dynamics can be better resolved using unprecedented high-resolution DKIST observations. We will investigate the detailed evolution of small-scale structures in light bridges and their role in triggering various types of activities in the upper solar atmosphere using DKIST observations.

UC-289: On-Disk Observations of the Generation, Propagation and Heating of Spicules (Hui Tian, Peking University)

Spicules are ubiquitous jet-like structures observed in the solar chromosphere, and they may play an important role in the mass and energy supply to the corona and solar wind. Despite many observational and theoretical investigations of spicules, we still understand neither the generation mechanisms of spicules nor the energy transport processes associated with spicules. Photospheric convection and magnetic field evolution are likely the key to understanding the generation of spicules. Spicules have also been observed to carry MHD waves that may lead to substantial heating of the local plasma during their propagation. We propose to investigate the formation, upward propagation and heating process of spicules through the unprecedented high-resolution DKIST observations of the photosphere and chromosphere. We will also study the role of spicules in coronal heating using complementary data from Solar Orbiter/SPICE, SDO/AIA and IRIS.

Appendix B. Acronym Glossary

AAS	American Astronomical Society
ACE	Advanced Composition Explorer (NASA)
AFS	Arch Filament System
AIA	Atmospheric Imaging Assembly (SDO)
aka	Also Known As
ALMA	Atacama Large Millimeter Array
AR	Active Region
ASDA	Automated Swirl Detection Algorithm
ATST	Advanced Technology Solar Telescope (original name of DKIST)
AU	Astronomical Unit
AURA	Association of Universities for Research in Astronomy, Inc.
BAERI	Bay Area Environmental Research Institute
BDs	Bright Dots
BHU	Banaras Hindu University (Indian Institute of Technology)
BBSO	Big Bear Solar Observatory
CCD	Charge Coupled Device
CDS	Coronal Diagnostic Spectrometer (SOHO)
CH	Coronal Hole
CIRES	Cooperative Institute for Research In Environmental Sciences (CU-Boulder)
CMEs	Coronal Mass Ejections
CoMP	Coronal Multi-channel Polarimeter (HAO)
CRISP	CRisp Imaging SpectroPolarimeter (Swedish Solar Telescope)
Cryo-NIRSP	Cryogenic Near-IR Spectropolarimeter (DKIST)
CSP	Critical Science Plan
CU Boulder	University of Colorado, Boulder
DKIST	Daniel K. Inouye Solar Telescope (formerly ATST)
DL-NIRSP	Diffraction-Limited Near-Infrared Spectropolarimeter (DKIST)
DST	Dunn Solar Telescope
EB	Ellerman Bomb
ECFT	Elemental Coronal Flux Tube
EF	Evershed Flow
EIS	Extreme-ultraviolet Imaging Spectrometer (*Hinode*)
ESA	European Space Agency
ETH Zürich	Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology)
EUI	Extreme Ultraviolet Imager (Solar Orbiter)
EUV	Extreme Ultraviolet
FHNW	Fachhochschule Nordwestschweiz (University of Applied Sciences Northwestern, Switzerland)
FIDO	Facility Instrument Distribution Optics (DKIST)
FIP	First Ionization Potential
FISS	Fast Imaging Solar Spectrograph (BBSO)
FOV	Field of View
GONG	Global Oscillation Network Group
GSFC	Goddard Space Flight Center (NASA)

GST	Goode Solar Telescope (Big Bear Solar Observatory, California)
HAO	High Altitude Observatory
HMI	Helioseismic and Magnetic Imager (SDO)
HXR	Hard X-Ray
HXR	Hard X-Ray
IAC	Instituto de Astrofísica de Canarias (Spain)
IBIS	Interferometric BIdimensional Spectrometer (Arcetri Observatory)
IEF	Inverse Evershed Flow
IFU	Integrated Field Unit (McMath-Pierce Solar Telescope Facility)
IMaX	Imaging Magnetograph eXperiment (SUNRISE)
IMF	Interplanetary Mean Field
IRAP	Institut de Recherche en Astrophysique & Planétologie (Toulouse, France)
IR	Infrared
IRIS	Interface Region Imaging Spectrograph
IRIS SMEX	Interface Region Imaging Spectrograph Small Explorer Mission (NASA)
ISAS/JAXA	Institute of Space and Astronautical Science/Japan Aerospace Exploration Agency
ISEE	Institute for Space-Earth Environmental Research (Nagoya U., Japan)
ISIS	Integrated Science Investigation of the Sun (Parker Solar Probe)
ISON	International Scientific Optical Network
ISOON	Improved Solar Observing Optical Network
KHI	Kelvin-Helmholtz Instability
KIS	Kiepenheuer Institute for Solar Physics (Freiburg, Germany)
KP	Kitt Peak
LBs	Light Bridges
LCT	Local Correlation Tracking
LHT	Local Helioseismology Technique
LOS	Line Of Sight
MBP	Magnetic Bright Point
METIS	Multi Element Telescope for Imaging and Spectroscopy (Solar Orbiter)
MHD	Magnetohydrodynamic
MLSO	Mauna Loa Solar Observatory (HAO)
MOMFBD	Multi-Object Multi-Frame Blind Deconvolution
MSFC	Marshall Space Flight Center (NASA)
MSSL	Mullard Space Science Laboratory (UCL)
NAOJ	National Astronomical Observatory of Japan
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NIR	Near Infrared
NJIT	New Jersey Institute of Technology
NLFFF	Non-Linear Force-Free Field
NLTE	Non-Local Thermodynamic Equilibrium
NAOJ	National Astronomical Observatory of Japan
NORDITA	Nordic Institute for Theoretical Physics (Stockholm, Sweden)
NSF	National Science Foundation
NSO	National Solar Observatory
NST	New Solar Telescope (NJIT Big Bear Solar Observatory)

NUV	Near Ultraviolet
OCP	Operations Commissioning Phase (DKIST)
PFSS	Potential Field Source Surface
PHI	Polarimetric and Helioseismic Imager (Solar Orbiter)
PIL	Polarity Line Inversion
PJs	Penumbral Jets
PMOD	Physikalisch-Meteorologisches Observatorium (WRC, Davos)
POS	Plane-of-Sky
PRD	Partial Frequency Redistribution
PSP	Parker Solar Probe
QUB	Queen's University Belfast (Ireland, UK)
RBE	Rapid Blueshifted Excursions
RHD	Radiation-Hydrodynamical
RHESSI	Reuven *Ramaty High Energy Solar Spectroscopic Imager (NASA)*
RMHD	Relativistic Magnetohydrodynamics
ROSA	Rapid Oscillations in the Solar Atmosphere
RTI	Rayleigh-Taylor Instability
SCB	Sequential Chromospheric Brightening
SDO	Solar Dynamics Observatory (NASA)
SMEX	Small Explorer (IRIS)
SO	Solar Orbiter (see also SolO (official ESA acronym)
SOHO	Solar and Heliospheric Observatory
SOI	Solar Oscillations Investigations (SOHO)
SolO	Solar Orbiter (ESA)
SOLIS	Synoptic Optical Long-term Investigations of the Sun (NSO)
SOT	Solar Optical Telescope (*Hinode)*
SOT/SP	Solar Optical Telescope Spectro-Polarimeter (*Hinode*)
SOUP	Solar Optical Universal Polarimeter (*Yohkoh*)
SPICE	Spectral Imager of the Coronal Environment (Solar Orbiter)
SST	Swedish Solar Telescope
SSUB	Small-Scale Umbral Brightening
STEREO	Solar TErrestrial RElations Observatory (NASA Mission)ipc
STIX	Spectrometer Telescope for Imaging X-Rays (Solar Orbiter)
SUC	Science Use Case
SUMER	Solar Ultraviolet Measurements of Emitted Radiation (SOHO)
SW	Solar Wind
SWA	Solar Wind Analyzer (Solar Orbiter)
SWEAP	Solar Wind Electrons Alphas and Protons (Parker Solar Probe)
SWG	Science Working Group (DKIST)
SXR	Soft X-Ray
TAW	Torsional Alfvén Waves
TB	Tera Bytes
TRACE	Transition Region and Coronal Explorer
TWIKH	Transverse Wave Induced Kelvin-Helmholtz
UCL	University College London
UDs	Umbral Dots
UFs	Umbral Flashes

UK	United Kingdom
UV	UltraViolet
VBI	Visible-light Broadband Imager (DKIST)
VCA-NLFFF	Vertical Current Approximation Nonlinear Force-Free Field
ViSP	Visible Spectropolarimeter (DKIST)
VLA	Very Large Array
VSM	Vector SpectroMagnetograph (SOLIS)
VTF	Visible Tunable Filter (DKIST)
VTT	Vacuum Tower Telescope (Tenerife, Spain)
WISPR	Wide-Field Imager (Parker Solar Probe)
WL	White Light
WSO	Wilcox Solar Observatory
XRT	X-Ray Telescope (*Hinode*)