Project Documentation
Document SPEC-0036
Rev D

Operational Concepts Definition Document

Alexandra Tritschler
Science Group

Robert P. Hubbard
Systems Group

June 2019

REVISION SUMMARY

1. Date: 1 June 2008 - 30 April 2009
Revision: A
Changes: Initial Release

2. Date: September 2009
Revision: Draft A1
By: Rob Hubbard and Bret Goodrich.
Changes: Added Section 4.6, Daily workflow for science and engineering operations at the summit (RH). Modified definition of administrator actor and added NSO DL actor (BG). Added use case section, including derived concepts (RH, BG). Added a requirement to push down JPEG images in a timely way to support remote participation.

3. Date: February-June 2010
Revision: Draft A2
By: Alexandra Tritschler
Changes: Restructuring and rewrite.

4. Date: July-August 2010
Revision: Draft A3
By: Alexandra Tritschler and Rob Hubbard.
Changes: Modifications related to the parallel operation of multiple instruments. Elimination of the requirement to perform two experiments at the same time. Addition of the requirement for abort, cancel and pause. Automated aspects of an experiment added to the text. Clean-up of text.

5. Date: 4-6 August 2010
Revision: Draft A4
By: Alexandra Tritschler and Rob Hubbard.
Changes: Modifications based on the teleconference August 2nd, 2010.

6. Date: June 2011
Revision: B
By: Alexandra Tritschler.
Changes: Implementation of observing model, science operations, technical operations.

7. Date: September 1, 2011
Revision: Draft B1
By: Alexandra Tritschler.
Changes: Minor corrections and typo fixes from Draft 6

8. Date: Summer-Winter, 2012
Revision: Draft B2

By: Alexandra Tritschler.
Changes: Description of operations lifecycle, experiment lifecycle, proposal lifecycle, interactions with the major ATST systems, description of the functionality of “OCS Operation GUIs”, instrument failure, examples of science operations.

9. Date: June 2013
Revision: C
By: Alexandra Tritschler.
Changes: Changes due to Project Scientist and Systems Engineering review. Minor correction of typos, changes of terminology to align with OCS specification. Addition of procedures and functionality involved for calibrations, target definition and AO lock point definition, addition of a short description of the facility control system, description of functionality of “Wave-Front Correction System GUI”, “Instrument Control System GUI”, and “Facility Control System GUI”. Red text color introduced by PS calling out ATST construction requirement sections and/or text. Initial formal release of document.

10. Date: June 2019
Revision: D
By: Alexandra Tritschler.
Changes: Changes as defined in CR-0960 submitted to the Change Control Board (CCB) and approved 20-Mar-2020.

Table of Contents

1 Overview

1.1 Scope

This document describes the operational concepts for the Daniel K. Inouye Solar Telescope (DKIST) formerly called the Advanced Technology Solar Telescope ATST). The document describes the environment in which the DKIST is envisioned to operate, and describes DKIST specific operational characteristics and procedures exemplified by operational and observational scenarios. This document elaborates on operational concepts for (a) the DKIST summit facility and (b) potential remote operations conducted from the Remote Office Building (ROB) located in Pukalani, Maui.

1.2 Purpose

The Operational Concepts Definition (OCD) document identifies and places requirements on DKIST system components and thus provides traceability for design decisions. In addition, the OCD serves as a medium to achieve general agreement between stakeholders on the concepts themselves and the consequential design requirements. Last, not least, the OCD forms the basis for long-term planning of DKIST operations.

1.3 Audience

The OCD addresses potential customers and users of the observatory (scientists, instrument builders/developers, operations staff, etc.), system engineers, software developers, but also contractors, architects and sponsors.

1.4 Sources

The concepts defined in the OCD derive from various sources. Many of the high-level concepts and the consequential design requirements trace back directly to the DKIST Science Requirements Document (SPEC-0001, SRD). Significant concepts also derive from careful study and rationalization of workflows, operational practices and observing procedures performed at current ground-based (solar) facilities. The exploration of the life cycle of proposals (solicited observing requests (imagined to be executed at the DKIST). Much of the information was extracted through interaction with the NSO and DKIST scientific staff, the DKIST science working group, the instrument development partners, users of the current generation of solar telescope and taking into account the new opportunities and constraints specific to the DKIST (e.g., site characteristics).Some concepts trace back to Common Engineering Practices and standards.

1.5 Referenced Documents

- SPEC-0001, *ATST Science Requirements Document.*
- SPEC-0061, *ATST Hazard Analysis Plan.*
- SPEC-0122, *DKIST Data Model.*
- SPEC-0133, *ATST Hazardous Zones Fully Automated Control Access.*
- TN-0094, *Environmental Conditions on Haleakalā.*
- Rimmele, T.R. et al. 2005, *Advanced Technology Solar Telescope: a progress report.*

- *Uitenbroek, H., 2006, Evaluation and Selection of Solar Observing Programs.*
- OPS-OT-SPEC-002, *Operations Concepts Definition for the DKIST Operations Tools.*

1.6 Definitions

Change-Over Time	Time spent on changing (a) the configuration of an instrument from one Experiment to another Experiment or (b) the light distribution to the instruments from one coudé room configuration to the next configuration including the switch from on-disk to coronal observations.
Data Set	Individual images or spectra that are closely associated and kept together. The recorded outcome of an Observing Program.
Data Set Parameter	DKIST Data Set Parameters (DSP) are keywords (CSF attributes) and their values that in combination with an instrument-level control script completely control the activities of an instrument during execution of the instrument-level control script (see SPEC-0122). A DSP is the smallest contributing building block of an Instrument Program. Conceptually, a DSP results in the smallest data set that is still of (scientific) value.
Data Set Parameter Sequence	A DKIST Data Set Parameters Sequence (DSPS) is an ordered combination of DSP's or subgroups of DSP's over which can be iterated/looped/cycled respectively. One Instrument Program contains one DSPS.
Data Product	A single unit of science observation produced by an instrument. For imaging instruments (including tunable filters instruments), a data product is a single image or a group of images (a scan) processed into a single final image such as e.g. a magnetogram or a dopplergram. For slit-based instruments, a data product may be a single spectral line region image (a spectrum) or it may be a map of the spectral region over an area on the Sun (a map).
Downtime	Time that the telescope is not operational because of un-predicted mechanism failures, scheduled repairs and/or maintenance/engineering procedures and weather conditions.
Experiment	A DKIST Experiment includes all activities (automated and non-automated) that are involved in its implementation (i.e. translation of a Proposal into an Experiment and its components that can be automatically executed), quality assurance, execution and completion thereof, and all outcomes that may result from those activities (e.g. parameters, programs, scripts, collected data). A DKIST Experiment is derived from one approved DKIST Proposal.
Facility Instrument	Instrument that is permanently installed and fully integrated into the DKIST control system architecture (OCS, ICS, CSS, and DHS) and has the full Common Services Framework (CSF) functionality based on the common services framework (CSF). DKIST operations staff operates and maintains facility instruments. Facility instruments are available to all Investigators during the Proposal process.

Guaranteed Time	Guaranteed Time is time that arises from contractual obligations of DKIST/NSO with organizations having provided software, hardware or other. Guaranteed Time can be executed in Service Mode or Access Mode or as defined in the contract otherwise.
Header Information	Information about an image or a data set that is relevant for calibration, processing and diagnosing purposes. Synonymous with metadata.
Instrument	Device to record scientific data.
Instrument Performance Calculator	Software tool or application allowing Investigators to get familiarized with the capabilities of a Facility Instrument and providing support during the proposal preparation phase.
Instrument Program	DKIST Instrument Programs are part of Observing Programs. Instrument Programs encode the actions to be taken by the individual instruments pertaining to that particular Observing Program. Instrument Programs are executed by instruments. Observing Programs can include sequences of one or more Instrument Programs for each requested instrument.
Instrument Program Sequence	A DKIST Instrument Program Sequence (IPS) is an ordered combination of Instrument Programs for an individual instrument. One Observing Program can contain multiple IPS's for the same instrument.
Instrument Program Task	A DKIST Instrument Program Task refers to a specific category of instrument measurements and the activities leading to those measurements. Instrument Program Tasks are focus, align, dark, gain, polcal, telcal, wavecal, scatteredlight, target, transmission. One Instrument Program pertains to one Instrument Program Task. The Instrument Program Task can differ from the Observing Task of the Observing Program.
Instrument Set	A DKIST Instrument Set is the combination of instruments operated in parallel during an observation. The Instrument Set is identified in the DKIST Proposal. One DKIST Proposal can contain more than one Instrument Set. One Observing Program can contain more than one Instrument Set.
Must-Complete Instrument	A must-complete instrument is an instrument that is essential for the pursuit and fulfillment of the science goal of a DKIST Proposal. The must-complete instrument is identified in the DKIST Proposal by the Investigators during Proposal Preparation. The Investigators of a DKIST Proposals can identify more than one must-complete instrument
Observation	Activity of recording specific data sets with scientific instruments. The term may also refer to any data collected during this activity and as such can be used to define the data type. Observing task is a synonym.
Observing Program	A DKIST Observing Program is comprised of Observing Program parameters, an Observing Program script and a set of keywords (CSF attributes) and their values that in combination with the Observing Program script completely control the activities of the telescope, its subsystems, WFC and the instruments. Observing Programs are the building blocks of a DKIST Experiment and the basic scheduling units for the DKIST Observatory

	Control System (OCS). The OCS executes Observing Program scripts. Observing Programs are dedicated to and associated with a specific Observing Task.
Observing Task	A DKIST Observing Task refers to a specific category of measurements and the activities leading to those measurements. Minimum standard Observing Tasks are focus, align, dark, gain, polcal, telcal, wavecal, scatteredlight, target, transmission. One Observing Program pertains to one Observing Task.
Principal System	Main observatory control systems including the observatory control system (OCS), telescope control system (TCS), instrument control system (ICS), data handling system (DHS), and the facility control system (FCS).
Proposal Cycle	The Proposal Cycle refers to a defined period of time during which the proposal (and experiment) lifecycle activities are accomplished.
Proposal	A DKIST Proposal is a solicited document outlining all details sufficient to generate and perform a DKIST Experiment. A DKIST Proposal is prepared by Investigators applying for the allocation of telescope time.
Proposal Program	Type of program under science operations specified in a DKIST Proposal (i.e. standard, synoptic, Target of Opportunity).
AO-Optimized Instrument	The AO-optimized instrument (see also DKIST documentation SPEC-0036 and SPEC-0129) is an instrument that benefits from a correction of any pre-determined wave-front degradation introduced by static imperfections in NCP optics (including the instrument's internal optics) located optically after the beamsplitter that diverts light into the Wave Front Correction system (WFC-BS1).There can be only one AO-optimized instrument or none. The PI identifies one AO-optimized instrument (during Proposal Preparation or Proposal Finalization) or choses to have none. The choice of an AO-optimized instrument comes with the risk of degrading any other instrument's optical performance participating in the Experiment.
Repository	Permanent storage system capable of retaining data for later retrieval.

1.7 Abbreviations and Acronyms

ACS	Acquisition Control System
AMO	Access Mode Observing
AO	Adaptive Optics
aO	active Optics
ATST	Advanced Technology Solar Telescope

CSS	Camera Software System
Co-I	Co-Investigator
DHS	Data Handling System
DKIST	Daniel Ken Inouye Solar Telescope
DM	Deformable Mirror
DSP	Data Set Parameters
DSPS	Data Set Parameters Sequence
DSSC	DKIST Science Support Center
DST	Dunn Solar Telescope
ECS	Enclosure Control System
FCS	Facility Control System
FIDO	Facility Instrument Distribution Optics
GIS	Global Interlock System
GISS	Global Interlock System Status
GOS	Gregorian Optical System
HOAO	High Order Adaptive Optics
ICS	Instrument Control System
IP	Instrument Program
IPC	Instrument Performance Calculator
LOAO	Low order Adaptive Optics
MCS	Mount Control System
M1CS	M1 Control System
NSO	National Solar Observatory
OCD	Operational Concepts Definition
OCS	Observatory Control System

OP	Observing Program
OT	Operations Tools
PA&C	Polarization Analysis & Calibration
PI	Principal Investigator
QA	Quality Assurance
SRC	Science Review Committee
SMO	Service Mode Observing
TAC	Time Allocation Committee
TEOA	Top End Optical Assembly
TRC	Technical Review Committee
TCS	Telescope Control System
TN	Technical Note
ToO	Target of Opportunity
TTM	Tip-Tilt Mirror
WFC	Wave-Front Correction
WFS	Wave-Front Sensor

2 Operational Guidelines

The DKIST will be the largest and most capable solar telescope in the world. The DKIST replaces the 0.8 m and 1.5 m class general purpose solar telescopes, built in the 1960's and 1970's operated by the National Solar Observatory (NSO), and complements and provides support and context observations for existing and future space missions.

The DKIST will serve the US and international solar physics community for decades. As such it is required to be an observatory that allows for the flexibility to address a large number of diverse scientific questions in the most efficient way not only during the first years of operations but also in the long term. In order to sustain this flexibility and fulfill its mission, the DKIST must be able to adapt and respond to new scientific challenges that may potentially involve a new technological environment in a reasonable period of time.

"Ground-based telescopes have observed the Sun for more than a century. Our close vantage point allows studying details on the solar surface for which the involved timescales are of the order of seconds to minutes. Hence, many new and scientifically important discoveries are now mostly achieved based on unique data sets that are the result of observing the Sun in a different way than before, i.e., new instruments, different wavelengths, higher cadence, higher spatial resolution, new data reduction techniques, etc." (Uitenbroek, 2006).

The DKIST therefore must offer not only a diverse suite of solar instrumentation, but also allow for a flexible configuration and combination thereof, without compromising efficient and reliable operations. It should be noted that this constitutes one of the reasons for the remarkable differences between the operations of solar and nighttime observatories. For the latter still mostly permanent instrument configurations are in use and target availability does not play the same crucial role for day-to-day operations as in operations of a solar observatory. Typically, instruments are operated one at a time instead of in combined complex multi-instrument configurations. This is very different when the Sun is observed. Observations taken at different times observe evolved solar structure subjected to different observing conditions that can only be compared in a statistical sense. It is impossible to go back to the identical target at a later point in time and gather additional information. In this perspective solar observations suffer from the consequences of both, an inevitable intrinsic (target availability, observing conditions) and an operational (e.g., sequential fixed scheduling of observing programs) inefficiency.

In order to guarantee that the DKIST can sustain and fulfill its long-term objective, the following conceptual strategies are introduced. .

2.1 Efficiency

The purpose of the observatory is to observe the Sun and acquire high quality and high impact scientific data. In order to achieve this purpose efficiently, the DKIST will perform community driven science guided and directed by solicited competitively peer-reviewed observing requests (Proposals) that are prepared, planned and executed taking every possible advantage of good observing conditions and solar target availability while at the same time preparing for the technical readiness (in the short and long-term) to do so. Specifically the latter has different needs, often driven by necessity involving different resources.

2.1.1 Science

The community and its members directly guide DKIST science and all observations performed at the observatory. This guidance is communicated through solicited observing requests (Proposals) prepared by community members (proposal investigators). The DKIST will adopt a fixed length Proposal Cycle that governs science operations and will at least on a biannual basis ask for input and send out a call for proposals (i.e. the solicitation cycle is 6 months). Investigators will use an integrated proposal tool consisting of a graphical user interface facilitating proposal preparation and submission. The DKIST will accept proposals during a defined submission window. All submitted Proposals are subjected to a competitive peer review for scientific merit and technical feasibility to assure that the DKIST is exploited to its best potential. The outcome of this review will be a ranked list of approved DKIST Proposals that is reconciled with the estimated available observing time for the upcoming cycle.

The DKIST Science Requirements Document (SPEC-0001, SRD) describes science that the DKIST will address. The present document in Section 7 describes some examples of observing scenarios supporting the science described in the DKIST Science Requirements Document.

2.1.2 Operations Model

Driven by the different needs and resources involved in the preparation for technical readiness (in the short and long-term) versus the preparation and execution of science observations the DKIST distinguishes between two types of operations: *Science Operations* (SciOps) and *Technical Operations* (TechOps).

Science operations encompasses all activities that (a) plan and prepare for solar observations and data acquisition, whether performed external to the summit (Science operations Planning and Monitoring) or at the summit (Observatory Operations), and (b) monitor all such operations. Specifically for science operations, the DKIST offers two different observing modes for Investigators: *Service Mode Observing* (SMO) and *Access Mode Observing* (AMO). Observing modes specify how observations are scheduled and carried out. Under each observing mode, the DKIST offers different program types from which the Investigator can choose, including: *regular/standard*, *synoptic*, and *Target of Opportunity (ToO)*. For further details, see Section 3.1 and 3.2.1,

Technical operations encompasses all activities supporting technical readiness (short and long-term) and the longevity of the observatory (maintenance and engineering). Technical operations by nature are performed at the Observatory. The DKIST is far more complex than currently operated ground-based solar facilities. Maintenance and engineering efforts will play a far more important role and need stronger support and thorough planning. For Technical operations, the DKIST therefore implements plans for performance monitoring, preventive maintenance, engineering and planned downtime.

The DKIST plans Science operations on a long-term (6 months), medium-term (1-3 months), and short term (days to week(s)) basis. The long-term planning is driven by the length of the solicitation cycle. The medium-term planning is driven by co-observing (see, Synergies), access mode, coudé laboratory preparations (see, Standard FIDO and DHS Configurations), and specific calibration planning. The short-term planning is driven by the Sun (solar changes) and weather conditions.

2.1.3 Synergies

Current solar ground-based observatories regularly support and co-observe with other observatories and missions (coordinated observations). These co-observing efforts benefit the science goal, specifically if additional wavelength information and/or time coverage is needed. It is expected that the DKIST will be requested to co-observe with other observatories or missions on a regular basis. The DKIST allows and supports these co-observing efforts. The DKIST will coordinate such co-observing efforts on the Proposal, i.e. Experiment level (not on a lower level, no synchronization on exact start time, see also Sect. 8.7).

2.1.4 Proposals and Experiments

All Science Operations and their related observations science operations are directly traceable back to an approved DKIST Proposal. An approved Proposal contains all information necessary to perform an Experiment with the DKIST. A DKIST Experiment includes all activities (automated and non-automated)that are involved in its implementation (i.e. translation of a Proposal into an Experiment and its components that can be automatically executed), quality assurance, execution and completion thereof, and all outcomes that may result from those activities (e.g. parameters, programs, scripts, collected data) ADKIST Experiment is derived from an individual approved Proposal and as such will contain a reference (e.g. proposal identifier) to the relevant approved Proposal. It should be also mentioned that some technical operations if related to facility calibration measurements additionally need to be traceable in time.

An Experiment is logically built using a hierarchical approach where each Experiment contains a sequence of *Observing Programs* each fulfilling a Observing Program Task and defining what the telescope and its subsystems have to perform, where each Observing Program contains Observing Program parameters and sequences of *Instrument Programs* for each requested instrument and each fulfilling an Instrument Task defining what the instruments have to accomplish, and where each Instrument Program contains Instrument Program parameters and a sequence of *Data Set Parameters* each allowing for different instrument parameter settings. Observing Programs can be executed in any order chosen by the user (sequential is one option) while all Instrument Programs associated with the same Observing Program are performed as controlled by the Observing Program and all Data Set Parameters associated with the same Instrument Program are performed as controlled by the Instrument Program. Experiments are further described in Section 4.3 Experiments at the Summit in this document.

2.1.5 Instrumentation Suite

The DKIST is required to address a large number of diverse scientific questions (see SPEC-0001, SRD) with each likely emphasizing distinct layers of the solar atmosphere, with structures of different sizes and evolutionary time scales and/or the connectivity amongst those. As such the DKIST must offer an adequate suite of solar instrumentation composed of but not solely restricted to two-dimensional imaging instruments and slit-based instruments where each instrument is capable of multi-wavelength observations (either sequential or at the same time). A sensible mixture composed at a minimum of both instrument categories each operating in *wavelength ranges* that allow probing the solar atmosphere from the photosphere up to the chromosphere or even corona making use of the individual capabilities of the instrument will be crucial for the success of the DKIST. Furthermore, the detection of polarized light to determine the strength and orientation of the magnetic field throughout the solar atmosphere in general and in the corona in particular is a major scientific driver of the DKIST. It is therefore necessary that the instrumentation suite features spectropolarimetric and coronal capabilities.

The following instruments should be available (see also SPEC-0001):

- Two-dimensional imaging instruments:
    - Broad-band imager: imaging instrument using comparably broad filters operated at visible wavelengths probing photospheric to chromospheric layers.
    - Tunable narrow-band imager: tunable imaging spectrometer and spectropolarimeter operated at visible wavelengths probing photospheric to chromospheric layers.
- Slit-based instruments:
    - Visible/near IR spectrograph: slit-based spectrometer and spectropolarimeter operated at visible and near-IR wavelengths probing photospheric to chromospheric layers.
    - Near-IR/SWIR polarimeter and spectrometer: slit-based cold spectrometer and spectropolarimeter operated in the near to short-wavelength IR probing coronal layers off-limb and photospheric to chromospheric layers on disk.

At a minimum the individual instrument categories should be able to perform the following activities:

- Two-dimensional imaging instruments:
    - Broadband channel: sequentially scan $L \geq 1$ times through $N \geq 1$ filters and take up to $M \geq 1$ images per filter.
    - Narrowband channel: sequentially scan $L \geq 1$ times through $N \geq 1$ filters, tune through $K \geq 1$ wavelength points and take up to $M \geq 1$ images per wavelength point.
- Slit-based instruments:
    - Sequentially scan the solar surface $L \geq 1$ times with $N \geq 1$ steps, a slit width ΔW, a step width ΔN and take up to $M \geq 1$ images per slit position in possibly more than one wavelength region.

2.1.6 Multi-Instrument Operations

It is expected that many proposals will ask for the use of more than just one instrument at the same time to obtain larger wavelength coverage and/or make use of different instrument capabilities. Therefore, the DKIST will support the parallel operation of multiple instruments. All instruments that are part of the same experiment are called an “instrument set” (see Section 9.5).

During a multi-instrument Experiment all participating instruments share the telescope. This simple fact has some major implications. A very important implication is safety. It is required that neither a single instrument nor the instrument set will have control over the telescope or any of its subsystems like secondary focus devices or the wavefront correction (WFC) system. The telescope is controlled from a level higher than the instruments (i.e. the Observatory Control System).

The use of multiple instruments in parallel sharing the light beam may result in that not all instruments will achieve the same optical quality as if operated individually. Thus, the DKIST will support the PI to identify one (or none) *WFC or AO optimized instrument* for which the DKIST will make an attempt to achieve the same optical quality as if operated individually.

Furthermore, the DKIST will address the following in the context of multi-instrument operations: (1) how is the light distributed to the instruments, (2) how are all those instruments prepared and configured for operation in an optimum way, (3) when do instruments start data acquisition and how are the instruments temporally coordinated during operations (i.e. an observation), (4) what defines the completion of an experiment, (5) what happens when one instrument or instrument component that is part of a multi-instrument experiment fails during an active experiment, (6) how is the complementary data (i.e. calibration data and metadata) acquired and allocated to the actual science data?

2.1.6.1 *Light Distribution to the Instruments*

The DKIST will make available a combination of mirrors, windows and dichroic beam-splitting elements that allow feeding multiple facility instruments at the same time with light that is within the wavelength range that they were designed for. As the individual instruments operate in overlapping wavelength ranges this *Facility Instrument Distribution Optics* (FIDO) will either direct all light in a specific wavelength range or no light to a facility instrument (no sharing of the same wavelength range amongst individual facility instruments) to make optimum use of the instruments individual capabilities. The FIDO will also allow directing all light to a selected facility instrument and no light to the remaining facility instruments. The FIDO is required to be configurable to allow for (the maximum of) combinatory flexibility. The FIDO will adopt a standardized unambiguous and intuitive naming scheme for its FIDO configurations.

2.1.6.2 *Observing Tasks*

Based on current experience and practices, all instruments perform similar activities driven by very common needs on a typically daily basis (depending on the instruments stability). The DKIST categorizes these common activities into specific *Observing Tasks* or just *Tasks*. Tasks provide a simple measure for the activities that are expected from the telescope to support those instrument activities and the type of data that is produced as an outcome of all of those activities. The following Tasks are identified:

- Align: record data utilized to center the instruments FOV on a reference.
- Focus: record data utilized data to focus the instrument.
- Dark: record data utilized to calibrate for dark current and false light contributions
- Gain: record data utilized to calibrate for transmission inhomogeneity of the detector.
- Observe: record science data.
- PolCal: record data utilized to calibrate for the influence of non-solar polarization (cross-talk) introduced by non-common and common path optics not part of the telescope optics (mostly light distribution optics, WFC optics and instruments themselves.).
- Target: record data utilized to determine detector image scale and relative orientation between data from different instruments.
- ScatteredLight: record data that allows calibrating for background and scattered light contributions.
- Transmission: record data that allows to calibrate for the variation of the spectral transmittance of a, for instance, band-pass filter (important for instruments where the spectral FOV is only a few Angstroms).

- WaveCal: record data utilized for determination of a wavelength reference and wavelength scale.
- TelCal: record data utilized to calibrate for the influence of non-solar polarization (cross-talk) introduced by common path telescope optics.

For further additional information related to these Tasks see Section 6.

For efficiency purposes, the DKIST will coordinate and combine instruments during these Tasks as much as possible. This approach should not prohibit that the activities coupled to a specific Task can be initiated and accomplished for each instrument individually and independently, if necessary.

It is important to re-emphasize that while those Tasks ideally should be fulfilled jointly by all instruments, in practice this will be very difficult to achieve. Some instruments may prefer to perform individual Tasks in very different or even multiple ways requiring a different activity of the upfront optics so that the light beam cannot be shared anymore by all instruments. A very good example may be the approach taken on how to record the so-called flat fields during the “gain task”. Some instruments may prefer a flat-field lamp (upfront or internally) others may prefer having the solar image move across the detector, others may need both. As a consequence, it is necessary that any Task can be fulfilled by an individual instrument following its individual approach independently from all other instruments whenever needed.

2.1.6.3 *Preparation for Multi-Instrument Operation*

Multi-instrument operations can require substantial time needed for setup of the instruments (e.g. focus task, align task) on a per Experiment basis. Hence, the DKIST should strive for minimizing that time by performing those activities as efficiently as possible, i.e. sensibly coordinated and to the extent possible when conditions are not optimum for science observations (i.e. during clouds and standby conditions, prior elevation limit for opening is reached, and after sunset). Particularly, preparatory activities for a specific Experiment and its requested instrument combination (that do not require a re-configurations of FIDO) should be to the extent possible and practical executable without sunlight before or right after sunrise whenever possible depending on the details of the activity and its time consumption.

2.1.6.4 *Start of Data Acquisition*

The instruments have to be operated concurrently and coordinated not only with the telescopes activities, but also with each other. This temporal coordination occurs on different temporal levels and depends on the circumstances under which the instruments are operated. For most known science applications it is sufficient that instruments start jointly without tight inter-instrument coordination enabled (coordinated level). Sometimes, however, the science goal requires that tight and accurate time limits on the inter-instrument coordination are enabled (synchronized level). The DKIST on a best effort basis will support also the latter option.

The data acquisition of individual instruments as initiated by the submission and execution of an Observing Program, should start without any delays because instruments still have to perform tasks in order to get into a ready condition. All those tasks should be completed already (the instruments are pre-configured). The start signal should be passed to the instruments within less or equal 1 second. If needed, instruments should be able to start within 5 milliseconds from each other once they have received the start signal (synchronized level).

For all of the above mentioned it is crucial that all DKIST systems adhere to the same time. It is therefore that the DKIST adopts a time standard and make available a standard reference time service that all clocks are synchronizing with.

2.1.6.5 *Calibration Data*

All science data requires calibration data. The acquisition of calibration data is time consuming, specifically if multiple instruments are involved. The DKIST strives minimizing that time by performing all related activities as efficiently as possible through combining the instruments (if applicable) during those calibration activities and diverting the execution of those activities to the extent possible to conditions that are not optimum for science observations. The latter does imply that it should be possible to perform those activities potentially without sunlight (i.e. during clouds and standby conditions, prior elevation limit for opening is reached, and after sunset).

2.1.6.6 *Instrument Failure*

Inn case that an instrument or instrument component that is part of an instrument set fails during the execution of an Experiment’s Observing Program and its respective script, the Observing Program script execution will continue by default (and so will the Instrument Program execution of the failing instrument) while a warning, health or alarm notification (depending on the severity) is generated. Manual intervention is required to either abort or cancel the entire Experiments Observing Program or the failing instrument and its Instrument Programs only. Specifically, if the failing instrument is an instrument that is essential for addressing the Proposals/Experiments science objective, the Experiments Observing Program should be cancelled or aborted and repeated at a later point in time (or regulated by policy otherwise). Instruments that are essential and crucial for the science objective of the Experiment (and Proposal) will be identified by the Proposal PI as must-complete instruments on the Proposal.

Although the DKIST makes attempts to minimize down time caused by failures of hardware or software components of any of the DKIST systems or devices (including individual instruments) by implementation of monitoring and preventive maintenance programs, failures cannot be avoided from happening. Therefore, it is important to clarify, for instance, the fate of potentially incomplete data sets, the respective tagging of the data, the possibly repetition of an experiment, and in general when can an experiment be considered as completed under such unusual circumstances and who is the authority involved in the decision process.

In the following, the focus is on incidents where individual instruments (or instrument components) fail during an active experiment. Failures can be either temporary or permanent relative to the expected duration to perform the relevant experiment. A criterion helping to decide whether the Experiment can be considered as completed or not is based on whether the failing instrument is a must-complete instrument or not. A must-complete instrument is identified in the DKIST Proposal by the Investigator as being crucial for the science goal of the Proposal. There can be more than one instrument identified as a must-complete instrument.

- ***Failure of a must-complete instrument***: if a must-complete instrument fails during an Experiments Observing Program execution, the Observing Program is cancelled and re-executed if possible (or as regulated by policy).

- ***Failure of a non-must-complete instrument***: if a non-must-complete instrument fails during an Experiments Observing Program execution, the Observing Program is continuing its execution until the must-complete instrument or instruments have completed (or as regulated by policy).

2.1.6.7 *Standard FIDO Configurations*

The support of multi-instrument operations during different Experiments on a daily basis while at the same time allowing flexible configurations of individual instruments using very different wavelengths within their wavelength coverage places an immense burden on operations (and significantly affects the calibration effort). A FIDO change is manual and expected to be time consuming (i.e. 1 day). Such an effort requires planning and scheduling. It is therefore that the DKIST should identify a limited number of *standard FIDO configurations* that will be offered minimizing the change-over time (and as such downtime) per Proposal Cycle and ease the calibration effort. Each individual standard FIDO configuration should be identified based on scientific demands and requests and ideally satisfy a significant fraction of Experiments thus optimizing scientific output.

2.1.7 Changing of Experiments

In order to make efficient use of observing conditions during the day, switching between Experiments science operations that do not require a re-configuration of the FIDO dichroic components but use a different combination of instruments or the same instruments with different configurations (still compliant with the current FIDO configuration) are minimized to a time of 10 min or shorter. This time scale includes software and instrument latencies and specifically the switch to an Experiment that requests the occulters and/or intends to observe the corona off the solar limb. It also should be possible through automation to pre-configure instruments and to sequence observations (i.e. the execution of Observing Programs and their respective scripts by the Observatory Control System) in advance without interfering with an ongoing observation.

2.1.8 Quality Assurance of Experiments

Prior planning and scheduling of an observation the respective Experiment’s Observing Programs are subjected to a quality assurance process in order to minimize or even prevent failure at the summit. In this context, the DKIST developed an end-to-end testbed that is kept in sync with the summit software systems allowing testing of Observing Programs, their scripts, and their Instrument Programs. This end-to-end testing does not perfectly emulate the summit systems and as such testing of Observing Programs at the summit on the real hardware is an additional and necessary step, but it will significantly reduce the overall time spent on testing at the summit.

Over time, with increasing knowledge, experience and confidence, time spent on testing (at the summit) and quality assurance of Observing Programs, their scripts, and Instrument Programs is expected to significantly decrease.

2.1.9 Software Foundation

Efficiency considerations also apply to the approach taken related but not limited to the use of communication protocols, information and data life cycle management (including metadata and database management), and other services like logging, error, health, alarm and notification management. Hence, the DKIST will make use of a common service model for the foundation of its software infrastructure, i.e. the Common Services Framework (CSF). The CSF is common to all major facility systems.

Furthermore, software and its components should not limit hardware, i.e. do not slow down the response (e.g. movement) of hardware components by more than 10%.

2.2 Adaptability and Flexibility

During its expected lifetime, the DKIST will face new scientific challenges and technological improvements. Therefore, in order to stay competitive and be able to adapt to the evolving scientific landscape the DKIST will (a) foster instrument development and (b) allow for instruments that are temporarily deployed and operated at the DKIST (i.e. visitor instruments). The integration of new instruments and potentially new technology will be made as easy as possible from a software systems perspective. Software systems will be scalable and extendable where possible. Instrument builders will be supported and provided with tools that are compliant with DKIST standards to ease and simplify the development and integration process. The development and integration process of instruments or cameras or other components and the operation of visiting instruments at the DKIST should be regulated.

2.3 Availability and Reliability

The DKIST should optimize its availability and the reliability of its systems and system components and as such minimize its down time caused by mechanism or system failures (or any kind of fault conditions) through allowing maintenance and engineering measures when warranted and implementation of a preventive (and/or predictive) maintenance and monitoring plan for all critical facility components (e.g. major optical elements of the telescope, adaptive optics system, instruments and sub-components, cameras). Procedures should be developed and in place supporting efficient diagnosis, management and treatment of those failures (this includes the Remote Operations Control Room at the DSSC).

In particular, monitoring and reporting actions must include software control systems. Software control systems need to be able to report about their own health and the health of their sub-systems or components, log all performance and configuration information and store this information permanently. Any unusual or fault conditions (i.e. warnings and alarms) must be reported.

See also Sect. 2.1.6.6 Instrument Failure.

The release and implementation of software control system updates should be regulated.

3 Observatory Control

The observatory performs and administers several tasks. Most of those tasks are allocated to the following observatory sectors: the enclosure, the telescope, the instruments, the cameras, data activities, tasks that concern the thermal conditioning of the facility, and safety related measures.

The DKIST adopts a modular approach, where each of these areas are controlled by an individual control system independently from each other but based on a common software foundation An important exception from this design, however, is the safety or hazard alert system (i.e. Global Interlock System), which is implemented and operated completely independent in order to provide a safe and hazard-free work environment.

However, to simplify operations and help achieve maximum efficiency, the DKIST makes use of additional overarching systems to overview, configure and coordinate individual control systems, to administer different instruments and to control different cameras with a common software architecture.

Some of those systems are crucial for observatory operations. Those systems are called *Principal Systems*.

3.1 Enclosure

The Enclosure Control System (ECS) is in charge of positioning the enclosure's azimuth (carousel) and altitude (aperture), and the opening/closing of the enclosure's aperture cover. Furthermore, the ECS controls and monitors any other activities within the enclosure, e.g., the thermal conditioning of its interior.

3.2 Telescope

The *Telescope Control System* (TCS) is responsible for precise and accurate pointing to and guiding of the Sun, and other celestial objects through controlling the Telescope Mount Assembly (TMA), i.e. the telescope mount and coudé rotator, and the Enclosure Although the TMA has its proper control system, i.e. the Mount Control System (MCS), the TCS is the hierarchically higher control system that under normal conditions will coordinate the movements of the TMA and the Enclosure. Specifically, the TCS allows offsetting the coudé rotator wrt mount and track at a different rate than the mount. The latter is aiding special calibration functions and the former is necessary to achieve a specific orientation of the solar image on the detector of an individual instrument. Furthermore, the TCS controls the configuration of the upper and lower Gregorian Optical System (GOS, or overarching Polarization Analysis and Calibration, PA&C) and aspects of the Top End Optical Assembly (TEOA). The latter is the host of the Lyot stop (necessary for coronal observations) and the former hosts the polarization calibration unit (upper GOS) and the aperture filter wheel in the secondary focus (lower GOS). The polarization calibration unit hosts a lamp, and a selection of linear polarizers and retarders (for different wavelength ranges supporting different instruments). The elements of the upper GOS can all be controlled independently from each other (in/out movement and rotation). The aperture filter wheel is equipped with different field stops, pinholes, various grids, a dark slide, and most importantly the occulters (coronal observations at the limb). The TCS accepts pointing information in different solar (i.e. heliographic, heliocentric, and projected coordinate systems as defined in Thompson 2006) and non-solar (AZ/El, RA/DEC) coordinate systems in order to support different observing scenarios (e.g. pointing off the limb, stars, planets and other celestial objects) but also ease any co-observing efforts (space missions and other observatories may specify pointing in different coordinates). Specifically, the TCS can follow pointing positions on the Sun taking into account and correcting for solar rotation and user-defined solar differential rotation. The TCS can perform various user-defined continuous scanning patterns (random, spiral, raster) aiding calibration procedures and potentially observing scenarios.

The TCS is a principal system.

3.3 Instruments

The *Instrument Control System* (ICS, not to be confused with the instrument control system that is in charge of an individual instrument and the control of its internal components) is in charge of administration and coordination of the operation of all instruments that are requested to participate in the same Observing Program (Instrument Set). The ICS distributes information (e.g., about setup, configuration) to those instruments and to the cameras (via the camera control system, see below) and as such controls how those individual instruments are configured. Specifically, the ICS coordinates the common start of data acquisition of all those instruments that are part of the Instrument Set. Furthermore, the ICS allows to cancel or abort an instruments individual Instrument Program or all Instrument Programs of that instrument during the Observing Program execution without affecting the other instruments participating in the ongoing observation.

Outside of the context and framework of an Observing Program, the ICS supports the OCS’s manual control, i.e. the ICS supports the generation (new), changing, saving (through a “save” and “save as” operation) and execution of Instrument Programs for an instrument. If an Instrument Program executes outside of an Observing Program, and data is saved, this data is saved as “manual”. This informs the DHS that this data is not transferred off-summit, but deleted. This deletion is an automatic time triggered operation of the DHS. Its prevention is a manual and pro-active process.

For monitoring purposes, the ICS is passes on messages that inform about the configuration, status and health of the instruments and components during operations. The ICS is able to report about failure of an instrument or an instrument component.

The ICS is a principal system.

3.4 Cameras

The *Camera Software System* (CSS) is in charge of the operation of all facility cameras. The CSS provides a common software architecture that allows access to and control of individually very different cameras (e.g. visible versus infrared detectors). The CSS is extensible and allows for an as easy as possible integration of and adaptation to current and future imaging sensor technology.

3.5 Data

The *Data Handling System* (DHS) is responsible for the administering, flow, display, distribution, and temporary storage (at the summit) of all DKIST data related to Science Operations (not engineering). In general, the DHS must deal with the high data rates (30 Hz) required and the large volumes of raw data (expected to be about 10-15 of TBs on a standard day) produced by the DKIST instrumentation. The DHS is scalable and extensible supporting the adding of future instrumentation. The DHS provides all functions and tools to manage the resources necessary to fulfill its responsibilities. For monitoring and diagnostic purposes, the DHS provides tools for data quality assurance (Quality Assurance displays, i.e. quick look and detailed displays) and data analysis during setup and observations. The DHS also allows for tasks such as searching for specific data sets and blocking their automatic deletion or deleting them from the temporary summit storage system. As of the large data volumes created, these functions (specifically data analysis) prohibit the increase of the data amount at the summit. Within its bandwidth (based on 4k detectors run at 30 Hz maximum), the DHS supports very different usage and combinations of the instruments related to cadences and data volume produced per second.). The DHS transfers and stores all DKIST data that it is responsible for to a temporary summit storage system under its ownership and control, keeping it there up to a maximum of 3 days. Typically, however, data will be transported off-mountain on the same day of data acquisition, but only after all science-data acquisition has seized (end of the observing day). The DHS also gathers and stores complementary data (such as but not limited to meta-data, calibrations, compressed thumbnails generated by the Quality Assurance System, etc.) that are critical for data calibration and analysis together with the acquired science data.

The DHS deletes all data obtained during “test” and obtained under the OCS’s manual control. This “test” and “manual” data is not transferred off-summit. The deletion process is an automatic time triggered operation of the DHS. Its prevention is a manual and pro-active process.

The DHS adopts a flexible and adaptable data structure and driven by a DKIST Data Model uses a definition of meta-data content that has sufficient information to allow for proper data reduction and analysis. The association of meta-data with its science and calibration data is an automated process. All science and calibration data and all of its meta-data is eventually ingested by the DKIST Data Center for further processing.

The DHS is a principal system.

3.6 Observatory

The *Observatory Control System* (OCS) is responsible for the overarching and centralized management, monitoring and control of all routine observatory operations (not engineering). The OCS accomplishes this task partly through other systems of the DKIST. Three major functions of the OCS are the efficient support of science observations and routine facility tasks, and the monitoring of system health and alarms. The OCS also has managerial responsibilities for the DKIST software systems. The TCS, ICS and DHS (as well as the OCS itself) are resources managed by the OCS. The OCS provides for direct control of these systems as needed while still supporting automatic performance of routine tasks. The OCS also manages the Common Services Framework (CSF), its services (e.g. event, alarm, and log) and its summit data stores. The OCS provides tools to examine system diagnostic information, handle alarm conditions, monitor safety systems, and support routine engineering tasks.

3.6.1 Science Observations

The OCS acts as the primary interface and tool for DKIST control during normal operations. The OCS imports and ingests lists of Experiments and their Observing Programs and Instrument Programs on a likely daily basis into the summit databases for testing, modification, and execution. The OCS allows to view lists of Experiments, select Experiments and Observing Programs and Instrument Programs, execute Instrument Programs and monitor their execution, update targets associated with Observing Programs, execute Observing Programs, and monitor Observing Programs during their execution.

The OCS executes Observing Programs that control the telescope and its subsystems (i.e. upper and lower GOS part of PA&C, WFC, TEOA, TMA, enclosure) through commanding the TCS, and the instruments (including cameras) though commanding the ICS. Specifically, the OCS supports multi-instrument operations. To guarantee traceability of all science observations, the OCS provides and ensures a unique and unambiguous association between an Experiment, its Observing Programs, and all products of the observation (i.e. all data that is produced during Observing Program execution) with its source Proposal.

For optimum efficiency and flexibility, the OCS allows control of the observatory in two different ways: manually and automatically. Both controls are available at all times. Both controls make use of the same (graphical) interfaces although access restrictions to a subset of the interfaces may apply.

The manual control of the OCS is tailored specifically to support the preparation of operations, the testing of Instrument Programs, and “exploring” the Sun in general. The manual control is the default of the OCS.

In manual control, the OCS supports to:

- Control the telescope and its subsystems independent from any Experiment or Observing Program.
- Control the instruments independent from the telescope, its subsystems, and any Experiment or Observing Program, through the ICS.
- Search, select and load existing Instrument Programs (whether default Instrument Program or part of an Experiment and Observing Program, or not).
- Control the instruments based on selected and loaded Instrument Programs (execution of an Instrument Program) through the ICS.
- Cancel/abort executing Instrument Programs on a per instrument basis through the ICS.
- Change a selected and loaded Instrument Program through the ICS.
- Save and rename any changes made to loaded Instrument Program as a new Instrument Program (default Instrument Programs or those part of an Experiment and Observing Program are protected) through the ICS.
- Enable/disable data write. If data is saved, the data is tagged as “manual” and set for automatic deletion at the summit after a specific time frame through the DHS.

The automatic control is tailored specifically to support efficient execution of Observing Programs and testing of Observing Programs with all mechanisms involved or not (simulators may be used, or the TCS is by-passed). It is important to remark that in automatic control the telescope and all its subs-systems are controlled mostly automatically as prescribed in the Observing Program with only minimal interaction (i.e. WFC related activities and fine-tuning of pointing position either prior or during Observing Program execution).

In automatic control, the OCS supports to:

- Import and ingest Experiment lists.
- Search, select and load Experiments and Observing Programs.
- Update and fine-tune telescope (pointing, coudé orientation) and WFC information for Observing Program targets prior or during Observing Program execution.
- Execute a loaded Observing Program for science or calibration data acquisition (data save toggle off disabled).
- Report execution status and allow augmentation of automatic execution status.
- Report of percent complete of execution, start and end time.
- Report light level, Fried Parameter, and independent seeing parameter (if applicable) during Observing Program execution.
- Report any instrument parameters that have been changed prior execution.
- Test Observing Programs.
- Enable/disable data write during testing of Observing Programs. If data is saved, the data is tagged as “test” and set for automatic deletion at the summit after a specific time frame through the DHS.
- Cancel/abort an executing Observing Program for either testing purposes or when running the Observing Program for real.
- Enable/disable telescope involvement during testing of Observing Programs only.

The OCS also provides mosaicking and pointing sequence support during Observing Program execution, makes available an observing condition monitor (displaying an integrated light-level, the Fried parameter, an independent seeing indicator, sky brightness, temperature, wind speed and direction, pressure, dew point, etc.), and allows the user to log comments (observing log).

3.6.2 Routine Facility Tasks

The OCS supports the transitioning of the facility between its high-level states, i.e. housekeeping, closed, opened, and stand-by, through the execution of respective facility task scripts. These scripts automate and sequence activities (limited by safety and feasibility) involved in the respective transition that otherwise would have to be performed for each system independently through their own individual interface.

3.6.3 Health and Alarms

The OCS monitors, displays, and reports health status and alarms of all those systems that are known to the OCS through the health and alarm services provided by the common service model part of the DKIST software foundation. For efficiency purposes, the OCS has the capability to aggregate health.

The OCS is a principal system.

3.7 Thermal Condition

The *Facility Control System* (FCS) is responsible for the high-level control and monitoring of those systems (Facility Thermal System: FTS; Facility Management System: FMS) that determine and manage the thermal conditioning of the observatory (i.e. enclosure, air knife, coudé laboratory, etc.).

The FCS is also responsible for operation of and providing information from the facility weather station, and for monitoring power supplies that provide limited power to the observatory in the event of loss of main power to the site.

The FCS is a principal system.

3.8 Infrastructure Components

DKIST infrastructure components include a summit facility and a support facility.

The summit facility is located on Haleakala, Maui, and involves the building that hosts the DKIST (including the telescope, upper enclosure, lower enclosure, and telescope pier assembly), the support & operations building and the utility building. The support & operations building is a multi-story structure attached to the telescope enclosure that houses the Summit Control Room (SUCR), offices, instrument laboratory, mechanical equipment room and other support spaces that benefit from proximity to the telescope and coudé instrument laboratory. The utility building is a single-story building located remotely from the telescope enclosure that houses equipment that, for reasons of heat and vibration, are required to be separated from the telescope and scientific instruments. The support facility (a.k.a. DKIST Science Support Center, DSSC) is located in Makawao, Maui, close to the University of Hawai'i Institute for Astronomy. The DSSC provides work offices for Maui based DKIST personnel and a Remote Operations Control Room (ROCR). The ROCR is equipped with a replication of the operations and quality assurance displays available at the summit and as such allows operations staff to guide and support observatory operations. It is assumed, that during Integration, Testing & Commissioning (IT&C) and the first years of operations all operations are conducted from the summit, while later in time responsibilities may migrate towards the support facility if safety and procedures allow doing so to minimize commuting and the number of personnel at the summit. , The functionality of the support facility therefore does not preclude full remote operations capability but is likely limited by safety, procedures, and possibly bandwidth. The support facility also allows remote participation of access mode Investigators.

4 Actors and Roles

In order to optimize its scientific capabilities the DKIST requires a skilled DKIST operations staff. The primary function of the operations team is to safely and efficiently operate and maintain the DKIST and support the solar physics community. This team includes scientists, specialists, technicians, engineers and administrators. The following section describes in general terms the role of various actors. Position descriptions of individual staff members supersede any general descriptions provided in this or other documents.

4.1 Scientists

4.1.1 Resident Scientist

The *Resident Scientist* is a solar scientist with strong expertise in observational solar physics. The Resident Scientist supports the design, generation and quality assurance effort of Experiments and Observing Programs derived from approved and finalized DKIST Proposals. The Resident Scientist supports the planning and execution effort of daily science operations, and performs the completion confirmation of Experiments and Observing Programs. Resident Scientists participate in the proposal review process, the technical feasibility assessment of submitted DKIST Proposals, and the planning of science operations on a larger time scale (proposal cycle and beyond).

The Resident Scientist assists visiting investigators during their access mode time.

4.1.2 Instrument Scientist

The *Instrument Scientist* is a solar scientist with strong expertise, experience and published record in observational solar physics and expert knowledge in instrument design and development. An Instrument Scientist is an expert user of and is responsible for the scientific performance of at least one DKIST facility instrument. The Instrument Scientist supports on site science and calibration data quality assurance processes, as needed, through the capabilities provided by the DHS. The Instrument Scientist develops new instrument programs (in communication with the Resident Scientist). The Instrument Scientist is likely to supports the design, generation and quality assurance effort of Experiments and Observing Programs derived from approved and finalized DKIST Proposals. The Instrument Scientist is involved in the technical assessment of submitted proposals during the proposal review process. The Instrument Scientist is responsible for the preparation and maintenance of manuals and other documents that in detail describe the capabilities of that particular DKIST facility instrumentation. The Instrument Scientist provides user support and is the contact person for instrument specific data related questions

4.2 Specialists

4.2.1 Science operations Specialist

The *Science Operations Specialist* (SOS) has a scientific and/or engineering background and underwent comprehensive special training. The science operations specialist is executing daily observatory operations tasks. Specifically, the science operations specialist is operating the telescope and instruments, and executing observations. Guidance concerning experiment selection and execution, target selection, data quality monitoring will be provided by the Resident Scientist(s) on duty.

4.2.2 Subsystem Specialist

The *Subsystem Specialist* has specialized engineering and/or scientific background for a specific critical subsystem that supports the instrumentation system. Examples of such subsystems include adaptive optics systems, and polarimetry systems.

4.2.3 Safety Officer

The *Safety Officer* is responsible for site safety.

4.3 Engineer

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

4.4 Technician

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

4.5 Administrative Support

Administrative support personnel provides general administrative support as defined in respective position descriptions.

5 Operations Model

5.1 Observing Modes

The DKIST provides two different observing modes corresponding observing time: *service mode* observing (SMO) and *access mode observing (AMO)*. Both, service mode and access mode observing require likely different tools and procedures that facilitate all necessary interactions between the users of the facility.

For efficient Science operations the DKIST implements the service mode that essentially moves away from the traditional model of fixed scheduling where only one Principal Investigator (PI) has exclusive access to the observatory during a block of observing time. Instead, by adopting a flexible service model observations are efficiently planned and executed only when solar conditions (target availability) and observing conditions (weather, seeing, etc.) are suitable, and when technical readiness of all systems is assured. By implication, this is without the PI being physically present due to the very dynamical planning and execution of the observations. It is assumed that he DKIST is operated for a significant fraction of the available observing time in this service mode. During Service Mode Observing (SMO) the DKIST offers different programs from which the Investigator can choose, which at a minimum include: *regular/standard*, *synoptic*, and *Target of Opportunity (ToO)*. In addition, the DKIST makes available an *Access Mode* when real-time decisions of and/or close interactions with the Principal Investigator (PI) are necessary, or when programs have special time constraints (or otherwise as guided by policy). Access Mode Observing (AMO) allows the Investigator to choose between the same programs as for SMO with the exception of *synoptic*. The Access Mode also supports instrument development efforts and programs that either have special-time constraints and/or special technical tasks to fulfill.

5.1.1 Service Mode Observing

The service mode provides flexible assisted observing where the observatory staff operates the telescope, instruments and the associated support systems. Service time is allocated in blocks of time (scheduled around access time or any other time constrained operations) during which individual experiments are executed on a dynamic basis. The observatory staff is responsible on a daily basis regarding what experiments are executed and what instruments are operated. The service mode renders the physical presence of the PI and/or Co-I’s difficult to plan and not required. Remote participation of the PI and/or the Co-I’s, however, may be desired or even necessary (depending on the complexity of the program) although difficult as the scheduling is by definition dynamic. The service mode allows making efficient use of target availability, weather conditions and technical readiness, and supports a broad range of different programs. Particularly, this mode is amenable to target of opportunity observations, can be used to perform surveys spanning multiple days and (long-term, solar-cycle scale) synoptic programs. The service mode does not preclude joint/coordinated (campaign) programs or other programs where special time constraints are given (e.g., rocket launch, balloon or space experiment). In case the target is not available during those latter “coordinated” programs, another experiment out of the pool of experiments can be executed (or as regulated by policy).

The service mode supports specific technical operations (i.e. those that either do not interfere or do not preclude potential continuation of science operations later on the same day or the next day) since those, depending on the requirements, could be performed during weather conditions that are not suitable otherwise. To fully support service mode observing, the observatory staffing level requires substantial support from resident scientists and instrument scientists in addition to the normal staffing with science operations specialist(s), subsystem specialists, engineers, and technicians.

5.1.2 Access Mode Observing

Access time for science operations is granted when real-time or very close interactions with the PI and/or Co-I's are necessary and/or special time constraints are given. For technical operations, access time is granted in case science operations facility calibration measurements need to be obtained. Access time is granted on a scheduled basis, i.e. a fixed block of time is allocated for the proposal and its associated experiment. Access time can be shared and granted to more than one PI during the same time period if no conflicts arise from this and non-interference is guaranteed. During access time the PI and/or Co-I's may be either granted physical access to the facility or can participate remotely from the DSSC.

5.2 Operational Types

Local weather (atmospheric conditions) and solar conditions (i.e. target availability, e.g. activity like sunspots) are the main criteria driving the decision of what operations are conducted at the facility. On a daily basis it will be decided whether conditions allow for solar observations or are more suitable for other tasks that are of technical nature generally referred to as maintenance and engineering although specific calibration measurements involving the telescope and instruments are not excluded here. Therefore, the DKIST will distinguish between two operational categories: *science operations and technical operations*. These two types could overlap in time and may not necessarily be exclusive. Depending on the details of tasks and their requirements, operations of either type could be accomplished in parallel, whether scheduled ahead of time or dynamically planned. Furthermore, neither science operations do exclude programs with low observing condition constraints nor do technical operations (see later e.g. measurements obtained in the context of a facility calibration plan, or performance monitoring plans, etc., that are tied to a DKIST proposals) exclude necessarily potential scientific output.

All science operations will require an approved DKIST proposal as a source. Technical operations that need data acquisition with instruments controlled through the Observatory Control System and those leading to downtime (known in advance), will also require a DKIST proposal.

5.2.1 Science Operations

All science operations will be based upon and directly traceable back to an approved DKIST proposal. An approved proposal encompasses all information necessary to perform an experiment with the DKIST. In this context a DKIST experiment includes all activities (automated and non-automated) and all products that may result from those activities (e.g. parameters, programs, scripts, collected data) that are involved in the implementation (i.e. translation of a proposal into an experiment and its constituent parts), simulation testing, and the execution and completion thereof. It is important to emphasize that a DKIST experiment is derived from an individual approved proposal and as such will contain a reference (e.g. proposal identifier) to the relevant approved proposal. It should be also mentioned that some technical operations if related to facility calibration measurements additionally need to be traceable in time.

Science operations are performed in service or access mode and are expected to lead to scientific output that is concluded with a publication. All science operations require an approved DKIST Proposal. The DKIST offers several types of programs tailored to accommodate a diverse scientific landscape, differing depending on the predictability of the solar target (predictable, quasi-predictable, or un-predictable, target of opportunity), the length of the observing time requested/needed (one proposal cycle or longer), and the type of setup used for the observation.

5.2.1.1 *Standard/Regular Program*

A regular/standard program is a short program where a user-defined setup, configuration and combination of instruments is used to obtain solar observations. A regular program is available during service time or access time.

A regular program does support coordinated observations that are jointly performed in collaboration with space and/or other ground based facilities and observations that have a broad community interest although those can last several days.

Key: duration (mostly short and single day), flexibility, diversity, user-specific instrument configuration, coordination, broad community interest.

Examples: studies of photospheric, chromospheric and coronal phenomena, including campaigns like e.g. IWY, *Hinode* HOPs, *SoHO* JOPs, coordination with other ground-based facilities and/or with a balloon (e.g. *Sunrise* IMaX and SUFI) or a rocket experiment (e.g. *VAULT, MOSES, Hi-C, EUNIS*).

5.2.1.2 *Synoptic Program*

A synoptic program is a monitoring program where the same setup, configuration and combination of instruments is used repetitively but maybe intermittently over a (long) period of time to observe different specimen of the same solar phenomenon. This is particularly useful to obtain large samples that allow characterizing the relevant phenomenon in a statistical sense and studying its potential variation on time scales determined by, e.g., the solar cycle (but not exclusively). A synoptic program is available during service time.

Key: repeatability, reproducibility and duration, fixed setup.

Examples: studies of granulation, the network and sunspots at different positions on the Sun and in different but defined wavelength regions, studies of the solar poles.

5.2.1.3 *Target of Opportunity Program*

A *target of opportunity* (ToO) program is a standard/regular program allowing for the study of solar phenomena that are rather rare and where the occurrence thereof is hard or even impossible to predict (in time and location). Those phenomena may have a well-defined trigger (which could allow for some predictability) or not. A ToO program can warrant a short response. A ToO program is available during service time or access time. A policy will regulate whether a ToO program can bump any other program (during access or service mode observing time).

Key: predictability or unpredictability of the solar target and response time.

Examples: flares, appearance of δ-spot, sunspot at disk center, flux emergence, penumbra formation, filament eruption, prominence eruption, sigmoid, planetary transits, and comets.

5.2.2 Technical Operations

The DKIST is far more complex than currently operated ground-based solar facilities. It is therefore expected that technical operations will play a much more important role and need to be strongly supported based on implemented plans for monitoring, preventive maintenance, engineering, and downtime aiming to keep the facility and all its components available and reliable.

Daytime technical operations are predominantly performed when science observations during service mode observing time are not feasible, or parallel with science observations when no conflict or interference is assured. It is thus crucial that technical operations and science operations are carefully planned and coordinated.

Technical operations cover a whole variety of tasks including the inspection, monitoring, maintenance, cleaning, engineering, repairing and calibration of system components. Technical operations are crucial for reduction of downtime, the sustainment of optimal technical performance and efficient operations in general. Technical plans will be reviewed (and approved if necessary, guided by policy). Some technical plans (e.g. facility calibration plan, see below) require data acquisition involving the telescope and the instruments. Those plans require the generation of an Experiment and Observing Programs (and their scripts) and execution through the OCS.

The DKIST anticipates the following technical plans.

5.2.2.1 *Performance-Monitoring Plan*

A performance-monitoring plan is a comprehensive system-wide plan that supports regular inspection, condition monitoring and potential characterization of all major systems including the enclosure, telescope, adaptive optics, and facility instrumentation and cameras. The goal of this plan is to detect and correct performance degradation to avoid potential failures before time allocated for science operations is lost or system efficiency is significantly reduced. As a consequence, this plan can trigger preventive maintenance. A performance-monitoring plan is executed when no science operations are possible or in parallel with science operations when no conflict or interference is assured and potentially during nighttime.

Key: inspection, availability.

Examples: inspection and monitoring of: soft coatings of optical elements, elements with refractive index matching fluids, degradation of materials used in/for complex optical elements, electronics and computers exposed to dirt and heat load, optical surfaces in general, windows of cameras, performance of temperature control systems, opto-mechanical and opto-electrical components, (vacuum) pumps, hydraulics, basic mechanical components.

5.2.2.2 *Preventive Maintenance Plan*

A preventive maintenance plan is a comprehensive and system wide plan that is mostly based on vendor recommendation and includes all major systems including the enclosure, telescope, adaptive optics, and instrumentation. A preventive maintenance plan also includes the regular cleaning of critical ATST components. The goal is to maintain system efficiency and maximize the time between failures. A preventive maintenance plan is executed when no science operations are possible or in parallel with science operations when no conflict or interference is assured and potentially during nighttime.

Key: maintenance, availability.

Examples: periodic cleaning of the primary mirror (e.g. CO_2) and smaller optical elements, cleaning of camera windows, maintenance of camera cooling systems, maintenance of pumps, AC maintenance, air filter replacement.

5.2.2.3 *Downtime Plan*

A downtime plan is a plan where the task involved precludes normal operations of any kind, e.g. when critical elements of the facility need to be disassembled, replaced, or repaired. A downtime program is executed during access time. A downtime program can apply to the telescope and any of its components. A downtime program can also apply to critical software systems when, e.g., upgrades are necessary.

Key: maintenance, availability.

Examples: re-coating of telescope optics, repairs or replacement of the deformable mirror, and upgrades that involve extensive testing.

5.2.2.4 *Instrument Engineering Plan*

An instrument engineering plan is a plan where the task involved precludes normal operations of an instrument, e.g. when critical elements of the instrument need to be disassembled, replaced, or repaired. An engineering plan can also apply to the instrument software system when, e.g. upgrades are necessary. An engineering plan is executed when no science operations are possible or in parallel with science operations when no conflict or interference is assured and potentially during nighttime.

Key: instrument support, availability.

Examples: testing of new instrument-level control scripts, software upgrades, installation of new filters, re-alignment, and other performance improvements.

5.2.2.5 *Facility Calibration Plan*

A facility calibration plan is a plan where the task involved includes obtaining specific measurements that are necessary for the calibration of scientific observations but which are not part of a DKIST science proposal. A facility calibration plan is a system-wide plan that supports condition monitoring and potential characterization of the telescope, facility instrumentation and cameras.

Key: calibration, monitoring.

Examples: measurements to characterize the telescope and its polarization properties, measurements to characterize specific narrow-band and broad-band filters, dichroic beam splitters, and optical elements with exotic coatings, measurements that characterize cameras in terms of linearity, quantum efficiency, temperature dependency, chip anomalies, and noise pattern.

5.3 Remote Operations

Remote operations are possible from the DSSC only. Remote operations support at a minimum, to monitor observatory operations through replication of operations and quality assurance displays. Remote operations from the DSSC are likely limited by safety, procedures (developed during IT&C), and possibly available bandwidth.

5.4 Remote Participation of Investigators

During approved AMO time, the DKIST supports remote participation of Investigators (the PI and/or his/her designees and Co-I's) from the DSSC. Remote participation support during approved SMO time is very limited and challenging (best effort basis only, with DSSC only, not with summit) due to the inherent dynamic nature of the scheduling. All remote participation is passive and for monitoring and target verification purposes (or as regulated by policy otherwise). Remote participation will be differently restricted depending on the location. The support facility and the NSO HQ are likely to be tightly coupled to the summit facility and therefore remote participation might be just limited by available bandwidth and safety considerations.

6 Science Operations Lifecycle

6.1 Introduction

The DKIST is projected to be the major future resource for solar research and as such needs to provide access to and attract not just the traditional ground-based solar scientists but is also expected to increase the user base significantly by drawing and pulling in non-traditional users that currently rely mostly on space-based missions and/or come from other astronomical communities (see e.g. ALMA for the most prominent recent example undergoing this experience). As a consequence, DKIST observing time is expected to be on high demand with significant contributions from very different users with varying experience and familiarities with the complex instrumentation and the data handling thereof (new user versus old or traditional user, bi-modal user base) probably requesting service mode observing time (although access mode observing time is not excluded here).

In order to identify common concepts that can be decomposed to derive operational requirements through use cases, the larger astronomical environment the DKIST will operate in, is carefully examined.

Because of their experience with ground-based and space-based observatory operations, the following facilities/observatories are selected as examples:

- Nighttime observatories radio facilities (e.g. Gemini, VLT).
- Radio observatories (e.g. VLA/VLBA, ALMA).
- Space-Missions (e.g. Hubble Space Telescope).

NSO's Dunn Solar Telescope (DST) for (a) regular PI time allocation and (b) DST Service Mode Operation time allocation. All these facilities have in common that a competitive peer-review of solicited proposals regulate and guide the access to the facility and allocated telescope time. . Proposals and their lifecycle govern all scientific operations. Although the exact details of that process may differ from facility to facility depending on the organizational infrastructure and implemented policies, the concepts are very similar. Proposals are prepared each by an individual (the principal investigator, PI) or a group (lead by a principal investigator) outlining and justifying the specific scientific purpose complemented by a more or less detailed description of the measurement process. At most of the larger facilities (specifically non-solar) the preparation of this information is facilitated and supported by sophisticated software tools (web-based, Java stand-alone applications) made available to the user (i.e. PI's). Those software tools allow the user to prepare and submit a scientific justification (by filling in LaTex/Word templates that are turned into PDF format) complemented by an observing strategy requesting specific observing conditions (seeing, image quality, sky brightness, etc.) and including very detailed and specific target and instrument information. To aid specifically the later, Instrument Performance Calculators are used and made available, helping the investigator becoming familiarized with an instrument and definition of the specific settings supporting the proposed science goal. Although not of particular importance at this point, those software tools are collectively referred to as *Phase 1 Tools.*

In nighttime astronomy (space missions and ground-based facilities) and radio astronomy, where service mode operations are nowadays an integral part of operations, the procedures involved to apply for time are largely prescribed. Telescope time is very competitive (the user base is very large and time is heavily oversubscribed) and literally expensive (time is charged to the minute and as such must be tracked properly). A competitive proposal peer review process where proposals are ranked based on scientific merit and technical feasibility (including the rejection of proposals) assures to optimize high-impact scientific output but equally important avoid severe complications during operations (oversubscription) that could have a significant impact on the performance of the observatory. Furthermore, the process supports to prevent that (a) proposal lists are easily overfilled by number as there is no mechanism in place that regulates oversubscription of observing time, (b) resident scientists are without guidance what proposals/experiments to prepare and plan for over others in case the observing condition specifics are very similar other than target availability, and (c) as the majority of PI's will request best observing conditions, the list is overfilled with high stringency proposals.

In many cases, the situation is further complicated by Guaranteed Time allocated to partner institutions (applying either for service mode or PI/classical mode) in combination with the existence of multiple independent TACs (of each partner institution). As a result, partner time (allocated in percentage) must be properly tracked and fulfilled, and the results from the individual TACs must be merged and negotiated (e.g. Gemini), a task that is often to the heavy burden of the facility organization.

Solicitations (in form of proposal calls) are regulated and currently happen either on a quarterly (e.g. DST) or semi-annual (e.g. Gemini), and sometimes just annular basis (e.g. ALMA, Hubble Space Telescope). In a subsequent step the proposals are reviewed by an appropriate forum or committee whose members typically review the scientific merit, although other factors like technical feasibility (technical assessment of the measurement process and whether it can address the science proposed) do play an equally important role and need to be considered. In principal, proposals can be approved or rejected. The outcome of the review process is a ranked and prioritized list (sometimes referred to as the *queue).* In some cases this list is further used to produce a coarser list by *grouping of proposals* with respect to required observing conditions and technical configurations, in combination with the ranking of the proposals. Software tools support the TAC and its members in accomplishing those tasks (e.g. ALMA's Proposal Manager Tool or Gemini's ITAC Tool). It is very important to note here, that in some cases, depending on the ranking of the individual proposal (scientifically), the observing conditions requested by the PI may not be identical to those assigned by the TAC after the review, or in other words: high-ranked science is rewarded with more stringency allowed related to the observing conditions. Although, it cannot be avoided that observing conditions may vary during data acquisition and it is very obvious that adhering to a very high percentage of stringency is lowering the probability that such a proposal/experiment can be executed. After the review is concluded and before actual observations related to a specific proposal can be prepared, scheduled and executed, approved proposals need to be translated into a format that can be executed at the observatory (i.e. scripts that control and coordinate the telescope and the instrumentation during data acquisition). How this is done in detail and what participation or interaction between facility staff and the PI's is expected, differs from facility to facility. However, in many cases the PI is directly involved in preparing and generating the direct input (e.g. *observing blocks*, *scheduling blocks*) to scripts run at the facility by using software tools that are commonly referred to as *Phase 2 Tools.* After careful preparation and validation of those, the observations are scheduled and executed. After successful completion (the definition of successful can vary and is also subjected to policies) of the execution of all observations (i.e. all necessary data has been acquired) needed for a proposal, the data is transferred to corresponding Data Centers (either owned or out-sourced) where processing with or without involvement of the PI may take place (this is referred to as *Phase 3,* currently only partially implemented for ESO's

VLT, to our knowledge) but ultimately data is made accessible. In principle, this concludes the proposal cycle.

Solar ground-based facilities (e.g. former NSO's DST, VTT/SST/GREGOR Canary Islands) nowadays operate still in a very different way. There are no service mode operations (for a many reasons) but only PI/classical mode operations and related to that there are no Data Centers connected to high-resolution ground-based facilities as the PI takes all data "home", literally. So far, there are no preparation tools that help the PI preparing a proposal, in rare cases templates are provided that need to be filled in, and in most cases the submission of a proposal and any communication/interaction with the facility operators is facilitated by email. Facilities are oversubscribed, but only in the sense that a PI does not get granted the number of days he/she may have requested but a reduced number of days that is still sufficient to have a high probability to get the quality observations needed to fulfill the science goal. In most cases all PI's can be still accommodated, rejection is a very rare case and a ranking and prioritizing of proposals is not enforced. As there is no rejection of proposals necessary and the fact that ground-based solar facilities are operated in PI/classical mode (the PI is making all real-time decisions as he/she is physically present), there is no strict scientific merit review (with the exception of the former OPTICON time now Solarnet time offered by solar facilities on the Canary Islands) but only a thorough technical assessment that assures technical feasibility of the proposal (this also applies to some space-missions, e.g. *Hinode*). A practice, though, is to group proposals that request similar set-ups (i.e. optical configuration and combination of the same instrumentation) in sequence to minimize set-up time when changing over to the next proposal. The PI typically travels to the observatory, is present during the setup time, makes all real-time decisions on when to start and stop science observations, what target to use, organizes and coordinates observations with other facilities in parallel (if applicable), and also (if the expertise and comfort is present) provides input on how (and when) calibration measurements are obtained. The proposal cycle is concluded and completed when the allocated time is over (independent on whether the data could be acquired or not), the PI copies the data from the local facility or instrument store onto a portable medium and travels to his/her home destination.

In the following, some of the important operational concepts and Operations Tools (OT) that many modern large facilities share and make available and the DKIST benefits from, respectively, are summarized.

Science operations Concepts in Summary

- A Proposal Cycle with a fixed timeline governs the planning and scheduling of Science operations.
- Proposal solicitation is cyclic (e.g. 12 months, 6 months, 4 months, or 3 months).
- Proposals submission is during a fixed time window that opens and closes (deadlines).
- A competitive peer-review proposal process part of the Proposal Cycle guides Science operations.
- Proposals are ranked/prioritized/grouped.
- Proposals are approved/rejected.
- The result of the proposal review process is a ranked/prioritized Proposal List that is reconciled with the estimated available total observing time.

- Tracking and accounting of requested observing time, available observing time, and actual observing time.
- An Operations Model including Service Mode Observing (dynamic planning and execution of observations during the physical absence of the Proposal PI).
- An Operations Model including PI/Classical/Visitor Mode Observing (fixed block time allocation with PI participation).

Operations Tools in Summary

- Tools supporting the preparation of proposals for PI's (i.e. Phase 1 Tools).
- Tools supporting the proposal review by a TAC and its members (e.g. ALMA).
- Tools supporting the definition and preparation of science operations and the relevant observations (i.e. Phase 2 tools).
- Tools supporting the planning and scheduling of science operations.
- Tools supporting the monitoring and tracking of science operations.

The DKIST Science operations Lifecycle (Figure 1) adopts many of the aforementioned concepts (most importantly a proposal cycle with fixed timeline, a competitive peer-review proposal process, and service mode observing.

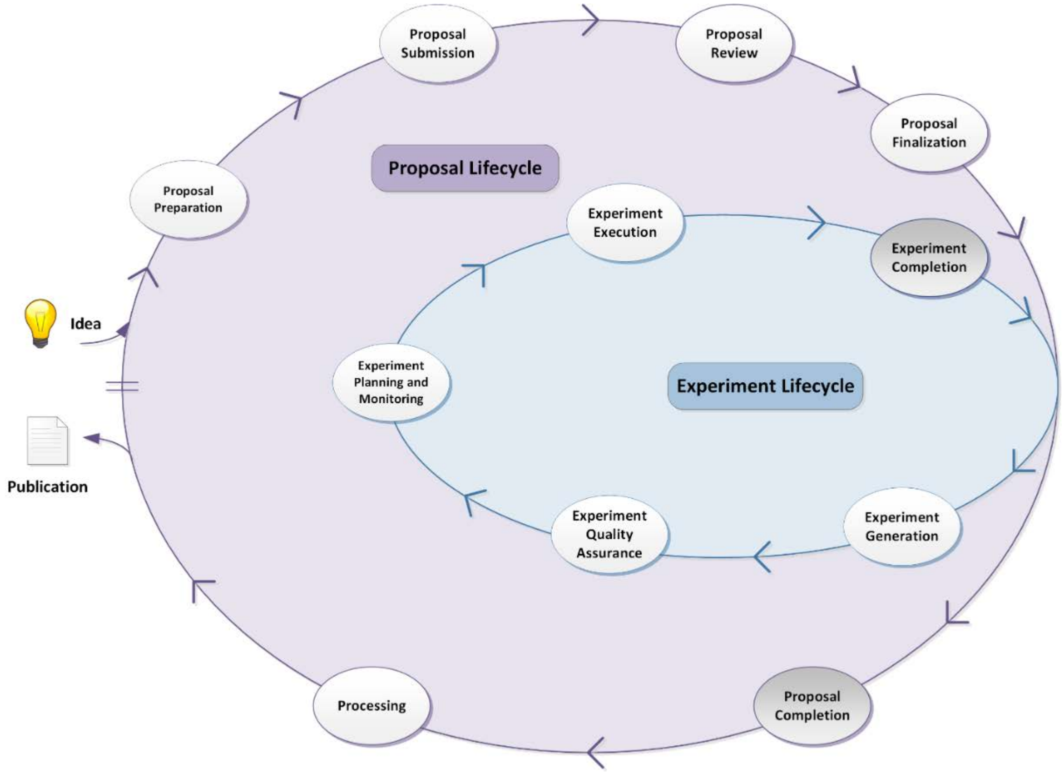


Figure 1: Science Operations Lifecycle.

The Science operations Lifecycle decomposes into a Proposal Cycle and an Experiment Lifecycle. Experiments for the most are the implementation of Proposals, i.e. their executable counterpart. Each cycle breaks down into a sequence of phases or stages, during which either DKIST Proposal or Experiment related activities are carried out.

These stages are as follows:

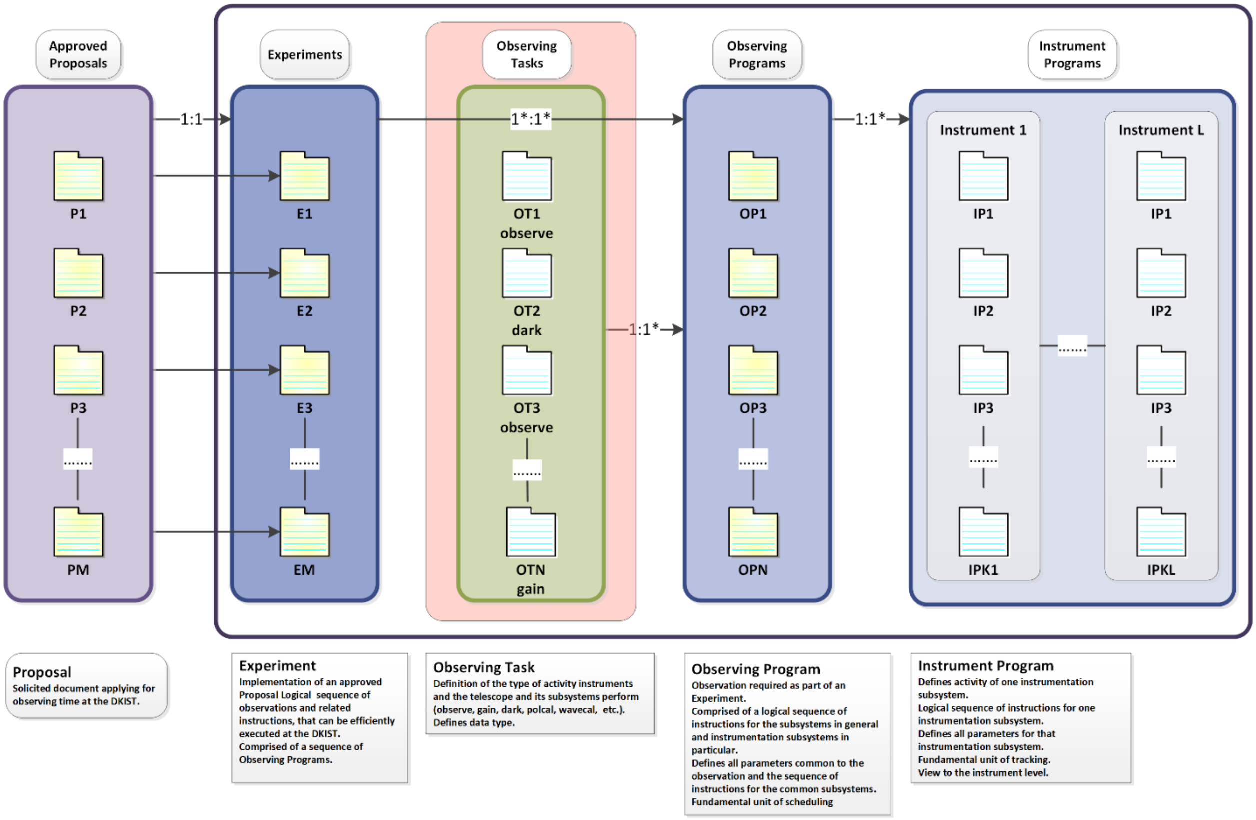
- **Proposal Lifecycle**:
    - Preparation: DKIST Proposals are prepared by Principal Investigators (PI's) in collaboration with their Co-I's (and the alternative contact for that matter) to apply for observing time at the DKIST.
    - Submission: Prepared DKIST Proposals are submitted by Proposal PI's during a proposal submission window.
    - Review: Submitted DKIST Proposals are reviewed (and ranked, approved, rejected) by a technical and science review committee (TRC, SRC, respectively) during a review window.
    - Finalization: Approved DKIST Proposals are finalized (in communication with the PI and/or instead the alternative contact) by the TAC chair or a designee and amended with approved TAC changes.
    - Completion: DKIST Proposals complete when their respective DKIST Experiment completes.

- **Experiment Lifecycle**:
    - Generation: For each approved and finalized DKIST Proposal one DKIST Experiment is created by operations staff (resident scientist, resident scientists, internal and external support scientists, instrument scientists).
    - Quality Assurance: Created Experiments, and their Observing Programs and Instrument Programs are subjected to a three-stepped acceptance process performed by operations staff (resident scientists, internal and external support scientists, instrument scientists, science operations specialists): component verification (qualification), integrated verification (simulation through an end-to-end facility), and validation (testing at the summit on real hardware).
    - Planning and Monitoring: DKIST Experiments are planned, dynamically scheduled, and monitored by operations staff (resident scientist, resident scientists).
    - Execution: Quality Assured Observing Programs of a DKIST Experiment are executed by operations staff (science operations specialists) at the summit during an execution window to acquire science data and calibration data.
    - Completion: Executed Observing Programs are assessed by operations staff (resident scientists) to define their completion status (and that of the Experiment) by inspection of Observing Program information acquired during its execution (Operator log, execution status, percent complete, light level and Fried parameter, calibration data status, etc.).

6.2 Experiments at the Summit

The essential activities performed at the DKIST evolve around or are related to DKIST Experiments. Experiments guide what science observations (including all calibration observations necessary) need to be executed. All science observations with the DKIST require an approved DKIST Proposal.

A DKIST Experiment defines and implements all contributing steps and activities necessary to fulfill the science goal of the source Proposal. In its very simplest form an approved DKIST Proposal contains a set of basic high-level instructions (e.g. telescope pointing and target description, instrument specifics, observing time on target, etc.) including maybe information about some specific instrument configuration parameters (e.g. exposure time, data rate, filters, number wavelength positions, signal-to-noise). However, those basic high-level instructions are not in a format that allows execution thereof at the DKIST. Instead, this information needs to be translated into a logical sequence of instructions and transformed into a format that can be efficiently executed at the DKIST in an automated manner with minimizing human interaction. To aid that purpose and allow for sufficient flexibility within an individual Experiment (e.g. multiple instruments participating, flexible configuration of individual instruments, multiple targets and pointing positions on the sun) the DKIST Experiment structure is logically decomposed into a hierarchy as depicted in Figure 2. The essential building blocks of a DKIST Experiment are: Observing Programs, Instrument Programs, and Data Set Parameters.



Proposal
Solicited document applying for observing time at the DKIST.

Experiment
Implementation of an approved Proposal Logical sequence of observations and related instructions, that can be efficiently executed at the DKIST.
Comprised of a sequence of Observing Programs.

Observing Task
Definition of the type of activity instruments and the telescope and its subsystems perform (observe, gain, dark, polcal, wavecal, etc.).
Defines data type.

Observing Program
Observation required as part of an Experiment.
Comprised of a logical sequence of instructions for the subsystems in general and instrumentation subsystems in particular.
Defines all parameters common to the observation and the sequence of instructions for the common subsystems.
Fundamental unit of scheduling

Instrument Program
Defines activity of one instrumentation subsystem.
Logical sequence of instructions for one instrumentation subsystem.
Defines all parameters for that instrumentation subsystem.
Fundamental unit of tracking.
View to the instrument level.

Figure 2: Experiment structure and breakdown into Observing Programs and Instrument Programs.

Each individual Experiment is created from and directly relates to an approved and finalized DKIST Proposal. Experiments and all their building blocks (Observing Programs and their Instrument Programs) are created external to the summit (and as such cannot be changed at the summit). Each individual Experiment contains descriptive metadata and a sequence of Observing Programs. Observing Programs contain descriptive metadata and all information needed for a specific observation, i.e. all instructions for all systems including the telescope, wave-front correction and the instruments. Observing Programs also include and are associated with an Observing Program script that executes the instructions and sequences the activities of the systems.

Observing Programs constitute the fundamental unit of scheduling. There is a 1*:1* relationship between Experiments and Observing Programs, i.e. that one and the same Observing Program can be part of several different Experiments (i.e. Observing Programs are re-usable) and that one Experiment can contain several Observing Programs. It is important to emphasize that each of those Observing Programs is directly related with and maps to a specific Task. The Task is a label providing information about what activities are to be expected during the execution of an individual Observing Program but also what it ultimately produces (data type: dark, gain, polcal, etc.). Each Observing Program contains all information for the telescope and its sub-systems. This information is structured in form of a target list and additional parameters. The target list can contain multiple targets (to allow for the automatic execution of a pointing sequence or mosaic) and for each of those its type (e.g. sunspot, filament, prominence, etc.), pointing coordinates, coordinate frame, rotation tracking method (i.e. none, fixed, standard, custom), WFC mode and lock-points or offsetting thereof, and coudé orientation. A DKIST solar target is a target that is located on or off the solar disk and that is clearly identifiable using a photospheric, chromospheric or coronal diagnostic in the visible or infrared light of the solar spectrum. The additional parameters contain information instructing the upper and lower GOS and instructing the telescope whether a scanning pattern is to be executed (i.e. random, spiral, raster, or none). The target list together with the additional parameters completely configure the telescope. The Observing Program also contains ordered sequences of instructions for each of the instruments requested during the observation, i.e. Instrument Programs. There is a 1:1* relationship between Observing Programs and Instrument Programs. An Instrument Program contains descriptive metadata and all information needed by the instrument to participate in the observation and produce specific data. Instrument Programs also include and are associated with an Instrument Program script that executes the instructions provided in the Instrument Program on the instrument level and sequences the activities within the instrument. The information and instructions within an Instrument Program are ordered and sequenced in form of Data Set Parameters, i.e. blocks of instrument parameters, like for instance exposure time, filter or wavelength, FOV, number of images, etc., including iterations over individual blocks or a combination of blocks. . Instrument Programs constitute the fundamental unit of tracking for completion. Each Instrument Program is directly related to a Task. This Instrument Program Task can differ from the higher-level Observing Program Task in order to allow the instruments to perform internal calibration tasks interlaced with science observations.

On a daily basis, decisions are made about what operations will be conducted and executed on the next day or days or even the current day. The decisions are based on weather and seeing conditions (observing conditions) and the forecast or prediction of those (where possible), target availability (solar conditions) and technical readiness of involved devices (mostly instruments), the availability of the requested FIDO configuration, but also the priority of the Experiment (as related to the Proposal

As Experiments and their observe task Observing Programs are created way ahead of time, an Observing Programs target list does not contain final pointing information as the final observing target does not exist at that point in time. Individual targets are created initially based on target types, pointing positions and ranges, and detailed descriptions provided by the PI in the relevant DKIST Proposal. Much of this information can be directly transferred to the Experiment and the observe Observing Program(s) during the generation of those, while other information needs updating closer in time to the actual execution. Some target lists may only contain dummy or inaccurate (pointing and other) information. There are exceptions to that, if targets are targets that are always available, like for instance the quiet sun, or the quiet corona, limb spicules, etc.

Once the Observing Programs have been tested (see Testing Observing Programs and Instrument Programs) and are ready to be scheduled for execution, they still need to await that the solar target is available, observing conditions are suitable, requested instruments are technically ready, and the needed FIDO configuration is actually available. If this is all fulfilled, the day (or possibly days) prior the execution is planned, targets are updated in the target lists and replaced with more accurate (but not final) information. Specifically, dummy pointing, WFC and coudé orientation information is updated per Experiment and observe task Observing Program and complemented with further Experiment and/or Observing Program descriptions (guidance for the summit, specifically related to observing targets).

Final observing targets are selected based on the target type and detailed descriptions of the target provided by the PI in the DKIST Proposal. In some cases but not on a routine basis (or as regulated by policy), targets are communicated with individual PIs, if they are available, the day or days ahead of a planned execution.

A priority Experiment List (ordered list of quality assured Experiments and their Observing Programs and Instrument Programs) with Experiments that are planned for the current day, the next day or during the coming week (if applicable) is created and communicated with the summit. The list description contains guidance on which Experiments to address first and individual Experiment descriptions contain guidance on which Observing Programs to address first. There can potentially be more than one Experiment List in order to be able to have a fallback scenario or contingency plan (e.g. because of an unexpected change of observing conditions for the next day, etc.). There are also Experiment Lists that contain only those Experiments and Observing Programs that are in need of validation (Test List, see below, Testing of Observing Programs and Instrument Programs), and only those Experiments that still need to be complemented with calibrations (Calibration List), i.e. the execution of calibration Observing Programs for a particular Experiment.

Any observation and acquisition of data is performed by executing Observing Programs (i.e. their scripts) that are part of an Experiment through the Observatory Control System under automatic control. During this control, the Observing Control script commands all necessary systems and the interaction between a human and the systems is reduced to an interaction prior or during execution to finalize pointing, coudé and WFC information (see below, Executing Observing Program).

The workflow prior execution is as follows:

- Target lists that pertain to Experiments and their observe task Observing Programs are edited external to the summit and existing “dummy” pointing positions (i.e. disk center) are replaced with more accurate information if possible. If that is not possible, the Observing Program description must contain more detailed information about each individual target part of the target list (e.g. NOAA numbers, preceding/following sunspot with rough pointing coordinates, etc.).
- Experiment Lists are prepared external to the summit.
- The OCS on a daily basis (or as necessary) imports Experiment Lists (this is a semi-automated process). The summit receives notifications when new Experiment Lists are available. Experiment Lists are prepared the day (likely the afternoon) prior to the observing day.
- The Experiment List description is inspected to identify what Experiments are prioritized for the day (or maybe days). The order in which the Experiments are listed reflects this prioritization, although it does not prevent that the Experiments can be addressed in a different order if this turns out to be necessary.
- The first Experiment is selected and its description is inspected for guidance on whether its Observing Programs need to be executed in a specific order (i.e. maybe some calibrations need to be executed prior the science observations). The order in which the Observing Programs are associated with the host Experiment reflects this guidance, although it does not prevent that the Observing Programs can be executed in a different order if this turns out to be necessary. It is also clearly displayed what tasks Observing Programs fulfill.
- An Observing Program is selected. By selecting a specific Observing Program important details about that Observing Program are displayed (see Interaction with the DKIST Control Systems,

Experiment GUI), including how the finalization of pointing, coudé, and WFC information is expected to be performed.

6.2.1 Executing Observing Programs

The Observing Program is submitted for execution through the OCS (see below, Executing Observing Programs), is closely monitored during the execution (see below, Executing Observing Programs, Monitoring), and either the execution completes or is terminated (see below, Executing Observing Programs, Completion). Upon submission for execution, the instruments are in a ready state and data acquisition commences as soon as the pointing, WFC and coudé orientation information is finalized (see below) and WFC is in a corrective mode.

It is also important to mention that instrument parameters (or Instrument Programs in general) cannot be adjusted or changed anymore once (or immediately prior) the Observing Program is submitted for execution. This can lead to erroneous data as it can have a large impact on any timing and synchronization aspects for an individual instrument (with its own or any external components). However, the OCS supports the adjustment of a very limited number of instrument parameters (i.e. scanning FOV of slit spectrographs, exposure times for some instruments) prior submission on a best effort basis. These “allowable” or “editable” instrument parameters are defined in the Observing Program for each instrument individually and the (graphical) interfaces do only allow to modify those parameters and no other.

6.2.1.1 *Telescope Pointing, WFC Details, and Coudé Orientation*

Each Observing Program includes pointing information, WFC information, and information about the coudé orientation included in form of a target list. The OCS displays this information. A target list can have multiple targets and as such allows executing pointing sequences. As Observing Programs are created and validated well in advance of their execution, these target lists contain either dummy or at the very most inaccurate pointing, WFC, and coudé orientation information that needs to be finalized for each of the actual observing targets part of the target list on the day of the execution. It is not excluded that only a subset of the information needs to be finalized.

This finalizing of the target list is performed through the OCS. Once a specific Observing Program is selected for execution (or testing, see below in Testing Observing Programs and Instrument Programs), the OCS displays all targets part of the Observing Programs target list on a full-disk image of the Sun (see Target Selection and Solar Monitoring, Observing Program Targets sub-section for details). The process of finalizing of targets can be performed in two different ways, i.e. prior (passive) or during (interactive) Observing Program execution (and testing if necessary). The information, about which way or interaction is expected, is encoded in the Observing Program and displayed through the OCS. Depending on what interaction is expected, the activities are slightly different.

- **Passive**: Finalization is performed before the Observing Program is submitted for execution. In this case, the following is expected. For the purpose of the exercise, it is assumed that the Observing Program is required to perform a special case of a “pointing sequence” (see also Example Observing Scenarios), a 3 by 3 “telescope mosaic”, i.e. assembling a larger FOV as provided by the instruments FOV by observing 3 x 3 adjacent (or slightly overlapping) single FOV’s and as such 9 different subfields or tiles in total. This “mosaicking” is accomplished by changing the pointing of the telescope (versus moving the instrument detector) and each of the 9 tiles are associated with pointing information and default WFC off-set information. In this scenario, the telescope has to re-point 9 times within the same Observing Program, the number of tiles is “9”, the number of targets is “1”, and WFC is disabled and enabled 9 times. For a “telescope mosaic”, the coudé orientation can be changed only for the base pointing position and not on a per tile basis. For simplicity, it is assumed that the coudé orientation for the base pointing position is such that North is specified as “up” for one of the requested instruments and does not need to change. **The workflow is as follows**: the telescope is moved to the first pointing position (base position of the mosaic) and the target and the pointing is verified (see Target Selection and Solar Monitoring). Then the WFC system is enabled (using the default WFC offset information, i.e. boresight). If the WFC system successfully performs on the FOV as seen by the WFS using the default WFC information, then there is no further change needed, the WFC system is disabled and the telescope is moved to the next pointing position (first tile position). If the WFC system fails to perform then the FOV as seen by the WFS needs adjustment until the WFC system successfully performs which may imply either small changes to the pointing position or offsetting WFC. This process is repeated for all tile pointing positions. All activities prior submission for execution are done in the OCS’s manual control through its telescope and WFC interfaces. At the end of this process, all changes are saved and the target list associated with the Observing Program is updated. Only then, the Observing Program is submitted for execution. During the execution of the Observing Program, no further fine-tuning is expected and the script execution is not halted (see below, Interactive). This does not exclude that it might be necessary. The OCS allows WFC system and telescope pointing (including potential coudé orientation) changes to be made during Observing Program execution and data acquisition through its telescope and WFC interfaces.

- **Interactive**: Finalization is performed during Observing Program execution. In this case, the following is expected. For the purpose of the exercise, it is assumed that the Observing Program is required to perform a special case of a “pointing sequence” (see also Example Observing Scenarios), a “center-to-limb variation” of the e.g. solar granulation from disk center to the west limb of the sun in equidistant steps of about 100 arcsec. In this scenario, the telescope has to re-point about 9 times within the same Observing Program, the number of targets is “9” and the WFC system is disabled and enabled 9 times. For a “center-to-limb variation”, the coudé orientation can be changed per pointing position (i.e. per target), although this is not foreseen by this particular use case. **The workflow is as follows**: the Observing Program is submitted for execution and the telescope moves automatically to the first target and pointing position, WFC is enabled, both as instructed by the Observing Program through the target list information (using the predefined pointing coordinates and the default WFC offset information, i.e. boresight). Then the execution of the Observing Program script is halted. The target and the pointing is verified (see Target Selection and Solar Monitoring). If the WFC system successfully performs on the FOV as seen by the WFS using the default WFC information and the pointing coordinates do not require to be changed as part of target verification, then there is no further change needed, and the script execution can continue (manual confirmation), Instrument Programs are passed to the instruments, data acquisition starts until all Instrument Programs are completed (reported as “done”). Now the script commands the telescope to move to the second target and pointing position, WFC is first disabled (prior the move) and then enabled, and the progression of the Observing Program script is halted again. If the WFC system failed to perform then the FOV as seen by the WFS needs adjustment until the WFC system successfully performs. This may imply either small changes to the pointing position or offsetting WFC. The process as described repeats until the script iterated through all targets part of the target list, and the Observing Program script completes, reporting “done”. In this scenario all changes made to the target list (i.e. pointing details, WFC details, coudé orientation details) after submission of the Observing Program are auto-saved (to keep an accurate record).

The fact that an Observing Program indicates and has encoded the interaction as “Interactive” does not exclude that all targets pertaining to an Observing Program can be finalized prior submission as described in “Passive”. Furthermore, the fact that an Observing Program indicates and has encoded the interaction as “Passive” does not exclude that it can be ignored under special circumstances (i.e. no finalization is performed at all because not necessary).

6.2.1.2 *Monitoring*

During Observing Program execution, monitoring plays a crucial role. The following is monitored closely:

- Observing conditions: an environmental monitor made available by the Observatory Control System is used to monitor weather parameters (temperature, pressure, dew point, wind speed, wind direction), Fried parameter, independent seeing indicator, light level, and sky brightness.
- Performance of WFC: Fried Parameter. The Fried parameter is also an Observing condition indicator, but is only of value (availability) if WFC is in one of its correction modes and locked.
- Solar conditions: a live solar monitor made available by the Acquisition Control System is used to monitor the conditions on the Sun (see Target Selection and Solar Monitoring, Monitoring the Live Sun subsection for details) and to indirectly visualize potential cloud movement along the line of sight of the observation.
- Progression of the Observing Program: the Observing Control GUI made available by the Observatory Control System is used to monitor the progression of the Observing Program Script execution. Specifically, the percent complete and remaining execution time are observed.
- Progression of instruments through their individual Instrument Programs: the Observing Control GUI made available by the Observatory Control System is used to monitor the progression of the execution of individual Instrument Programs (indirectly, through the import of an Instrument Control System GUI). Specifically, the percent complete and remaining execution time, and the changes of individual instrument dependent instrument parameters are observed (e.g. filter, wavelength point, scan number, map number, accumulation number, slit position, tile position, etc.)
- Data Flow: a limited number of configurable data quality assurance displays made available by the Data Handling System are used to monitor raw data (quick look data) and/or detailed data (detailed plugins) coming from user-selected individual instruments and their cameras. Specifically, a multiplexed monitor displaying thinned data coming from all cameras (whether in use or not) participating in the Observing Program execution is used to overview the data flow.
- Bandwidth, Data Write, Storage: the Observing Control GUI made available by the Observatory Control System is used to monitor bandwidth load/strain, data write, and storage capacity (indirectly, through the import of a Data Handling System GUI).

- Systems Health, Alarms and Safety: a systems Health, Alarm and Safety monitor made available by the Observatory Control System is used to monitor health, alarms and safety status of all systems (and their components) the Observatory Control System knows about. The Observatory Control System is monitoring the health, alarm and safety status at all times, not just during Observing Program execution.

If conditions warrant, the Observing Program execution is terminated (see Early Termination), i.e. either cancelled (graceful) or aborted (non-graceful).A terminated Observing Program can be re-scheduled for execution (see Re-Runs).

6.2.1.3 *Completion*

Under normal conditions, an Observing Program completes its execution with a completion percentage of 100% (plus some margin). The completion of an Observing Program implies that all Instrument Programs from all must-complete instruments completed.. In this case, the OCS reports “done” with a completion percentage of 100% and automatically tags the Observing Program as ``done''. This does not prevent an Observing Program from being re-run (if necessary), nor does it overwrite or delete formerly acquired science data (filenames continue, no overwriting, data culling supported through the DHS is a manual and proactive process).

6.2.1.4 *Early Termination*

The execution of an entire Observing Program is terminated early if:

- Observatory safety warrants doing so.
- A system failure influences all data from all participating instruments.
- Observing conditions (weather and/or seeing) degrade too much or are too fluctuating to continue (and as such are outside the range for the Observing Program).

In case the Observing Program execution is terminated early through the initiation of a “cancel”, the OCS reports “done” with a completion percentage of less than 100% and automatically tags the Observing Program as ``done''. The automatic execution status (i.e. “done”) of the Observing Program is amended manually with a “cancel” tag through a functionality of the OCS. In case the Observing Program execution is terminated early through the initiation of an “abort”, the OCS reports “aborted” with a completion percentage of less than 100% and automatically tags the Observing Program as ``aborted''. In either case, depending on the exact completion percentage, the Observing Program can be still considered as completed though.

The execution of an individual Instrument Program or an entire instrument can be terminated early without terminating the execution of the entire Observing Program. Instruments or individual Instrument Programs of an Observing Program are early terminated if the instrument or instrument components fail during execution affecting the data. In case an Instrument Program execution or an entire instrument is terminated early through the initiation of a “cancel”, the ICS reports “done” with a completion percentage of less than 100% and automatically tags the Instrument Program as ``done''. In case the Instrument Program execution or the entire instrument is terminated early through the initiation of an “abort”, the ICS reports “aborted” with a completion percentage of less than 100% and automatically tags the Instrument Program as ``aborted''.

Despite this early termination of instruments or Instrument Programs, the host Observing Program can still be considered as completed if the instrument affected by the termination is a non-must complete instrument (as identified by the PI on the Proposal).

6.2.1.5 *Re-Runs*

Observing Programs that have been terminated early may be eligible for re-scheduling, i.e. a re-run. Observing Programs are re-scheduled for execution if their early termination:

- was caused by the failure of a must-complete instrument, or
- was caused by a system failure that affected the data of all instruments, or
- was caused by degrading observing conditions resulting in a completion percentage that is not deemed sufficient to fulfill the purpose (or task) of the Observing Program (i.e. science or calibration).

Re-runs do not invalidate any data that has been obtained by a prior run.

6.2.1.6 *Operator Log*

Unusual events (e.g. clouds, WFC performance decreasing, cancel or abort initiated, system warnings, peculiar solar conditions or events, etc.) occurring during Observing Program execution are documented and logged using an Operator Log provided by the OCS. This logging mechanism is always available. During Observing Program execution, the log is automatically associated with the executing Observing Program (through its Observing Program ID).

6.2.1.7 *Calibration Measurements*

All scientific observations are complemented by calibration measurements. Those measurements and the resulting data sets (including metadata) are necessary in order to be able to remove or at a minimum reduce instrumentally introduced signals in the scientific data. There are different calibrations depending on the needs of the individual instrument (see below, Types).

The main guideline is to obtain calibration measurements when conditions are not suitable for science observations. However, this critically depends on the needs of individual instruments. Some instruments require to have certain calibrations executed immediately prior the science observations (i.e. execution of an observe Observing Program), other instruments will require calibrations taken in certain time intervals depending on the instruments stability. Specifically the latter does imply that those calibrations may be obtained during conditions that are otherwise suitable for science observations. Some instruments have mitigated this by using internal instrument mechanisms so that those calibrations can be obtained without influencing the telescope light beam and as such interrupting the observing process of the other instruments.

Instruments are combined and operated in parallel controlled through an Observing Program during calibration measurements. Exceptions are only made when individual instruments have additional needs (that cannot be combined with others) or where technical limitations will require calibrating instruments separately or combined in sub-groups.

6.2.1.7.1 Types

The most common types of calibration measurements include:

- <u>Dark calibrations</u>: calibrations that are based on measurements that allow determining the detector background noise and false light contributions. Dark measurements do typically not depend on wavelength, but on exposure time (non-linear or quasi-linear) and temperature. Dark measurements are obtained by shutting off the light path to the detector. This can be accomplished by a dark slide placed in a focal plane, e.g. the Gregorian focus. Dark measurements can be taken at any point in time as long as the light path and the environmental conditions are not changed.
- <u>Gain calibrations</u>: calibrations that are based on measurements that allow determining the pixel-to-pixel transmission irregularities of the detector sensor (so-called flat-fields). Gain measurements depend on wavelength and exposure time. Gain measurements can be obtained in different ways: with a lamp, by defocusing the telescope, by moving the image of the Sun continuously across the detector in a user-defined and controlled but automated way (e.g. random, circular), and by deforming the wave-front using the deformable mirror of the adaptive optics system. In practice, often a combination of those different approaches is used.
- <u>Target calibrations</u>: calibrations that are based on measurements that allow determining the detector image scale. Target measurements are particularly important during multi-instrument operations when data resulting from different ATST instruments need to be compared and relative orientation and magnification or demagnification need to be known. Target measurements are obtained with specific target slides placed in an image plane, e.g. the Gregorian focus. Typical targets include: dots, line grids with different grid-line distances, Air force radicals, special patterns (e.g. stars), but also pinholes of different sizes. Target measurements depend on wavelength but not on exposure time. Target measurements can be taken at any point in time as long as the configuration of the light path is not altered.
- <u>Wavelength calibrations</u>: calibrations that are based on measurements that allow establishing an absolute or relative wavelength scale. Wavelength measurements are typically obtained for two-dimensional spectrometers by scanning the pre-filter using either a (spectral) lamp or the Sun as a light source.
- <u>Polarization calibrations</u>: calibrations that are based on measurements that allow determining the artificial polarization introduced by optics (including instrumentation) that is located behind a polarization calibration device. Polarization measurements that allow determining the influence of the instrumentation are typically acquired with a polarization calibration device which is the combination of a linear polarizer and retarder that is located at a convenient location (mostly in a collimated beam) along the light path. Linear polarizer and retarder can be moved independently in and out of the light path and can be rotated independently. Polarization measurements depend on wavelength and (for the DKIST) time during the day.
- <u>Telescope calibrations</u>: calibrations that are based on measurements that allow determining the artificial polarization introduced by the telescope optics before a polarization calibration device. Telescope measurements depend on wavelength and time. Telescope measurements that allow determining the influence of the telescope optics are typically obtained by utilizing a rotating linear polarizer device placed at the entrance of the telescope. The aperture size of the DKIST, however, makes such an approach impractical.
- <u>Scattered Light and Background calibrations</u>: calibrations based on measurements that allow determining the contributions of scattered light (dispersed, non-dispersed) and background light

(off-limb observations, dispersed, non-dispersed). Scattered light and background measurements are typically acquired using pinholes.

- Transmission calibrations: calibrations that are based on measurements that allow to determine the influence of band-pass limited optical components.

Under special circumstances or for specific instruments, other rather non-common types of calibration measurements are used during the data reduction:

- Sky-transparency calibrations: calibrations that are based on measurements that allow determining the influence of transparency variations introduced by the Earth's atmosphere (e.g. cirrus clouds).
- Sky-brightness calibrations: calibrations that are based on measurements that allow determining the background brightness of the sky. Sky-brightness measurements are necessary for the calibration of coronal observations.
- Sky-polarization calibrations: calibrations that are based on measurements that allow determining the background polarization of the sky.
- Standard polarimetric star calibrations: calibrations that are based on measurements of known stellar polarization signals.

Some of those calibration measurements (as adopted by current ground-based solar facilities) are time-consuming and rely on sunlight (specifically gain calibration and polarization calibration), both, depending on the instrument they are needed for. This is additionally complicated by the fact that those calibration measurements may need to be executed on a daily basis as soon as individual instruments configuration changed (different wavelengths observed in different instrument modes) and potentially as close as possible in time to the science observation. In practice, this conflicts with the attempt and goal to execute as many science observations (execution of different observe Observing Programs for different Experiments) as possible during favorable seeing conditions. A stable performance of instruments (specifically the repeatability of mechanisms) and the telescope will help mitigate this situation, although, this cannot be relied on in advance.

In summary, calibration measurements may need to be interlaced with science observations depending on the stability of individual instruments. Under special circumstances, this can imply to schedule a full day of calibration measurements on days where the seeing conditions are not suitable for any science observations.

The standardization of operations including a fixed light-beam distribution to the instruments (i.e. FIDO configuration) combined with specific instrument configurations can significantly mitigate the problem. Standardized operations have the potential to ease the calibration effort and might allow obtaining valid calibration measurements even after considerable time has passed depending only on the stability of individual instruments. Note, that this should not prevent or exclude customized FIDO and instrument configurations if they have been approved (e.g. by the TAC during access mode observing).

6.2.2 Testing Observing Programs and Instrument Programs

In order to minimize failure at the summit during execution with data acquisition, Experiments and their building blocks undergo a quality assurance process. As a last step in this process (for the most part this process is external to the summit using an end-to-end test bed of summit systems), Observing Programs and Instrument Programs are tested on the summit systems involving the real hardware. This summit testing is performed through the OCS in automatic control and if necessary also manual control. The time spent on this summit testing is expected to significantly decrease over time. Observing Programs are tested for verification of telescope activities (specifically sequencing and coordination of activities as instructed by the script) and all aspects of multi-instrument operations (e.g. aggregated bandwidth and DHS configuration, data flow and write rates, coordination of instruments amongst each other through, coordination of instruments with external devices, etc.). Specifically the latter is crucial as those aspects cannot be tested using the end-to-end testbed. The testing of Observing Programs can be performed with or without sunlight available. Ideally, Observing Programs are tested under as realistic conditions as possible including solar target availability, i.e. with sunlight (observatory in the open facility state) although under observing conditions that are not suitable for actual science observations and with the requested FIDO configuration. The latter and the solar target availability are goals that may or may not be achievable (as they constrain too much when testing can be performed). While most testing is performed without data acquisition, proper data flow, write and distribution can only be verified when data is actually saved. Therefore, testing supports both options. All data that has been obtained during testing is marked as such (i.e. marked as test) to clearly distinguish it from science data, and is only temporarily saved on the summit (less than 3 days) before it is automatically deleted. It is possible to inspect the data (e.g. checking count numbers and signal-to-noise ratios) whether saved or not through the DHS and its functionality. The DHS must be configured accordingly for Observing Program and Instrument Program testing.

The testing of Observing Programs at the summit is potentially a two-step process, depending on the outcome of the first step.

During the first step, an Observing Program to be tested is submitted to the OCS for execution. This execution for testing can be done in two different ways: with the telescope and all of its subsystems either involved (telescope active) or not (telescope passive). Although the OCS does not allow determine or define what Observing Programs are to be tested (i.e. it cannot change that status), the OCS allows to define under which circumstances the testing is performed, i.e. the selection of whether the telescope (and its subsystems) during Observing Program test execution is actively involved or is by-passed. During the execution, the progression of the Observing Program is closely monitored for any warnings, health changes and alarms of systems. Specifically, the progression of instruments is monitored.

- ***Pass scenario***: If no problems are encountered the execution completes. In this case, the OCS reports “done” with a completion percentage of 100%. The test is successful. If it is too time consuming to wait until the execution is complete (some Observing Programs could take an hour or longer), the execution might be aborted. In this case, although the OCS will report “aborted” and a completion percentage less than 100%, the OCS allows augmenting this automatic execution status as “done”, indicating a pass of the test.
- ***Fail scenario***: If problems are encountered, and depending on the details of the problems, either the execution of the Observing Program is aborted or the execution of participating instruments or Instrument Programs of those instruments is aborted, while the Observing Program with the remaining instruments continues to execute (multi-instrument scenario).

- Observing Program abort: in this case, the OCS will report “aborted” and a completion percentage less than 100%, but the automatic execution status is augmented as “aborted”, indicating a failure of the test.
- Instrument or Instrument Program abort: in this case, the Observing Program execution may complete with a completion percentage of 100%, the OCS reports “done” but the automatic execution status is augmented as “aborted”, indicating a failure of the test.

In either scenario, the OCS logs all activities and status changes. Specifically, the OCS makes available an Operator log that allows generating and logging categorized comments providing additional information complementing any execution (not just during testing but also when science data is obtained during an actual observations).

During a second step, Instrument Programs that failed during testing of an Observing Program are tested (this does not exclude that individual Instrument Programs that are part of an Observing Program or are new and are not part of an Observing Program and Experiment are tested prior Observing Program testing as described in the first step). Instrument Programs are tested for verification of instrument parameters (mostly timing aspects e.g. frame rates, synchronization between hardware components, etc.). Instrument Program testing is done on a per instrument basis through submission and execution of the Instrument Program using an instrument control interface provided by the OCS (Instrument Operations GUI). Specifically, these instrument control interfaces allow controlling instruments completely independent from any Experiment or Observing Program (if necessary).

The execution of the Instrument Program is either a success (execution completes without failure) or a fail (warnings are produced, health of instrument components may change, alarms may be produced, the instrument may abort immediately upon submission to execute or during the execution, the user may abort/cancel the execution). In the former case, another Instrument Program is tested. In the latter case, it crucially depends on the details of the failure. Some failures may be resolved at the summit while others may involve the need to make changes to the Instrument Program that are outside of the summits capabilities (the original Instrument Program that is part of an Observing Program is protected and cannot be changed at the summit with the exception of a limited set of instrument parameters, the “allowable parameters”). It is possible, however, to make changes to any instrument parameters and save those changes as a new Instrument Program that subsequently can be executed for verification. The pass and fail scenario is handled in the same way as for the Observing Program hosting the Instrument Program.

As the Instrument Programs have no control over the telescope (only the Observing Program has such information), any telescope pointing or other subsystem configuration needed for Instrument Program testing is done under manual control prior Instrument Program execution, using telescope and subsystem (i.e. mostly WFC, upper and lower GOS through PA&C) control interfaces provided by the OCS (i.e. Telescope/PA&C and WFC Operations GUI).

6.2.3 Target Selection and Solar Monitoring

The DKIST needs to identify observing targets (e.g. active regions, sunspots, pores, filaments, prominences, plages, etc.), point the telescope to selected targets, while at the same time being able to monitor solar conditions on the entire solar disk (or very large portions of it) and observing conditions along the line of sight. In order to be as autarkic as possible in these activities, the DKIST utilizes its Target Acquisition System (TAS), i.e. a small aperture telescope (resolving granular spatial scales but at a minimum micro pores at visible wavelengths) equipped with an H-alpha filter (with a bandwidth transmitting photospheric and chromospheric signals) and a camera. The TAS is streaming its full-disk imaging data of the live Sun at selectable rates up to 10Hz aligned with the DKIST telescope and oriented conform to external full-disk imaging data providers (e.g. *SDO* HMI and AIA, *GONG*, *SOLIS*). The TAS data can be displayed by the OCS for use during target finalization.

To complement the TAS imaging data and extend its diagnostic range, the OCS allows to select from various other full-disk imaging data made available by providers external to the DKIST, i.e. *GONG* network (magnetograms, intensitygrams, H-alpha), *SDO* HMI (magnetograms and intensitygrams) and AIA (selected channels), and *SOLIS* (magnetograms). The OCS updates the currently selected image source automatically, as made available by the provider. To further aid the target selection and monitoring process, the OCS also allows selecting and overlaying of different solar coordinate grids (after Thompson 2006, heliographic, heliocentric, helioprojective), indicators of the 5 arcmin and 3 arcmin circular FOV around the pointing position, indicators of the poles, a disk center marker and four limb markers (N-S-E-W), existing NOAA numbers for active regions, and an indicator of the 1.5 solar radii outer pointing limit.

6.2.3.1 *Observing Program Targets*

Once a specific Observing Program is selected for execution, the OCS displays all targets part of the Observing Programs target list through their pointing positions on a user-selectable full-disk image of the Sun (i.e. TAS, SDO HMI and AIA, GONG, SOLIS) for target finalization (see details in Executing Observing Programs, sub-section Telescope Pointing, WFC Details, and Coudé Orientation). Observing Program targets are created outside of the OCS. The OCS cannot delete an entire Observing Program target list, nor can new targets be added or existing individual ones be deleted. The OCS only allows to finalize individual targets. Prior target finalization, targets are verified. At the summit, targets are verified by having the telescope pointed at the first targets pointing position as encoded in the Observing Programs target list, performing a visual inspection of the WFC context viewers display and comparing that with the requested target type of that particular target and a complementary target description. Every target on the target list is associated with a specific target type (e.g. sunspot, pore, quiet sun, filament, coronal hole, etc.) and more details as part of the Observing Program description (when necessary). The WFC context viewer, however, only displays photospheric information. In case the target is not visible in the photosphere, an imaging instrument (under the OCS's manual control) is configured providing the additional information to verify the target in conjunction with the WFC context viewer. If the visual inspection and the comparison between the actual target and the requested target passes, then the target is finalized. If the inspection and comparison fails (e.g. target type is "sunspot" but telescope is pointing at the quiet sun at disk center, i.e. for instance in case of dummy or very inaccurate pointing positions), then the pointing of the telescope is corrected (manually) based on the guidance provided by the target type and the information in the Observing Program description in combination with communication with a resident scientist.

6.2.3.2 *Monitoring the Live Sun*

Solar conditions (target availability, target changes) are monitored the entire day. This is facilitated through a dedicated live display of the full-disk imaging data provided by the TAS independent from the OCS display (where the TAS may not be displayed all the time and other image data sources maybe selected). The dedicated TAS display indicates the current telescope pointing and the 5 arcmin circular

FOV (as defined by the prime-focus field stop). The dedicated display shows the TAS data at a user-selectable update rate with a maximum of 10Hz. As the TAS is equipped with an H-alpha bandwidth filter suitable for photospheric and chromospheric signals, the TAS allows to detect filament eruptions, flares, and (precursors of) flux emergence activity as they occur. Specifically, but not limited, to when executing an Observing Program, the TAS allows visualizing and monitoring potential cloud formation and movement along the line-of-sight of the observation leading to intensity fluctuations during data acquisition and impacting data quality and signal-to-noise ratios. In this latter context, the dedicated TAS display is not just a live solar monitor, but also serves as an observing condition monitor: it visualizes the cloud formation and movement occurring along the line-of-sight of the telescope pointing and it is the source of the light level displayed through the OCS. The TAS generates a light level by computing the TAS detected signal averaged over a 5 arcmin circular FOV centered on the current telescope pointing position and publishes this light level at a maximum rate of 15Hz.

6.2.3.3 *Non Observing Program Targets*

Outside of Observing Program targets, the OCS allows to create additional targets that may be necessary if the OCS is used in manual control. There is no limitation on how many non-Observing Program targets can be created. Non Observing Program targets can be created at any point in time. Non Observing Program targets can be deleted by the OCS. The workflow is as follows: the cursor is moved to the pointing position of a solar target (e.g. sunspot, filament, plages) identifiable in one of the user-selectable full-disk imaging data diagnostics. This pointing position is given a name, the target type is selected (from a menu), the coordinate frame for that target is selected, and then the information is saved. The target is then displayed with a marker and the target name on any of the user-selectable full-disk imaging data made available by the OCS. Non Observing Program targets can also be defined with a specific coudé angle. It is not necessary to move the telescope to create a non-Observing Program target. Non Observing Program targets are created temporarily and not permanently stored but deleted automatically when the respective OCS GUI is exited.

6.3 Experiment Completion

An Experiment completes (or is completed) when all activities and automated steps belonging to that same Experiment have completed. This entails the following:

- All of the required observe Observing Programs have executed and are confirmed as completed.
- Each of the observe Observing Programs that are confirmed as completed is supported by standard calibration measurements. This means that all standard calibrate Observing Programs that pertain to the relevant Experiment have executed and are confirmed as completed.

The completion confirmation of an individual Observing Program (and an Experiment) is a manual process that is performed after examination of the execution information that is associated with the Observing Program. This examination includes the assessment of status information (OCS execution status, override status information, completion percentage), operator log information (weather comments, system warnings, peculiarities during Observing Program execution), instrument status information, light level and Fried parameter variations during the execution. Not on a routine basis but only if deemed necessary, data is inspected through a capability of the DHS. It is not planned to cull any data that has been obtained under automatic control of the OCS, i.e. through the execution of an Observing Program script, prior to its delivery to the DKIST Data Center.

6.4 Operations Log

At the core of the operations log is the logging of information. In the following, the term logging refers to the (mostly) automated chronological recording of events in order to document evidence of a sequence of activities that have contributed to or affected a specific operation. Logging is essential to understand the activities of complex systems and to diagnose problems. . However, logging everything is rarely an option since it can have a significant impact on the performance during operations, particularly if non-real-time systems are involved in the recording of the information.

The DKIST generates and maintains the following logs:

- Engineering Log: documentation of events recorded with a specific granularity for performance monitoring purposes and fault diagnosis; for engineers, technicians, and specialists; automated and non-interactive.
- Observing or Operators Log: documentation of activities and events during observing, i.e. during execution of Experiments Observing Program; for scientists; partially automated and interactive.

The DKIST has a goal to generate a Science Operations User Log (SOUL), i.e. documentation of events and daily activities informing individual Investigators about the execution of their Proposal related science observations (observe Observing Program information), pointing positions, completion information, start and end time of the observation, and observing conditions during the execution of the observations. This SOUL would likely be supported by quick look data samples in form of thumbnails.

7 A Day in the Life of the DKIST

7.1 Introduction

DKIST Science operations embeds into the larger context of daily observatory operations. This involves procedures and activities that are performed daily (as at every optical ground-based observatory) allowing the observatory to transition from a high-level *Housekeeping* state (for the DKIST this is its *Nighttime* state) into other high-level states like *Opened* or *Closed* or possibly *Stand-By*. Figure 4 conceptualizes these high-level states, the transitions between them, and activities that are likely to occur during those states. At what times during the day transitions occur is mostly constrained by weather (i.e. likely humidity, temperature, wind speed) and guided by safety, but some technical reasons may apply as well.

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

For the middle part of most days, the survey predicts less atmospheric stability. Periods of good or excellent seeing are rare when the Sun is more than 50 degrees above the horizon (Rimmele et al. 2005). Therefore, the DKIST plans for on-disk diffraction limited observing with post WFC instrumentation at wavelengths up to 2 microns in the morning hours, while later times during the day and the afternoon is used for observing at larger wavelengths.

During routine operations and under normal conditions most Experiment related activities are facilitated through the Observatory Control System (OCS) and its Operations GUIs (see Section 9.2, Observatory Control System). Those activities are complemented with manual activities and activities that involve handboxes (see Section 9.1.1, Coudé Handbox). Under special circumstances only and not for routine operations Engineering GUIs (see Section 9.1.2, Engineering GUIs) are used, in order to make specific changes that are not possible through the OCS's Operations GUIs. If experience shows that engineering GUIs are used routinely for specific operations, however, those responsibilities can be transferred to the OCS's respective Operations GUIs (or, equally, responsibilities of Operations GUIs can be removed if utilized very infrequent).

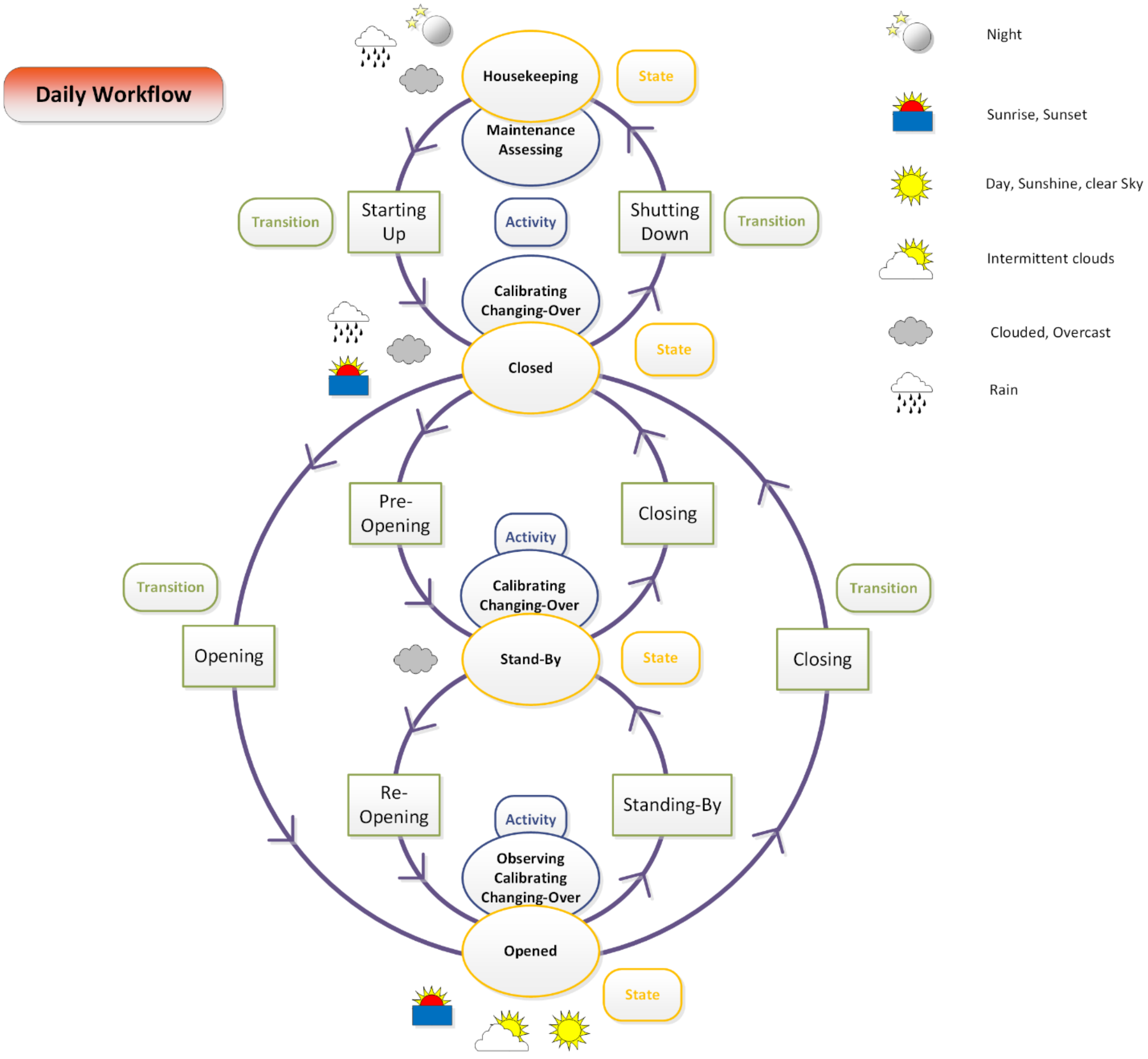


Figure 3: High-Level states and transitions used for the workflow scenario.

In the following, Figure 3 provides guidance to describe a daily workflow scenario outlining what work is accomplished to transition the observatory and what work is performed when in a specific high-level state. Specifically the latter is kept generic and not tied to the specific details of an Experiment or the context within it is executed. Most activities are executed from the summit control room (SUCR) through operations graphical user interfaces with exceptions where this is procedurally disallowed or technically not feasible.

It is presumed that the operations staff has an understanding of what Experiments are planned for execution. The day before, the resident scientist based on weather forecast, seeing prediction models (if existent), current solar conditions (target availability), and knowledge about what has been executed on the current day, has made a decision about what operations should be conducted, and has produced a list of Experiments that are planned for execution on the coming day (see Sections 6.2 Experiments at the summit). This priority list is shared with the summit and ingested by the Observatory Control System (OCS). The priority list contains Experiments that have undergone the quality assurance process.

As mentioned earlier, safety plays a very important role. Some of the activities described in the workflow scenario are significantly influenced or even completely controlled by safety considerations. The DKIST provides a formal hazard analysis plan in SPEC-0061, ATST Hazard Analysis Plan. All safety requirements placed on DKIST observatory systems appear in the relevant systems hazard analysis documentation, as they become the adopted mitigation for identified hazards. For instance, hazard analysis has identified several hazardous zones within the facility where the access will be restricted and regulated (see SPEC-0133, ATST Hazardous Zones Fully Automated Control Access). These zones include, e.g., the telescope movement envelope in general and the telescope azimuth floor and Nasmyth platform in particular, the enclosure cable wrap level, the utility level, the mezzanine level and the coudé level. Out of this list, the telescope level, the mezzanine level and particularly the coudé level (i.e. where all instruments are located) are those areas where regulated and restricted access have a large impact on daily efficient operations if access is too restrictive and procedures guided and developed by safety are not practicable. Therefore, the DKIST has implemented procedures for getting sign-off on a waiver to allow access to those areas that are otherwise restricted. The correct order of activities and procedures, and the exact conditions for all transitions are established during the IT&C phase of the DKIST project.

7.2 Starting-Up

The observatory is transitioning from its nighttime state (Housekeeping) into the high-level “Closed” state. In the “Housekeeping” state the observatory is in a state where power consumption is minimized and where possible systems are shut down and powered off. Some systems may pose an exception, like the FCS for nightly ice making, monitoring weather and environment status, and passing on information when to power-up other computers. Similarly it is assumed that the DHS will stay (partially) alive, at least enough and as long as data reduction and transfer activities are still ongoing. Additional exceptions might apply to Common Service Framework servers and the OCS computer.

This starting-up transition involves possibly two major steps: an assessment step and an actual transitioning step.

A typical work day starts officially when the operations staff arrives at the summit about 1 hour 30 min before sunrise. In general, the operations staff has to make sure that the observatory is operational and is in a state that allows preparing for and executing observations. This may include meetings (e.g. safety) and a systematic walk through the facility to visually inspect and check off areas like the enclosure and the coudé laboratory before major equipment is powered up and energized. Whether this major equipment has to be energized and de-energized on a daily basis is determined during IT&C. (e.g. major moving parts like the TMA and the enclosure).

The starting-up transition is completed when the observatory has transitioned successfully into the “Closed” state. In the “Closed” state the M1 cover and the enclosure aperture shutter are closed, the GOS shutters are closed, and the enclosure, telescope mount and coudé are likely in one of the park/stow positions (depending on weather conditions, maintenance activities, bearing load balancing purposes).

7.2.1 Assessing

This step includes all work and activities involved in assessing the state of the observatory and preparing it for transitioning into the Closed state. This step is completed when all the DKIST systems have been assessed and any required corrective measures have been taken (if applicable).

The following activities are expected:

- Hold a safety meeting and inspect the observatory including a walk through to verify the status of the observatory, and (if applicable) interpret and correct fault conditions.
- Access the Observatory Control System.
- Check data transfer and storage status, i.e. has all data transferred off summit, how much space is left for current day's data acquisition, etc.
- Review weather and the status of internal and external environmental conditions.
- Review the current observing plan.
- Establish communication with resident scientist (if applicable).

To support those activities, the following tools are used:

- A tool that allows access to the OCS and its operations GUI's.
- A tool that allows importing and reviewing the current or updated observing plan i.e. an Experiment List (or Lists) and its Experiments and Observing Programs.
- A tool informing about how much space is left on devices for data acquisition, but also how much has been transported off the mountain overnight, whether such progress was stopped or not completed, for whatever reason, and how to finish it. There should be an estimated time provided for freeing storage space. This could be called the "data usage analyzer" (ring chart indicating disk usage, file system capacity, overview over files, etc.).
- Health status GUIs and other tools (e.g. hardware status panels) that allow to assess the status and condition of the following systems and answer the relevant questions:
    - **Enclosure**: Are the enclosure's mechanical and control systems in their expected state?
    - **Telescope:** Are the telescope's mechanical and control systems in their expected state?
    - **Facility conditions**: Have all temperature control systems preconditioned all optical elements to the state appropriate of the time during the day? Are all interior spaces within the expected range of temperature and humidity? Is the facility control system in its expected state? Is the facility thermal system in its expected mode (on-disk, coronal, maintenance, housekeeping, or precondition)?
    - **Observatory**: Is the observatory control system in its expected state?
    - **Instrument**: Are all instruments in their expected state? Is the relevant control system in its expected state?
    - **Data**: Is the data handling system in its expected state? How much disk space left? Has all data scheduled for transport been successfully transported off-site? If not: how long will it take?
    - **Safety or hazard alert**: What is the state of the global interlock system? Are any systems locked out?
- A tool that allows monitoring weather and other observing condition indicators using a graphical user interface. Are external conditions within operational ranges? Can the enclosure (carrousel

entrance and vent gates, shutter) be opened without risk (e.g. how large are the chances of precipitation, cloud coverage, fog based on weather station information and weather forecasts?)?

- A tool that allows assessment of who is present on the summit and where they are (e.g., via intercom, video monitors, webcams).
- A tool that alarms about fault conditions (via fault display) through an operations graphical user interface providing sufficient information to allow determination of the source of the fault. For diagnosing purposes the systems should provide a logging mechanism where all relevant systems information can be extracted. All logs should be stored permanently also for long-term monitoring purposes.
- A tool that allows to establish communication with the resident scientist(s) (i.e. visual and voice).

The actors and roles involved in the above tasks are likely engineers and technicians including a safety representative, all supported and complemented by science operations specialists and resident scientist(s).

7.2.2 Transition

This step includes all work and activities involved in transitioning the observatory into the Closed state in preparation for Opening. This involves possibly two different steps: a power starting-up and a software starting up. During the power starting-up, mechanisms are energized (where allowed and applicable). Power starting-up can involve manual activities not supported directly through the OCS. Software starting-up is supported directly through the OCS and may or may not involve the moving of mechanisms.

This step is completed when all systems have started up and the observatory has transitioned into the Closed state.

The following activities are expected:

- Power-up equipment (where applicable).
- Startup individual systems and the respective control systems.

To support those activities, the following tools are used:

- A tool that allows to power up equipment where applicable and safe to do through software and operations graphical user interfaces (otherwise, this is a manual activity).
- A tool that allows to start-up systems and their respective control systems supported through software and operations graphical user interfaces (i.e. likely TCS and its subsystems, ICS, and instruments).

The actors and roles involved in the above tasks are likely science operations specialists and engineers and technicians (if major equipment power-up is involved).

7.3 Opening

The observatory is transitioning into the high-level Opened state. On normal observing days it will be necessary to open as soon as possible after sunrise within telescope and enclosure limitations. Those limitations are 10 degrees at a maximum (with a goal of 7 degrees). Prior to allowing sunlight on any telescope component, it is verified that it is safe to do so (i.e. review of weather and status of external and internal environmental conditions again).

The opening transition is completed when the observatory has transitioned successfully into the “Opened” state. In this state, the telescope is slewed to the ephemeris of the sun, the M1 cover and the enclosure aperture shutter are open, the WFC system is calibrated, the telescope is tracking and pointing at disk center, and sunlight enters the coudé laboratory (i.e. the GOS shutters are open).

The following activities are expected:

- Move/slew telescope and enclosure to the ephemeris of the sun. It is assumed that the telescope, coudé, and enclosure are in one of the park/stow positions. It is likely that there are multiple park/stow positions, depending on weather and for technical purposes.
- Open the vent gates to allow free airflow from outdoors as soon as possible so that thermal equilibrium is achieved between the outside and inside of the enclosure.
- Open the enclosure aperture shutter.
- Enable tracking.
- Move 2.8 arcmin FOV in and open GOS shutters.
- Open the M1 cover.
- Verify WFC system, quasi-static alignment, and M1 status.
- Point telescope to sun center.
- Perform all calibrations and alignment procedures for the WFC system (including the context viewer). This can include moving in and out of a pinhole, alignment of the lens-let array with respect to the pupil, focus, darks, flatfielding, boresight alignment, etc. It is expected that these routine WFC calibrations are performed in the framework of a facility task as automated as possible.
- Establish coordinates by sun-center procedure (move to solar limb, etc.). This cannot be done when the Sun is too low.

Establish communication with resident scientist (if this has not happened already) and confirm/verify details and possible execution constraints of current days Experiment List (what Experiments Observing Program(s) to execute first and target/pointing details, if necessary, calibration constraints, etc.).The exact sequencing of some of the above activities is established during IT&C.

Goal: Perform all instrument related actions in preparation of planned Experiments that do not require sunlight, e.g., instrument alignment, focus, grating positioning, filter tuning with internal spectral lamp.

Goal: Obtain instrument data that is needed for calibration purposes but does not need sunlight (spectral lamb profiles, laser profiles, darks).

Important Note: Any instrument related calibrations can only be performed if it is known which Observing Program to execute first (i.e. it is known which instruments in which configurations observing at what wavelengths). At this point in time only those calibrations can be performed that are independent from wavelengths or do not require reconfiguration of the entire instrument. It is expected that this process will become more efficient during operations.

To support those activities, the following tools are used:

- A tool that allows monitoring of and displays the time until sunrise and sunset through an operations graphical user interface.
- A tool to slew the telescope, coudé, and enclosure out of its current position (i.e. park/stow, or other) to the current ephemeris position of the sun (or a target in general) using an operations graphical user interface or a portable, cordless device supported by visual contact (e.g. video monitoring of the enclosure).
- A tool to open the enclosure aperture shutter using an operations graphical user interface.
- A tool to condition the enclosure using an operations graphical user interface (i.e. high level states like observing, housekeeping, maintenance, with choice of manual or automatic). The same tool should provide status updates about the power supply, air-knife, vent gate control, temperature, etc., statuses'.
- A tool to open the M1 cover using an operations graphical user interface.
- A tool to open the GOS shutter(s) and control the configuration of the upper and lower GOS using an operations graphical user interface.
- A status screen that allows verification of WFC, quasi-static alignment and M1 status (e.g. shape, conditioning, etc.).
- A tool to execute routine WFC calibrations and alignment procedures using an operations graphical user interface.
- A tool to execute the sun-center (or limb-finding) procedure to establish coordinates using an operations graphical user interface.
- A tool to point the telescope using an operations graphical user interface. Specifically, a tool that allows pointing the telescope to specific pre-defined positions, i.e. sun-center, and the N-E-S-W limb.
- A communication tool (e.g., email, phone, skype, slack) that allows establishing contact with resident scientist(s) to verify Experiment List, Experiment and Observing Program details.
- A tool that provides all necessary information, details and possible execution constraints of the current days Experiment List (to confirm/verify what Experiments Observing Program(s) to execute first and target/pointing details, if necessary, calibration constraints, etc.).

As mentioned earlier, there is a goal to also perform some instrument calibrations at this point in time if possible and more efficient. That requires knowledge about what exact Experiments "observe" task Observing Programs to execute first so that a subset of the respective "calibration" task Observing Programs could be targeted (e.g. those that are not requiring or in need of sunlight and are independent of wavelength and/or a specific instrument configuration). In preparation for execution of any Observing Program, the DHS must be configured appropriately.

If this has happened then the following activities are expected:

- Configure the Quality Assurance Displays for data monitoring and assessment.
- Execute "align" task Observing Program(s). This is a task that can potentially be performed with an artificial light source (i.e. lamp in upper GOS) and independent of wavelength and/or a specific instrument configuration.

- Execute “dark” task Observing Program(s).

To support those activities, the following tools are used:

- A tool to configure the Quality Assurance Display for monitoring and displaying data coming from specific instruments and their detectors (i.e. Quick Look, Detailed Display) providing some statistical information (e.g. min, max, avg, rms values).
- A tool that executes selected Observing Programs through an operations graphical user interface.
- A tool that allows to monitor data and images from all instruments at once without prior configuration (all in one monitor).

The actors and roles involved in the above tasks are likely science operations specialists, subsystem specialists, instrument scientist(s), and resident scientist(s).

7.4 Observing

This phase includes all work and activities necessary immediately prior and during performing science observations. This phase ends ideally when all Observing Programs with the “observe task” pertaining to Experiments on the current days’ Experiment science priority list that were possible to execute have been executed (as weather and observing conditions allow).

The main tool used during routine observing activities is the Observatory Control System (OCS). All routine observing activities are executed in automatic control of the OCS, i.e. through the execution of Experiments “observe task” Observing Programs and their scripts. During “observe task” Observing Program execution data is saved. This behavior cannot be changed through the OCS.

Decisions about what Experiment’s Observing Program(s) (for the “observe task”) are to be executed have been made and communicated (through the OCS’s Observing Control Tool and/or in direct communication with the resident scientist). The WFC system is calibrated and in idle mode, the limb algorithm has been executed, the telescope is pointing at disk center and tracking the Sun, and the 2.8 arcmin GOS FOV is in the beam. All Experiment specific and required pre-observation preparations and possible calibrations are finished (i.e. align, and darks) while others may still be necessary to execute (see Calibrating).

Dummy pointing positions for targets (default likely disk center) have been updated with rough pointing information the day before. All WFC lock-point defaults of all targets of all Observing Programs planned for execution are set to boresight.

Conditions are suitable for the execution of an “observe task” Observing Program. Statistically it is likely that the best seeing will occur when the Sun is only 15 degrees above the horizon, which is typically about 1h 25 minutes after sunrise.

Observing and data acquisition commences at the discretion of the resident scientist, in consultation with the science operations specialists and the PI or his/her designee (when participating from the DSSC during AMO, or if available and on a best effort basis only during SMO).

The following activities are expected:

- Select the Experiment through the OCS's Observing Control Tool.
- Select a specific "observe" task Observing Program that is planned for execution.
- Assess Observing Program details and verify that the requested FIDO configuration and the requested DHS configuration is compliant with the current FIDO configuration (of the coudé table) and the current DHS configuration (this should never be in conflict as Experiments and Observing Programs that request something else should never be on the days priority list planned for execution at the summit to begin with).
- Assess potentially the Observing Programs Instrument Programs and their details.
- Verify what instruments are used during the execution and configure the quality assurance display(s) accordingly to be able to monitor the data during data acquisition when executing an Observing Program depending on the selected Experiment and the Observing Program planned for execution.
- Finalize the target(s) prior (or during) execution of the Observing Program script.
- Submit the Observing Program to execute the Observing Program script.
- Log additional information or any peculiarities (temporary warnings, temporary weather changes, solar events, etc.) and add comments about activities during Observing Program execution.
- Monitor WFC performance.
- Monitor observing and weather conditions.
- Monitor the progression of the observation, i.e. OP and IP progression information (completion percentage and instrument details) and data either in raw format (through a configured Quick Look display, or more detailed through a configured Detailed display).
- Monitor files written and data storage capacity.
- Monitor time until zenith blind spot and time until cable wrap limits are reached.
- Stop the execution of an observing program when conditions warrant and/or stop all operations and place the facility in stand-by or close when conditions warrant protecting equipment. Too large variations or degradation of weather conditions or observing conditions may warrant the termination of the execution of an Observing Program at any time (in communication with the resident scientist).
- Terminate the execution of an Observing Program script if an instrument that was marked as a must-complete failed and continue with another Observing Program that does not request that particular instrument. If the failing instrument was not marked as a must-complete the default is that the observing continues.
- Under special circumstances (and in communication with the resident scientist) manually override/amend the Observing Program status (if terminated early).
- Inspect data (after data acquisition) for completion confirmation (if necessary).

To support those activities, the following tools are used:

- A tool that allows selection and viewing of a specific Experiment and its details (e.g. description, PI contact information) facilitated through an operations graphical user interface.
- A tool that allows selection and viewing of a specific Experiments "observe" task Observing Program(s) and details (e.g. description, coordination details, mosaicking, observing task, program type) facilitated through an operations graphical user interface.

- A tool to assess that the requested FIDO configuration and the requested DHS configuration is compliant with the current FIDO configuration (of the coudé table) and the current DHS configuration (this should never be in conflict as Experiments and Observing Programs that request something else should never be on the days priority list planned for execution at the summit to begin with).
- A tool that allows selection and viewing the Observing Programs Instrument Programs and details (e.g. description, instrument task, parameters) facilitated through an operations graphical user interface.
- A tool that displays what instruments are used during the execution of an Observing Program script via an operations graphical user interface.
- A tool to configure the quality assurance display(s) through an operations graphical user interface.
- A tool to display and monitor data for quality assurance purposes during data acquisition when executing an Observing Program depending on the selected Experiment and the Observing Program planned for execution. The tool should allow selection between raw data and processed data (for more details).
- A tool that by default and without any interaction necessary displays the data published by all facility cameras (all in one monitor of all cameras).
- A tool to finalize Observing Program target(s) prior (or during) execution of the Observing Program script facilitated through an operations graphical user interface. Specifically, this tool allows to orient the selected solar target in a very specific way within the FOV of one identified instrument (e.g. slit orientation with regards to the selected solar target) and displays this orientation on real solar data for visual verification. This tool also allows fine-tuning of the lock points with or without changing the telescope pointing and changing the WFC mode. The same tool includes the limb tracker allowing control over- and under-occulting.
- A WFC context viewer display.
- A tool to inspect the target within the sub-apertures, to lock and un-lock the high-order and low-order WFC system, and to activate/de-activate the limb tracker.
- A tool to submit a selected Observing Program for execution of its Observing Program script through an operations graphical user interface.
- A tool that allows logging categorized comments during Observing Program execution using an operations graphical user interface.
- A tool to monitor WFC performance (including the limb tracker) through an operations graphical user interface (e.g. Fried parameter or other metrics).
- A tool to monitor weather and observing conditions through an operations graphical user interface.
- A tool to monitor the progression of the observation, i.e. Observing Program and Instrument Program progression through operations graphical user interfaces.
- A tool to monitor files written and data storage capacity through an operations graphical user interface.
- A tool for early termination of the execution of an Observing Programs script, and/or an individual Instrument Program part of the Observing Program, and/or an entire instrument that is part of the Observing Program facilitated through an operations graphical user interface. Each of

those activities leaves the telescope, its systems, and the instrumentation in a safe and ready state. In order to allow for the proper reaction to the cause of the early termination, the tool makes available:

  - **Cancel (graceful termination)**: applicable when changes of conditions (e.g., thick clouds, fog, danger of rain, increased wind speeds) are expected or when systems performance is not as expected. In this case it should be guaranteed that the last data write is completed and no data is compromised or corrupted. The data should indicate that the Experiment and Observing Program has been canceled.
  - **Abort (non-graceful termination)**: important to account for conditions that require immediate actions to protect equipment or personnel. In this case, the last data write may not be completed. The data should indicate that the Experiment and Observing Program has been aborted. Incomplete/corrupted data should be tagged as such in order to sort it out.

- A tool that displays which instruments are must-complete instruments.
- A tool to manually over-ride the execution status of an Observing Program through an operations graphical user interface.
- A tool to inspect specific data sets after data acquisition using an operations graphical user interface.
- A tool to sequence the execution of Observing Programs facilitated through an operations graphical user interface.
- A tool that allows monitoring of and displays the time enter and exit the zenith blind spot through an operations graphical user interface.
- A tool that allows monitoring of and displays the time until cable wrap limits are reached through an operations graphical user interface.
- A tool that allows inspection of data acquired.

The actors and roles involved in the above tasks are likely science operations specialists, instrument scientist(s), and resident scientist(s).

7.5 Calibrating

This phase includes all work and activities necessary in support of performing science observations. This phase ends ideally when all Observing Programs with a “calibration task”, pertaining to individual Experiments “observe task” Observing Programs that were executed, have been executed (as weather and observing conditions allow).

The main tool used during routine calibration activities is the Observatory Control System (OCS). All routine calibration activities are executed in automatic control of the OCS, i.e. through the execution of Experiments “calibration task” Observing Programs and their scripts. During “calibration task” Observing Program execution data is saved. This behavior cannot be changed through the OCS.

Conditions are suitable for the execution of a “calibrate task” Observing Program but will critically depend on the needs/demands of individual instruments. Some instruments will require to have certain calibrations executed prior the science observations (i.e. execution of an “observe task” Observing Program), other instruments will require calibrations taken in certain time intervals depending on the instrument's stability. Specifically the latter does imply that those calibrations are obtained during conditions that are suitable for science observations (i.e. interlaced). The main guideline, however, is to obtain calibration measurements when conditions are not suitable for science observations and combine as many instruments as possible during any of the calibration tasks.

The execution of “calibrate task” Observing Programs does not involve the active performance of Wave-Front Correction. The WFC mode is either idle or “calibrate” with the choice of “unflat”. There is also no or very limited activities related to target finalization. Most standard calibrations that are requiring sunlight are obtained with the telescope either pointing at sun center or performing a continuous scanning pattern (e.g. “gain task”, circle or random). As a special case, during polarization calibration measurements (i.e. “polcal task”, “telcal task”), the upper GOS is commanded to sequence through specific combinations and orientations of the polarizing and retarding optics while the telescope is not moving or changing its current configuration at all. Some calibrations will likely be possible to be executed when using an artificial light source.

The “align task” and “focus task” calibrations are special cases of a calibration. The “align task” Observing Program is executed to align all instruments to the same reference and as such to each other. During execution of the “align task” Observing Program, the lower GOS is commanded to move in a pinhole indicating the boresight of the telescope. This task can be potentially executed using an artificial light source instead of sunlight, and as such could be executed while the telescope is in the Stand-By state or maybe even Closed state. The “align task” may or may not be necessary to be executed every day on a per Experiment and “observe task” Observing Program basis. During execution of an “align task” Observing Program, each instrument is running a “processing plugin” analyzing the pinhole data and taking corrective measures. “Align task” data may or may not be saved.

The “focus task” Observing Program is executed to focus instruments. Depending on the repeatability of positions and the stability of individual instruments, this task will likely be executed every day on a per Experiment and “observe task” Observing Program basis (as wavelengths may change between “observe task” Observing Program). The “focus task” Observing Program will only focus the instruments for the specific wavelengths or filters requested during the “observe task” Observing Program. During execution of the “focus task” Observing Program, the lower GOS is likely commanded to move in a target or field stops slide (depending on the instruments needs). During execution of a “focus task” Observing Program, each instrument is running a “processing plugin” analyzing the data and taking corrective measures. “Focus task” data may or may not be saved.

All of the above are encoded in the Observing Program and executed automatically.

In general, calibration measurements are obtained performing the same tasks using similar tools and procedures (if not the identical) than during acquisition of science observations (i.e. the execution of “observe task” Observing Programs, see section “Observing”). In support of each “observe task” Observing Program executed, the following activities are expected:

- Prior “observe task” execution: select Experiments “align task” Observing Program and submit for execution.
- Monitoring of the execution of the “align task” Observing Program and assessment of the result.

- Prior “observe task” execution: select Experiments “focus task” Observing Program and submit for execution.
- Monitoring of the execution of the “focus task” Observing Program and assessment of the result.
- Select Experiments “dark task” Observing Program and submit for execution. The “dark task” Observing Program will obtain dark measurements for all instruments combined in the Observing Program commanding the lower GOS to move a the dark slide into the beam. “Dark task” measurements are assumed to be independent of wavelength and telescope pointing, but do depend on exposure time. There could be more than one “dark task” Observing Program per Experiment, depending on the needs of individual instruments. For the first Experiments “observe task” Observing Program planned for execution, this task can be potentially executed when the observatory is “Closed” (or in “Stand-By”) prior any other tasks.
- Select Experiments “gain task” Observing Program and submit for execution. The “gain task” Observing Program will obtain flat field measurements for all instruments combined in the Observing Program commanding the lower GOS to move a field stop slide into the beam and using the telescope performing a continuous motion pattern (random or circle) around a pre-defined target position (default disk center) possibly with the deformable mirror of WFC set to “unflat”. “Gain task” measurements depend on wavelength, telescope pointing, and exposure time. There could be more than one “gain task” Observing Program per Experiment, depending on the needs of individual instruments (some instruments may require a lamp flat in addition).
- Monitoring of the execution of the “gain task” Observing Program and assessment of the result.
- Select Experiments “target task” Observing Program and submit for execution. The “target task” Observing Program will obtain target measurements for all instruments combined in the Observing Program commanding the lower GOS to move a target slide into the beam and likely the telescope performing a continuous motion pattern (random or circle) around a pre-defined target position (default disk center) possibly with the deformable mirror of WFC set to “unflat”. “Target task” measurements are assumed to depend on wavelength. During “target task” measurements the target image is stabilized and not rotating.
- Monitoring of the execution of the “target task” Observing Program and assessment of the result.
- Select Experiments “polcal task” Observing Program and submit for execution (only for spectropolarimeters). The “polcal task” Observing Program will obtain polarization calibration measurements for all spectropolarimetric instruments combined in the Observing Program commanding the upper GOS to move a polarizer and retarder into the beam, the lower GOS to move a field stop into the beam and using the telescope likely performing a continuous motion pattern (random or circle) around a pre-defined target position (default disk center) possibly with the deformable mirror of WFC set to “unflat”. “Polcal task” measurements depend on wavelength. During “polcal task” measurements the GOS is stabilized and not rotating. During “polcal task” measurements the upper GOS is commanded to sequence through a pre-defined combination of orientations of the polarizer and/or retarder, while the telescope pointing or the execution of the continuous motion pattern remains unchanged. There could be more than one “polcal task” Observing Program per Experiment, depending on the needs of individual instruments. One of those “polcal task” Observing Programs could be a “sky polarization” calibration. For those, the telescope needs to be slewed over the avoidance zone prior execution. This will likely require either “closing” or “standing-by”.
- Monitoring of the execution of the “polcal task” Observing Program and assessment of the result.

- Select Experiments “wavecal task” Observing Program and submit for execution (if applicable). The “wavecal task” Observing Program will obtain measurements for all instruments in the Observing Program in need or requesting these.
- Monitoring of the execution of the “wavecal task” Observing Program and assessment of the result.
- Select Experiments “transmission task” Observing Program and submit for execution (if applicable). The “transmission task” Observing Program will obtain measurements for all instruments in the Observing Program in need or requesting these.
- Monitoring of the execution of the “transmission task” Observing Program and assessment of the result.
- Select Experiments “scatteredlight task” Observing Program and submit for execution (if applicable). The “scatteredlight task” Observing Program will obtain measurements for all instruments in the Observing Program in need or requesting these measurements commanding the lower GOS to move e.g. a pinhole in. “Scatteredlight task” measurements depend on wavelength and may depend on telescope pointing. There could be more than one “scatteredlight task” Observing Program per Experiment, depending on the needs of individual instruments.
- Monitoring of the execution of the “scatteredlight task” Observing Program and assessment of the result.

To support those activities, the following tools are used:

- A tool that clearly displays the task of an Observing Program.
- A tool that clearly displays the task of an Instrument Program.
- A tool that allows monitoring of and displays the statuses of the upper and lower GOS.
- A tool or tools that allow proper assessment of all “calibrate task” measurements. This includes success metrics for “focus and align task” measurements.
- A tool that allows to set the deformable mirror of WFC to “unflat”.
- A tool that allows to select and execute a continuous motion pattern of the telescope (i.e. random or circle around a pre-defined position on the sun).
- A tool that allows monitoring of and displays the statuses of the telescope (including the coudé rotator).
- A tool that allows monitoring of and displays the time enter and exit the zenith blind spot.
- A tool that allows to slew the telescope across the avoidance zone to a fixed AZ/EL position on the sky.

The actors and roles involved in the above tasks are likely science operations specialists, subsystem specialist(s), instrument scientist(s), and resident scientist(s).

7.6 Changing-Over

Changing-over is not an observatory state nor a transition. Changing observing conditions, solar conditions and the needs of Experiments related to the former require the facility to be adaptable allowing for changes supporting as many Experiments on an individual day as technically possible.

In order to make efficient use of the observing conditions and the solar target availability on a daily basis there is an operational need to allow for multiple experiments to be addressed on the same day. To do so this may require changing:

- how the light is distributed to the individual instruments by changing dichroic beamsplitters and/or moving mirrors,
- how individual instruments are configured, and
- how facility thermal systems are operating in (e.g. from observing on-disk to coronal, maintenance, housekeeping).

The re-distribution of the light-beam through a change of the FIDO dichroic beam-splitters is an up to 1-day effort and requires planning and scheduling. The simpler change that switches between usage of any pre-WFC and post-WFC instrumentation is a 10-30 min effort.

The actors and roles involved in the above tasks are likely science operations specialists, engineers, instrument scientist(s), and resident scientist(s).

7.7 Standing-By and Re-Opening

The observatory is transitioning into the high-level Stand-By state. In this state, the enclosure and the M1 cover are closed but the telescope is following and tracking the Sun. The observatory is operational but there is no sunlight entering.

The observatory is transitioned into the Stand-By state if temporary weather changes warrant doing so, for instance cloud formation (or substantial wind increase). In this scenario, the observatory may still be operational and there are several activities that could be performed:

- Calibration measurements that can make use of the lamp in the GOS instead of sunlight.
- Calibration measurements that require the lamp in the GOS instead of sunlight.
- Change-Over to (or from) the Cryo-NIRSP.

The observatory is transitioning back into the high-level Opened state after the weather has been reviewed and conditions allow continuing with sunlight entering the observatory (i.e. Re-Opening) or the observatory is transitioning into the high-level Closed state and then potentially shutting-down for continuing with technical operations (maintenance).

The DKIST site on Haleakalā is subject to the formation of fog accompanied by relative humidity levels above the operational limit of 70% or even light rain. Weather records on the summit show that these episodes are sometimes short but might require turning on dehumidification systems inside the enclosure. In this particular scenario, the observatory may not be operational and able continuing to track the sun.

The actors and roles involved in the above tasks are likely science operations specialists, instrument scientist(s), and resident scientist(s).

7.8 Closing

The observatory is transitioning into the high-level Closed state. In this state, the M1 cover and the Enclosure are closed, while systems are still energized. This transition can be performed form either the Open or Standing-By state. The telescope is not tracking and may or may not be in one of its parked/stowed positions (including the coudé). Depending on the time during the day and/or as long as weather conditions allow, some science and/or technical operations will continue until decided otherwise.

The Closing transition may or may not be the reverse of the Opening transition. Nevertheless, it is likely that the same tools are shared during both transitions.

The actors and roles involved in the above tasks are likely science operations specialists, instrument scientist(s), and resident scientist(s).

7.9 Shutting-Down

The observatory is transitioning into the high-level (nighttime) Housekeeping state. This transition is de-energizing systems in a sequenced and coordinated way involving likely two different steps: a software shutting-down and a power shutting-down. During the power shutting-down, mechanisms are de-energized (where allowed and applicable). Power shutting-down can involve manual activities not supported directly through the OCS.

The Shutting-Down transition may or may not be the reverse of the Starting-Up transition. Nevertheless, it is likely that the same tools are shared during both transitions.

The actors and roles involved in the above tasks are likely science operations specialists and engineers and technicians (if major equipment power-up is involved).

8 Example Observing Scenarios and Targets

The DKIST performs all of its observations and obtains all data through “observe” or “calibrate” task Observing Programs and the execution of an Observing Programs script by the OCS in automatic control. Each Observing Program contains a target list with one or more targets (see Experiments at the Summit). Each target is associated with a type, coordinate frame and pointing coordinates, solar rotation tracking method (i.e. none, fixed, standard, custom), WFC mode and WFC lock-points or off-setting thereof, and a coudé orientation. A DKIST solar target is a target that is located on or off the solar disk and that is clearly identifiable using a photospheric, chromospheric or coronal diagnostic in the visible or infrared light of the solar spectrum.

8.1 On-Disk Observations

The DKIST obtains all of its high-resolution (i.e. mostly spatial resolution) on-disk observations using photospheric and chromospheric diagnostics accessible in the visible and infrared region of the solar spectrum. The DKIST cannot observe the on-disk corona. The on-disk corona can only be observed in highly ionized lines in the UV and EUV region of the solar spectrum and is as such inaccessible from the ground. All the high-resolution on-disk observations are performed in conjunction with the Wave-Front Correction system (WFC, high-order adaptive optics) providing a wave-front corrected beam shared by all post-WFC instruments. The interaction with that system during the observation and execution of an Observing Program script is minimized and mostly controlled through the Observing Program script wherever possible and safe to do with the exception of the definition or fine-tuning of the lock-point and or offsetting of the lock point (target finalization) Fine-tuning the lock point and/or offsetting the WFC system are tasks that can be either performed prior or during Observing Program execution depending on the details and goals of the Observing Program (see Experiments at the Summit, Executing Observing Programs for more details).

Target types (identified in photospheric and chromospheric diagnostics):

- Sunspot:
    - FOV: observed FOV contains a sunspot (umbra and penumbra and surrounding quiet sun) or parts of a sunspot, and its fine structure (penumbral filaments, penumbral dark, cores, light bridges, penumbral grains, central umbral dots, peripheral umbral dots).
    - Visual Verification: target is visible in WFC context viewer (high-spatial resolution broadband photospheric diagnostic) and/or chromospheric (Ca II K, H-alpha, H-beta) and molecular band (TiO band, G-Band) diagnostics on DHS provided QA displays.
    - Occurrence: within activity belt, +/- 40 degrees latitude, all longitudes.
    - Frequency: solar cycle phase dependent.
- Pore:
    - FOV: observed FOV contains one or more pores.
    - Visual Verification: target is visible in WFC context viewer (high-spatial resolution broadband photospheric diagnostic) and/or chromospheric (Ca II K, H-alpha, H-beta) and molecular band (TiO, G-band) diagnostics on DHS provided QA displays.
    - Occurrence: within activity belt, +/-40 degrees latitude, all longitudes.
    - Frequency: solar cycle phase dependent.

- Plages:
    - FOV: observed FOV contains Plages.
    - Visual Verification: target is visible in WFC context viewer (high-spatial resolution broadband photospheric diagnostic) and/or chromospheric (Ca II K) diagnostics on DHS provided QA displays.
    - Occurrence: within active regions.
    - Frequency: solar cycle phase dependent.
- Quiet Sun:
    - FOV: observed FOV contains quiet sun fine structure like granules, inter-granular lanes, and possibly magnetic flux concentrations of various sizes and strengths (depending on whether the inter-network or network is covered by the FOV).
    - Visual Verification: the target is visible in the WFC context viewer (high-spatial resolution broadband photospheric diagnostic) and/or molecular band (TiO, G-band) and/or chromospheric (Ca II K, Ca II 854.2 nm) diagnostics on DHS provided QA displays. The latter specifically important for identification of the network.
    - Occurrence: unconstrained.
    - Frequency: unconstrained.
- Filament:
    - FOV: observed FOV contains parts of a quiet or active region filament.
    - Visual Verification: target is visible in chromospheric (H-alpha, H-beta, Ca II 854.2 nm, Ca II K) diagnostics on DHS provided QA displays.
    - Occurrence: within +/-60 degrees latitude, all longitudes.
    - Frequency: solar cycle phase dependent.
- Coronal Hole:
    - FOV: observed FOV contains parts of a coronal hole.
    - Visual Verification: challenging with high resolution DKIST imaging diagnostics.
    - Occurrence: unconstrained.
    - Frequency: solar cycle phase dependent.

The identification of a Coronal Hole is challenging as it is typically detected in diagnostics that are not accessible from the ground with the exception of He I 1083 nm.

8.2 Off-Limb and Limb Observations

8.2.1 Coronal Observations

It is one of the major science requirements of the DKIST to observe the corona at high-spatial resolution close to or off the limb. The prerequisites for coronal observing are incorporated into the optical design of the telescope (e.g. off-axis obscuration-free design, low-scatter optics, movable Lyot stop and flexible occulting allowing over- and under-occulting). Furthermore, a rigorous cleaning plan supports controlling the contribution of dust accumulation on critical optical elements to the overall scattered light.

In general, coronal observations are challenged by extreme low light levels that drive the low-scattered light requirements (sky and optics). The extreme low light levels and low contrasts render current adaptive optics systems not feasible. In order to mitigate the seeing and scattered light influences during coronal observations, the DKIST will observe the corona predominantly in the infrared wavelength range where those influences are smaller than in the visible wavelength range. However, since the DKIST will observe the inner corona rather close to the solar limb, it is important to keep the image of the Sun stabilized. Therefore, the DKIST makes available a limb-tracking device when occulting the limb, stabilizing the solar image on the occulting edge. The limb tracker is available during over- and under-occulting- conditions (about +/- 5 arcsec).

Target Types (coronal diagnostics):

- Quiet Corona:
  - FOV: observed FOV contains parts of a quiet corona above the visible solar limb.
  - Visual Verification: challenging with high resolution DKIST imaging diagnostics.
  - Occurrence: unconstrained.
  - Frequency: unconstrained.
- Active Corona
  - FOV: observed FOV contains parts of the active corona above the visible solar limb.
  - Visual Verification: target is visible in coronal (Fe IX 789 nm) diagnostics on DHS provided QA displays.
  - Occurrence: within activity belt, +/-40 degrees latitude.
  - Frequency: solar cycle phase dependent.

Although the goal is to automate the usage of the occulter and the limb tracker as much as possible, it is expected that much of the procedural details, when involving the occulter and limb tracker in preparation for or during an observation (execution of an Observing Program script), are developed during operations.

In order to make a sensible decision about whether coronal observations are executed, the DKIST has a goal to make available a sky brightness indicator to identify conditions when the contribution from the sky's background are low.

The off-limb pointing of the DKIST is limited by safety allowing pointing off-limb up to 1.5 solar radii.

8.2.2 Chromospheric Limb Observations

Although not as challenging as coronal observations, observing the chromosphere poses some challenges for the WFC system when chromospheric phenomena are observed either close to or slightly above the visible solar limb (e.g. spicules, foot points and/or body of a prominence, active region loops). The WFC system supports observations at the limb or close to the limb specifically through its capability to allow offsetting the lock-point from the pointing position of the telescope (up to 15 arcsec from its boresight default).

Target Types (chromospheric diagnostics):

- Spicules.
  - FOV: observed FOV contains parts of the active corona above the visible solar limb.
  - Visual Verification: target is visible in chromospheric (H-alpha, H-beta, Ca II 854.2 nm, Ca II K) diagnostics on DHS provided QA displays.
  - Occurrence: unconstrained.
  - Frequency: unconstrained.

- Prominence:
  - FOV: observed FOV contains parts of prominence.
  - Visual Verification: target is visible in chromospheric (H-alpha, Ca II 854.2 nm, Ca II K, possibly H-beta) diagnostics on DHS provided QA displays.
  - Occurrence: within +/-60 degrees latitude.
  - Frequency: solar cycle phase dependent.
- Sunspot:
  - FOV: observed FOV contains a sunspot structure as observed at or close to the limb (i.e. active region loop system) and if on disk umbra and penumbra.
  - Visual Verification: target is visible in WFC context viewer (high-spatial resolution broadband photospheric diagnostic) and/or chromospheric (Ca II K, H-alpha, H-beta) and molecular band (TiO band, G-Band) diagnostics on DHS provided QA displays.
  - Occurrence: within activity belt, +/- 40 degrees latitude.
  - Frequency: solar cycle phase dependent.

Any of the above targets can be observed with occulting and the limb tracker. In that case, however, no high-order wave-front correction is currently available.

8.3 Pointing Sequences

At many times solar observations are not limited to the observation of just one target of the same species but rather multiples of those at different positions on the sun. Thus, the telescope pointing has to change many times during the execution of the same observe Observing Program script. The OCS supports these discrete pointing sequences through an Observing Programs target list. These pointing sequences can be un-ordered on a non-equidistant grid, like the observation of multiple sunspots or pores at very different positions on the sun, or they can follow a more ordered pattern like for a center-to-limb variation of the solar granulation or a mosaic to acquire an entire large active region. A very special example of a pointing sequence is to take a set of discrete measurements all with the same distance from sun center, i.e. on a circle centered on sun center. The radius of that circle or distance from sun center is only restricted by the pointing limitation of the TCS, i.e. 1.5 solar radii.

All pointing sequences can be executed with or without interaction for target finalization as encoded in the Observing Program (see Section Executing Observing Programs, Telescope Pointing, WFC Details, and Coudé Orientation). In fact, if the interaction is encoded as “Passive”, it is neither prohibited nor prevented to ignore it. This is specifically favorable for CLV’s of the quiet sun (with possibly many discrete pointing positions), but could be also applicable to large mosaics.

8.3.1 Center-to-Limb Variation

A *center-to-limb variation* (CLV) is a sequence of measurements performed at different distances from the disk center. A CLV is a special case of a pointing sequence. In principle, a CLV can be performed along any radial direction from Sun center. Most applications though are along the equator (e.g. quiet sun). Following the same sunspot over several days during its disk passage is sometimes also called a CLV.

8.3.2 Mosaicking

A mosaic is a special case of a pointing sequence. Observations of e.g. an active region or an entire filament require a very large FOV beyond the capability of most individual instruments. The observation of such a large FOV is supported by the OCS by sampling this larger FOV systematically through the definition of adjacent and/or slightly overlapping tiles. If multiple instruments are participating in the observation then the instrument with the smallest intrinsic FOV limitations likely determines the details of the mosaic. The large FOV can be recovered during post-processing when the individual tiles are patched together. Mosaicking is not limited to on-disk observations, but can also be performed at or off the limb (without occulting), restricted only by safety.

8.4 Target of Opportunity Observation

Target of Opportunity observations cover a variety of different phenomena depending on the individual predictability. The most notorious (solar) example are solar flares, but it is not excluded that sunspot occurrence during an extreme solar minimum could be also classified as a ToO. The DKIST supports the observation of such phenomena through a Target of Opportunity program.

8.4.1 Eruptive Phenomena

Solar eruptive events (i.e. flares, erupting filaments or prominences, Coronal Mass Ejections) are very hard to predict in time and location and require ideally a very rapid response. In the case of a flare often used as the typical example for a ToO, the response time needed is un-realistically short. By the time an alert is received during an ongoing Experiment (potentially non ToO) and the switch to an applicable ToO Experiment is accomplished including re-pointing of the telescope (excluding re-configurations of the FIDO dichroic components), the event is at its climax or in its gradual decay phase. Therefore, the DKIST does not “chase” such eruptive phenomena or events. Precursors of such events and prediction services are used instead to decide the day before or in the morning that a ToO is observed on a target with high probability to flare or erupt using an appropriated ToO Experiment (or as regulated by policy). Prediction services possibly include the subscription to the notification system of the *Max Millennium Program of Solar Flare Research* and using a fully automated solar flare forecasting system like *Flare Likelihood and Region Eruption Forecasting* (Flarecast) and its API. In addition, the GOES X-ray flux as provided through the Space Weather Prediction Center is monitored to track solar activity in general and specifically solar flares.

Typical target types for ToO observations are filaments (active, quiet) and prominences. The exact pointing details are challenging to define, but precursors could be identified by additional monitoring of polarity inversion lines and/or the development of parasitic polarity islands.

8.4.2 Flux Emergence and Active Region Development

The earliest visible indicator of emergent flux is a shape deformation accompanied by contrast changes of the granulation, changes in the convective flow pattern (on a large scale), and an increased brightness in Hα. Amongst those, the enhanced Hα brightness is currently the only one that is used since it does not require any data processing or resolving the granulation spatially. In absence of any other prediction models or indicators, it is assumed that real-time monitoring of the solar disk at moderate spatial resolution using Hα is necessary to somehow early identify emergent flux. Once flux emerges and pores are forming and growing, a very important ToO observation is the formation of a sunspots penumbra.

Another interesting example is the development of a δ-spot, and higher up in the solar atmosphere above a sunspot at the limb observations of coronal rain (not every active region shows coronal rain activity).

Typical target types for ToO observations are pores and sunspots.

8.4.3 Solar Eclipses, Planets and Comets

Although quite predictable in time, observations of a sunspot at sun center, a solar eclipse (total, annular or partial), a planetary transit or a planet at small elongations, or maybe even a comet classify as a ToO.

These predictable ToO observations are planned for as any other observation, with the only difference that they have specific time constraints and/or require additional actions to be taken during the preparation phase. For some of those, timing and coordination will be crucial. This is particularly applicable to solar eclipses and planetary transits (1st and 2nd contact). The DKIST specifically supports the observation of planets and comets through planetary ephemeris and orbital elements.

8.5 Spectropolarimetric Observations

The detection of solar polarized light and the determination of the strength and direction of the magnetic field of the Sun throughout the atmosphere is one of the major science objectives of the DKIST. Since polarization cannot be detected directly (only intensities can be detected), the incoming light beam is modulated in order to create and record different mixtures of the Stokes parameter I (intensity) with all other Stokes parameters (V,Q,U) that are subsequently analyzed before the modulated intensity states are recorded on the detector.

Spectropolarimetric observations are obtained as any other observations. The measurement of polarization, however, is severely challenged by artificial polarization (cross talk) that is introduced by seeing, the telescope optics and the instrumentation itself. In order to calibrate spectropolarimetric data properly the contribution of this artificial polarization needs to be determined through the analysis of specific polarization calibration measurements. These polarization calibration measurements are typically obtained by feeding the instruments with known polarization states that are created by a polarization calibration unit or device placed at a convenient location. This allows determining cross-talk contributions originating from all optical components located behind the polarization calibration unit itself. Any cross-talk contribution originating from optical components prior this calibration unit cannot be determined. The DKIST makes available a calibration unit and developed a methodology (i.e. polarization calibration plan) allowing a proper calibration of spectropolarimetric data over a broad wavelength range to correct for artificial polarization introduced by the entire optical train of the telescope and the instrumentation. This polarization calibration unit part of Polarization Analysis & Calibration (PA&C) located in the upper GOS (i.e. after M2 and prior the gregorian focus) is configurable to the needs of individual instruments allowing to move its components (linear polarizers and retarders) independently in and out of the beam and rotate them with respect to each other by specific angles. The polarization calibration unit allows determining the cross-talk contributions from M3 to the instruments. The impact of M1 and M2 is determined using independent telescope calibration measurements.

8.5.1 Telescope Calibration Measurements

Telescope calibration measurements are obtained by executing an Observing Program with the “telcal” task. The acquisition of telescope calibration measurements is a facility calibration task. During the execution of a “telcal” task Observing Program, the telescope is pointing likely at a magnetic region on the sun (sunspot, pore) and tracking, i.e. the target list contains one target, while WFC is possibly in a corrective mode (i.e. seeing limited) to provide some image stabilization.

Frequency: infrequent, after re-coating of M1 and M2.

8.5.2 Polarization Calibration Measurements

Polarization calibration measurements are obtained by executing an Observing Program with the “polcal” task. These polarization calibration measurements are obtained for each spectropolarimetric science observation using the same instruments with identical wavelengths. During the execution of a “polcal” task Observing Program, the upper GOS hosting the polarization calibration optics is instructed to sequence through a table of configurations (encoded in the Observing Program) at which each the instruments are acquiring data. During the entire execution, the telescope is (a) pointing likely at the “quiet sun” at sun center and tracking, i.e. the target list contains one target, or (b) performing a continuous scanning motion, likely a circle or a random motion around sun center, in which case the target list also contains only one target (“quiet sun” at sun center). In either case, WFC is in its idle mode with the DM possibly in its “unflat” position. The coudé rotator may or may not be in a fixed relation to the Gregorian focus when executing a “polcal” task Observing Program.

Frequency: daily, potentially multiple times per Experiment.

8.5.3 Sky Polarization Calibration Measurements

Sky polarization calibration measurements are obtained by executing an Observing Program with the “polcal” task. The sky polarization calibration measurements are possibly complementing routine polarization and/or telescope calibration measurements. The target list of this “polcal” task Observing Program contains a non-solar target type (i.e. the “sky” away from the sun) observed at different fixed sky pointing positions (i.e. AZ/EL positions). During Observing Program execution, the upper GOS hosting the polarization calibration optics is instructed to sequence through a pre-defined table of configurations very similar to a normal polarization calibration for each of the sky pointing positions. During the measurement process, the telescope and the coudé are not moving.

These measurements are complicated by the fact that they are taken on the sky away from the sun outside the avoidance zone (i.e. ranging from 1.5 solar radii out to 25 degrees from sun center). The avoidance zone cannot be crossed when the telescope is in the “Open” state. Although the goal is to automate these measurements as much as possible, it is expected that the procedural details, when preparing for such an observation (execution of an Observing Program script), involve manual steps that cannot be performed or controlled by an Observing Program script.

Frequency: infrequent.

8.6 Target Orientation and Stability

In many observing scenarios (in either automatic or manual control of the OCS), the solar image or the image of the gregorian focus will need to be (a) oriented in a user-defined way on the detector and (b) kept in that orientation during the observation. It is, however, mechanically very challenging and operationally impractical to design instrument detectors rotating by arbitrary angles and remotely controlled around their axes. Thus, the DKIST enables control of the orientation of the solar image or an image of the gregorian focus for one selected instrument by offsetting the coudé rotator azimuth with respect to the mount azimuth by a known amount depending on the specifics of the orientation and compensating for image rotation of the image on the detector (where possible) through rotating the coudé platform at the adequate rate. The DKIST supports the following orientations through its telescope control system (TCS).

8.6.1 Fixed Relation to the Sun

There are three different options that fall into this category. The orientation of the image on the detector is

- coupled to the sun’s rotation axis: e.g. North up, South down, parallel to a defined direction of the detector,
- coupled to the solar limb: e.g. limb parallel or perpendicular to a defined direction of the detector, or
- coupled to a solar structure: e.g. filament body parallel or perpendicular to a defined direction of the detector.

During an observation (i.e. during Observing Program script execution through the OCS in automatic control or during Instrument Program execution through the OCS in manual control) each of the above orientations is maintained and kept without any intervention. For each detector of each instrument, a principal direction (or axis) is defined and stored. Two of the above options are solar target specific and as such the involved angles to achieve the orientation are unknown in advance. The specific coudé rotator azimuth offset angle (coudé angle) is identified and saved with the target prior observing in a manual process. In this manual process that is based on visual inspection, the coudé table is rotated until the solar structure (i.e. the target) as displayed (by the WFC context viewer or through the Quality Assurance display provided by the DHS) is oriented in the required way (i.e. parallel or perpendicular) to the defined direction of the detector. Specifically if a slit-based instrument is involved, the location of the slit on top of a solar image is displayed through the Quality Assurance display provided by the DHS.

8.6.2 Fixed Relation to the Local Horizon

There is one option that falls into this category. The orientation of the image on the detector is in such a way that the impact of the spectral dispersion caused by the Earth’s atmosphere is parallel to a defined direction of the instrument. For a slit-based instrument, this is parallel to the slit (or along the slit).

While this orientation is maintained and kept during an observation (i.e. during Observing Program script execution through the OCS in automatic control or during Instrument Program execution through the OCS in manual control), the solar signal rotates.

8.6.3 Fixed Relation to the Gregorian Focus

There is one option that falls into this category. The orientation of the image on the detector is in such a way that features of a target located in the gregorian focus (e.g. the lines of a grid target) are aligned with a defined direction of the detector.

While this orientation is maintained and kept during an observation (i.e. during Observing Program script execution through the OCS in automatic control or during Instrument Program execution through the OCS in manual control), the solar signal rotates.

8.7 Co-Observing Efforts

Many observing scenarios will request co-observing with other observatories or missions. The DKIST supports this co-observing or coordination and current coordination options include

- Satellites (e.g. *Hinode, IRIS*),
- Encounter missions (e.g. Solar Orbiter, Solar Parker Probe Plus),
- Other ground-based observatories (e.g. GREGOR, SST or other Canary Island facilities, GST, ALMA),
- Balloons (e.g. Sunrise),
- Rockets (e.g. *Vault*, *Moses, Clasp*),

or a combination of the above.

Current practice is (and independent of any operational details of the different partners and any policies that may or may not regulate the coordination with the DKIST), that the co-observing participants communicate and interact with each other on a daily basis to prepare for the next day or days actual observing time or window that has been granted (or agreed upon).The PI of the relevant Proposal for the co-observing effort is responsible for the coordination and informing all participants about exact pointing positions planned for the day, the coming day, or coming days. Emails and email aliases are used to share and communicate any information although other channels can be used amongst individuals (e.g. skype, zoom).

Assuming that a DKIST Proposal requesting coordination (and providing relevant details like requested time window, dates, and individual co-observing partners) has been approved, the DKIST will adopt these current practices as a baseline approach. The Proposal PI will inform the DKIST (i.e. resident scientists) about targets and pointing positions on a daily basis or as adequate. Resident scientists will incorporate those details (i.e. pointing information and execution window of the Observing Program script) into the planning of summit operations and instruct operations staff accordingly.

It is very important to emphasize that there is no difference in a coordinated or non-coordinated Observing Program or Observing Program script. The coordination (execution time) is loose and not implemented in the actual Observing Program or its script. It is the responsibility of the operations staff to execute the Observing Program during the requested coordination time window (or as regulated by policy).

In some specific cases, very tight time constraints may exist. For instance, a typical rocket flight takes only 3-5 minutes. Proper communication with the PI thus plays an important role particularly on the flight day where the exact launch time must be communicated on an almost a real-time basis.

9 Interactions with the DKIST Systems

9.1 Tools

As experienced and practiced at ground-based observatories, all observatory operations is of interactive nature where the operations staff is either directly or indirectly in contact with equipment and systems. During most technical operations (i.e. maintenance and engineering), the nature of the work is rather hands-on and direct, while during much of daily science operations the interaction with the DKIST systems is rather indirect facilitated through graphical user interfaces (GUIs). The DKIST differentiates between two types of GUIs: Engineering GUIs and Operations GUIs.

Alternatively, or complementary to GUIs, wired mobile devices (laptops, handboxes) are used.

9.1.1 Coudé Handbox

The coudé handbox (or handpaddle) is a wired portable handheld device with tactile/haptic input functionality providing access to and allowing interaction with some of the DKIST systems.

The coudé handbox allows the following activities:

- Move (slew) the telescope with the choice of different velocities (within safety limitations).
    - Move (slew) along different coordinate axis:
        - Cartesian: (x, y) in [arcsec].
        - Heliographic: (theta, phi) in [degrees]
    - Move directly to a specific coordinate:
        - Disk center
        - N/S/E/W limb.
- Rotate the coudé table (within safety limitations).
    - Rotate continuously until stopped.
    - **Goal**: Rotate by a specific angle to establish a specific orientation of the instrumentation with:
        - Fixed relation to the Sun (e.g. slit aligned with a solar structure).
        - Fixed relation to the local horizon.
        - Fixed relation to the gregorian focus.
- Provide access to the lower Gregorian Optical System (moving in/out of field stops, pinholes, dark slide, targets, and occulters).
- Provide access to the Lyot stop (move in/out).
- Activate/deactivate random or any of the specific continuous motion patterns of the telescope (i.e. raster or spiral).
- **Goal**: Activate/deactivate specific solar rotation tracking method:
    - Rigid rotation (i.e. fixed).
    - Differential rotation (i.e. standard or custom).

Current procedures at solar ground-based facilities make frequent daily use of and rely on handboxes specifically during preparatory work for science and technical operations.

9.1.2 Engineering Graphical User Interface

An Engineering GUI (Eng GUI) is a versatile, all-purpose interface providing maximum functionality i.e. all information and actions necessary to allow

- complete (stand-alone) control of the electronic device or system and its components,
- engineering tests,
- software debugging, and
- hardware operations.

Engineering GUIs are used in extreme cases (failure scenarios) and under special circumstances. Engineering GUIs are a tool for engineers, instrument scientists, or any other specialists of the respective electronic device or system. Engineering GUIs are accessible through the OCS although not part of the OCS.

9.1.3 Operations Graphical User Interface

An Operations GUI (Ops GUI) is a graphical user interface providing a subset of the functionality of the respective Engineering GUI for that device or system. Operations GUIs are used for daily routine science operations. Operations GUIs are a tool for science operations specialists. Operations GUI's are part of the OCS.

9.2 Observatory Control System

During daily routine science operations and in preparation of those, all interactions with the DKIST systems are through the OCS and its Ops GUIs. In order to manage, monitor and control the observatory and support the activities and tasks described in Sections 6 (Science operations Lifecycle, Experiments at the Summit), 7 (A Day in the Life of the DKIST), and 8 (Example Observing Scenarios) of this document, the OCS provides the following categories of Ops GUIs:

- Environment related (passive).
- Health, Alarm and Safety related (passive).
- Facility related (interactive).
- Telescope related (interactive, passive).
- Target selection related (interactive).
- Experiment related (interactive).
- Instrument related (interactive, passive).
- Data related (interactive).
- Wavefront-correction related (interactive).

Some of the Ops GUIs are mostly passive as they are predominantly for monitoring purposes, while others are highly interactive to be able to either initiate and/or stop various activities of individual systems. The initiation of an activity (i.e. mechanism movement) through an Ops GUI is pro-active, i.e. nothing starts automatically because an individual Ops GUI (or Eng GUI for that matter) is “started”.

The OCS's organizes its Ops GUI's on multiple displays for an un-obscured view of information and access to functionality where most important for routine science operations, but also layered and nested where less frequent access is needed.

9.2.1 Environment

For monitoring purposes of weather and observing conditions, the OCS makes available an “Environment Monitor” Ops GUI with displaying the following information:

- Temperature (numerical, evolving graph).
- Humidity (numerical, evolving graph).
- Barometric pressure (numerical, evolving graph).
- Dew point (numerical, evolving graph).
- Wind speed (numerical, evolving graph).
- Wind direction (numerical, evolving graph).
- Light level (numerical, evolving graph).
- Sky brightness (numerical, evolving graph).
- Independent seeing indicator (numerical, evolving graph).
- WFC Fried Parameter (numerical, evolving graph, in correction mode only).

The OCS displays the information numerically and in form of an evolving graph versus time during the day with a user-selectable time scale (i.e. 6 min to 12 hours, default 2 hours).

Outside of the OCS’s “Environment Monitor Ops GUI”, the Acquisition Control System (ACS) makes available a dedicated life monitor of the full-disk Sun allowing detection of solar events (i.e. flares, emergent flux, erupting filaments) and moving clouds or cloud formation along the line of sight. For monitoring purposes of the sky, an all-sky monitor external to the OCS is available in the summit control room.

9.2.2 Health and Status

For monitoring purposes of system health, alarm notifications and safety status, the OCS makes available a high-level “Health, Alarm and Safety Monitor” Ops GUI with displaying the following information:

- Telescope Control System (TCS): health and alarms.
- Wavefront Correction (WFC): health and alarms.
- Polarization Analysis & Calibration (PA&C): health and alarms
- Enclosure Control System (ECS): health and alarms.
- Mount Control System (MCS): health and alarms.
- Top End Optical Assembly (TEOA): health and alarms.
- Feed Optics Control System (FOCS): health and alarms.
- M1 Control System (M1CS): health and alarms.
- Acquisition Control System (ACS): health and alarms.
- Individual Instruments: health and alarms.
- Observatory Control System (OCS): health and alarms.
- Instrument Control System (ICS): health and alarms.
- Data Handling System (DHS): health and alarms.
- Facility Control System (FCS): health and alarms.
- Global Interlock System Status (GISS): health and alarms, interlock status of major components.

The OCS displays the aggregated health and alarm status of each of these systems using colored Icons separating visually health from alarms. Health status can be good, ill, or bad. The health and alarm Icons are interactive and clicking on an Icon displays the health or alarm status of each individual component (contributing to the aggregated health) of that system expanded in a tree format. The OCS also displays the aggregated observatory health status, allows displaying all health and alarm statuses of all systems at once. Alarms raised by individual components (not the aggregated alarm) are associated with an additional description aiming to provide details about the cause of the alarm, and time stamps for the first and last raise time. The OCS allows acknowledging and dismissing of alarms and to comment on individual alarms.

In addition to the “Health, Alarm and Safety Monitor” Ops GUI, the OCS provides a status panel (part of the “Solar Monitor and Target Selection Control” Ops GUI) with the following observatory information:

- Calendar: current date, UTC time, local Maui time, Boulder time.
- Sun: P-angle, B0-angle, diameter, Elevation and Azimuth.
- Shutters: Enclosure aperture (open, closed), M1 cover (open, closed), GOS (upper, lower: open, closed).
- Limits: time to sunrise and sunset, time to reach cable wrap limits, time to enter and exit of zenith blind spot.
- Telescope: TCS mode, coordinate frame, pointing position in different solar coordinates systems, current RA/ DEC and AZ/EL position of target, scanning motion indicator (raster, spiral, random, none), current TCS wavelength (in microns), solar rotation tracking method indicator.
- GOS: upper and lower GOS configuration.
- TEOA: Lyot stop (in, out).
- WFC: mode (off, idle, on-disk diffraction limited, seeing limited, limb tracker).
- Coudé Rotator: mode, angle, coordinate frame.
- Facility Thermal: FCS mode (housekeeping, maintenance, observing), air knife status (on/off).

The details of the information provided by the status panel is expected to change and evolve over time.

9.2.3 Facility Tasks

For support of daily facility tasks, the OCS makes available a “Facility Task” Ops GUI allowing execution of (where applicable) and guidance through the following procedures (at a minimum):

- Starting-Up (interactive): *Starting-Up* transitions the observatory from its nighttime state into the Closed state involving possibly two different steps:
    - Power starting-up: during the power starting-up, mechanisms are energized (where allowed and applicable) but not moved. Power starting-up can involve manual activities not supported directly through the OCS.
    - Software starting-up: during software start-up, software control systems are deployed and mechanisms may (or may not move) move performing homing activities, placing systems and their mechanisms into a default operational state.
- Opening (interactive): *Opening* transitions the observatory from the Closed state into the Open state through multiple steps possibly including:
    - Slew the telescope to the ephemeris position of the sun

    - Start tracking the sun (TCS mode is tracking).
    - Opening of the enclosure aperture shutter.
    - Configure the GOS for Opening:
        - Opening the GOS shutter(s).
        - Move 2.8 arcmin field stop into beam (lamp out and switched off, no polarization calibration optics in the beam).
    - Opening of the M1 cover.
    - Inspect sun sensor.
    - Executing the limb finding procedure.
    - Executing WFC calibration procedures.
- Standing-by (interactive): *Standing-By* transitions the observatory from the Open or Closed state into the Stand-By state through multiple possibly including:
    - Closing the M1 cover.
    - Closing the enclosure aperture shutter.
- Closing (interactive): *Closing* transitions the observatory from the Open or Stand-By state into the Closed state through multiple steps possibly including:
    - Close M1 cover.
    - Close enclosure aperture shutter.
    - Configure GOS for Closing:
        - Close GOS shutters.
        - Move 2.8 arcmin field stop in (lamp out and switched off, no polarization calibrations optics in the beam).
    - Slew telescope to one of the park/stow positions (depending on weather or other constraints).
- Shutting-Down (interactive): *Shutting-Down* transitions the observatory from the Closed state into the nighttime state involving possibly two different steps: a software shutting-down and a hardware shutting-down. During the hardware shutting-down, mechanisms are de-energized (where allowed and applicable). Hardware shutting-down can involve manual activities not supported directly through the OCS.

The transitions are automated and through execution of a script (where possible) with varying modularity depending on the details of the transition and the systems involved that need to transition and/or perform certain activities. At times, there is manual interaction required, i.e. the pro-active and manual confirmation that an action has been performed before a script may resume its execution, or that an action external to the script has to be performed manually before a script may resume its execution. During transitioning, information about the progression of any actions is displayed.

The details of this Ops GUI, i.e. details of the individual states and how to transition between them (automated or manual), including the possible addition of more transitions, is expected to evolve specifically during IT&C and the first years of operations. Once determined though (guided by safety), these states and transitions are not assumed to change frequently.

An emergency shutdown (i.e. de-energizing of major systems through sudden power cut-off) and the recovery from an emergency shutdown is not executed through software.

9.2.4 Telescope Control System

For pointing, telescope, and coudé rotator control purposes, the OCS makes available a “Telescope Control System” Ops GUI with the following functionality:

- Selection and choice of TCS mode (i.e. off, active, tracking).
- Selection and choice of TCS coordinate frame.
- Move the telescope until stopped with user-selectable different speeds or stepping increments.
- Provide and allow selection of solar rotation tracking method (i.e. none, fixed, standard, and custom).
- Provide and allow selection of continuous scanning pattern (i.e. none, circle, random).
- Rotate the coudé rotator to a specific offset angle to orient the solar image on the detector of a selected instrument in a specific manner.
- Rotate the coudé rotator by a specific user-defined angle.
- Selection and choice of coudé rotator coordinate frame.
- Rotate coudé rotator until stopped (limited by safety).
- Move Lyot stop in/out.

The “Telescope Control System” Ops GUI provides access to and allows controlling the telescope and the coudé rotator independent from Observing Programs, i.e. when in the OCS’s manual control.

The interaction with and control of the telescope (incl. coudé rotator) during and in preparation of science operations (see Executing Observing Programs) is crucial. Therefore, the “Telescope Control System” Ops GUI” is interactive (live) during the OCS’s automatic control.

It is expected that much of the details of this Ops GUI are subjected to change and evolving over time.

9.2.5 Gregorian Optical System

For observing and calibration support purposes, the OCS makes available a “Gregorian Optical System” Ops GUI with the following functionality:

- Provide selection of and allow opening/closing of upper GOS shutter.
- Provide selection of and allow moving the artificial light source in and out of the light beam (i.e. lamp in/out).
- Provide selection of and allow switching the artificial light source on or off (i.e. lamp on/off).
- Provide selection of and allow moving in and out of the light beam individual polarizers and retarders (independently from each other).
- Allow rotating an individual polarizer or retarder by a user-defined rotation angle (independently from each other).
- Provide selection of and allow rotating the aperture wheel to move into the light beam:
    - Dark slide.
    - 5 arcmin field stop.
    - 2.8 arcmin field stop.
    - 5 arcmin occulter.
    - 2.8 arcmin occulter.
    - Pinholes of different sizes.

    - Targets (e.g. grid line target, resolution target).
    - Other.
- Provide selection of and allow opening/closing of lower GOS shutter (independently from upper GOS shutter).

The "Gregorian Optical System" Ops GUI provides access to and allows controlling and configuring optics in the GOS independent from Observing Programs, i.e. when in the OCS's manual control. Specifically, the "Gregorian Optical System" Ops GUI allows configuration of the polarization calibration optics.

The interaction with and control of the GOS during and in preparation of science operations (see Executing Observing Programs) is crucial. Therefore, the "Gregorian Optical System" Ops GUI is interactive (live) during the OCS's automatic control.

It is expected that much of the details of this Ops GUI are subjected to change and evolving over time.

9.2.6 Solar Monitoring and Target Selection

For target identification, selection, and finalization purposes, the OCS makes available a "Solar Monitoring and Target Selection" Ops GUI with the following functionality:

- Display by default the full-disk image provided by the Target Acquisition Telescope.
- Provide selection of latest different full-disk images (different wavelengths or quantities) for display as provided by external providers (from all network stations GONG H-alpha, GONG magnetogram; SDO/HMI continuum intensity and magnetogram, SDO/AIA selection).
- Indicate current telescope pointing position through a marker on the solar image.
- Indicate current coudé orientation through a marker on the solar image.
- Provide selection of and display 5 arcmin or 2.8 arcmin circular FOV indicator overlay (drawn around current pointing position).
- Move telescope to any position on the solar image including positions off the limb up to 1.5 solar radii.
- Provide selection of and display coordinate system overlays (i.e. heliographic, heliocentric, helioprojective).
- Provide selection of and display celestial pole indicator overlay.
- Provide selection of and display 1.5 solar radii pointing limit overlay.
- Provide selection of and display sun center indicator overlay.
- Provide selection of and display N-W-E-S limb indicator overlays.
- Provide selection of and display NOAO AR number indicator overlay.
- Move telescope to any of the named overlay positions.
- Automatically display all targets part of an Observing Programs target list associated with a selected Observing Program (OP) on a per OP basis (OP targets).
- Allow to edit individual OP target information and save the updated information to the OP's target list (finalizing an OP target) prior and/or during Observing Program execution (Operator-WFC interaction FALSE/TRUE, depending on OP and OP script design):
    - Finalize pointing coordinates (including mosaic support, relative distances from a base pointing position).

  - Finalize coudé orientation (i.e. angle, frame).
  - Finalize WFC offsetting and lock-point details (if mosaic: for each mosaic tile).
- Display additional details of an individual OP target (cannot be changed):
  - Target List name.
  - Type (i.e. sunspot, quiet sun; pre-defined list).
  - Coordinate Frame.
  - WFC mode.
  - Solar rotation tracking method (i.e. none, fixed, standard, custom; if "custom" then display details).
- Move telescope to any of the indicated OP targets.
- Allow to create non-OP targets (transient).
- Allow to create non-solar targets (i.e. stars, comets, planets, and moon).

The "Solar Monitoring and Target Selection" Ops GUI is a target and pointing visualization tool supporting the OP target finalization process with the additional capability of moving the telescope to any allowed position on or off the solar disk. It also allows defining, creating and memorizing transient positions on the sun that are not part of a specific Observing Programs target list (and cannot be associated with those), but that might be of use and interest when operating in the OCS's manual control.

The interaction with and control of the telescope during and in preparation of science operations (see Executing Observing Programs) is crucial. Therefore, the "Solar Monitoring and Target Selection" Ops GUI" is interactive (live) during the OCS's automatic control.

It is expected that much of the details of this Ops GUI are subjected to change and evolving over time.

9.2.7 Experiments

For Experiment and Observing Program selection and execution control, the OCS makes available an "Observing Control" Ops GUI with the following functionality:

- Fetch different Experiment Lists (e.g. science list, calibration list, test list, as prepared by science operations outside of the OCS's).
- Add and display different Experiment Lists.
- Display details of a selected Experiment List:
  - Identifier.
  - Name
  - Description.
- Expand a selected Experiment List and display all of its Experiments and the Experiments status.
- Display details of a selected Experiment:
  - Identifier.
  - Title.
  - Principal Investigator information (name, email).
  - Alternative Contact information (name, email).
  - Observing Mode (i.e. service, access).
  - Program Type (i.e. Regular/Standard, Synoptic, and Target of Opportunity).
  - Coordination details (e.g. daily time window, dates, co-observing facilities).

    - Description.
- Expand a selected Experiment and display all of its Observing Programs and the Observing Programs status.
- Display details of a selected Observing Program:
    - Name.
    - Identifier.
    - Observing Task.
    - Reference Time.
    - Target List name.
    - Number of targets in Target List.
    - Required FIDO configuration.
    - Required DHS configuration.
    - Requested instruments (i.e. instrument set).
    - Must-complete instruments.
    - WFC optimized instrument.
    - Requested observing conditions.
    - Mosaicking requirements (i.e. FOV size, number of tiles).
    - Description.
    - Execution status override.
    - Test indicator (indicate whether OP is for “test”).
    - Interaction indicator (i.e. indicator whether target finalization is “passive” or “interactive”).
- Submit a selected Observing Program for execution (automatic control) and execute the Observing Programs script (only enabled for identified users).
- Allow early termination of an executing Observing Program (cancel or abort).
- Toggle data save on/off (only if OP is for “test”).
- Toggle TCS active/passive (only if OP is for “test”).
- Report completion percentage of an executing Observing Program (measured against the reference time).
- Report execution status (i.e. “done”, “aborted”, a cancel reports as “done”) after completion or early termination.
- Allow override of the OCS’s automatic Observing Program execution status of a completed or early-terminated Observing Program (with “done”, “cancel”, “abort”).

The “Observing Control” Ops GUI is the observing support execution tool through which all routine (science and calibration) observing activities are executed in the OCS’s automatic control, i.e. through the execution of Experiments Observing Programs scripts. All science observations (and calibrations) are obtained by running/executing an Observing Program script (Jython). Those scripts are generated external to the summit and cannot be changed at the summit. Every morning, possibly more than one Experiment List is imported into the OCS (and its database, the Summit Experiment Repository) informing the summit what science observations are planned for the day. These Experiment Lists, their Experiments and Observing Programs are displayed in a collapsible/expandable tree structure. Highlighted or selected Experiments and Observing Program details are viewed through individual tabs available through the “Observing Control” GUI. Specifically, the Observing Program view tab allows submitting the Observing

Programs respective script for execution, allows canceling and aborting the execution, and displays progression information through a percent complete bar. For displaying and viewing an Observing Programs Instrument Programs, see Section 9.2.11 Instrument Control System. The Observing Program view tab also indicates whether the respective Observing Program is for testing or not. If for testing, then the tab allows saving data (the default is not to save data) and “bypassing the TCS” or not (see Experiments at the Summit, Testing of Observing Programs and Instrument Programs).

It is expected that much of the details of this Ops GUI are subjected to change and evolving over time.

Outside of this “Observing Control” Ops GUI the OCS provides an Operator Log for documenting peculiar activities and events in real-time, not limited to, but specifically during Observing Program execution. Each log comment is associated with a time stamp, with Observing Program Identifiers (during Observing Program execution), and with a user-selected category (e.g. weather, solar event, instrument, problems, etc.). The category selection is easily expandable.

9.2.8 Instruments

For instrument control purposes, the OCS makes available an “Instrument” Ops GUI for each individual instrument with the following functionality:

- Create a new Instrument Program for a specific Instrument Task.
- Select and load an existing Instrument Program for a specific Instrument Task.
- Change an Instrument Program by changing its Data Set Parameters’ (DSP) values or by addition/deletion of an entire Data Set Parameters (DSP sequence building, where applicable).
- Save changes made to an Instrument Program (default Instrument Programs and Instrument Programs that are part of an Experiments Observing Program are protected).
- Execute an Instrument Program.
- Cancel/abort an executing Instrument Program.
- Report the execution status.
- Report completion percentage.
- Toggle data write on/off.
- Report and update on the progression during execution of an Instrument Program (manual control of the OCS) and during an Experiments Observing Program execution and testing (automatic control of the OCS).

The OCSs “Instrument” Ops GUI provides the capability and allows running the instrument independent of (a) any Experiment and Observing Program selected, (b) the telescope and any of its subsystems, and with or without data acquisition (manual mode). The “Instrument” Ops GUI allows selection and loading of any Instrument Program, whether they are part of an Experiments Observing Program or not (i.e. created under manual control of the OCS). Loaded Instrument Programs can be submitted for execution (the submission is a pro-active manual process) and progression information during execution is displayed by a percentage complete bar. The “Instrument” Ops GUI displays various instrument parameter fields (Data Set Parameters fields) that are populated with values (Data Set Parameters values) depending on the loaded Instrument Program and its Instrument Task. The “Instrument” Ops GUI for some instruments allows building sequences of Data Set Parameters (DSP) and iteration over those (or subgroups of those) depending on the instrument and its definition of a DSP.

The “Instrument” Ops GUI allows to cancel or abort any individual executing Instrument Program, whether part of Observing Program execution or not.

As monitoring an instruments progression and activities during any execution (but specifically during Observing Program execution) is of crucial importance, the “Instrument” Ops GUI displays the following information:

Broadband Imager

- Observing task.
- CWL of filter position in wheel.
- Number of images per file (if burst disabled).
- Number of images per burst (if burst enabled).
- Current exposure time.
- Current frame rate.
- Current number of iterations out of N iterations (or repeats, loop counters).
- ROI, full chip readout or ROI readout.
- Current binning.
- Image reconstruction enabled/disabled.

Tunable Imaging Spectropolarimeter

- Observing task.
- Spectroscopic or spectropolarimetric application enabled.
- Broadband or reference channel filter wavelength.
- CWL of filter position in wheel.
- Number of wavelength points.
- Number of images per wavelength point.
- Number of accumulations per wavelength point or modulation state.
- Current wavelength point ([nm or Angst]).
- Current wavelength point ([incremental, integer]) out of M.
- Current modulation state.
- Current exposure time.
- Current frame rate.
- Current number of iterations out of N iterations (or repeats, loop counters).
- ROI, full chip readout or ROI readout.
- Current binning.

Slit-based Spectropolarimeter

- Observing task.
- Spectroscopic or spectropolarimetric application enabled.
- Map or stationary slit application enabled.
- CWL of filters used.
- Map size (FOV).

- Slit width.
- Slit length.
- Spatial and spectral resolution.
- Number of slit positions.
- Slit step size.
- Grating angle.
- Wavelength Order.
- Number of images per slit position and modulation state.
- Number of accumulations per slit position and per Stokes I or modulation state.
- Current slit position out of N slit positions.
- Current modulation state.
- Current exposure time per frame.
- Current frame rate.
- Current number of iterations out of N iterations (or repeats, loop counters).
- ROI, full chip readout or ROI readout.
- Current binning.

Most of the above information corresponds to Data Set Parameters fields and their values on the respective “Instrument” Ops GUI.

It is expected that much of the details of these “Instrument” Ops GUI(s) are subjected to change and evolving over time.

The visualization of actual instrument data (i.e. images and spectra) is through the Quality Assurance System displays provided by the DHS.

9.2.9 Data Handling System

For managing, monitoring and control of data related tasks, the OCS makes available a “Data Handling System” Ops GUI with the following functionality:

- Initiation of the export/transfer of data with its metadata to an external off-summit repository.
- Deletion of specific data in specific stores part of the DHS.
- Change the DHS configuration.
- Display the current DHS configuration.
- Display, monitor and report of data storage and transfer levels for all instruments individually and for the system as a whole.

As the data storage capacity at the summit is limited, at the end of an observing day all data that was acquired under the OCS’s automatic control is transferred off the summit. The DHS Ops GUI allows initiating this activity. The DHS Ops GUI also allows monitoring the current summit storage capacity and provides information about the status of earlier off-summit transfers, and whether that activity succeeded or failed needing re-initiation. As different DHS configurations may be needed for the support of different Experiments and their Observing Programs, the DHS Ops GUI displays the current configurations and allows selecting and changing of standard configurations. The DHS configuration can be customized through a DHS tool that is available outside of the OCS. The DHS Ops GUI allows to search and identify (with specific pre-defined search criteria) for individual data files and supports deletion of those if applicable.

Outside of the OCS's "DHS Ops GUI", the DHS makes available GUIs and tools in the framework of its Quality Assurance System (QAS) that allow choosing and managing of its "Quality Assurance Displays" (quick look of raw data) and "Detailed Display Plugins" (some processing involved) for displaying data published by the instruments camera(s). These QAS displays need configuration and are limited in number. The DHS also makes available a specific multiplexed monitor displaying all potential data sources on one monitor at a (much) lower resolution than available through its other QAS displays. This monitor does not need configuration. This monitor is particularly important during Observing Program execution as it displays all data from all instruments at one glance allowing recognizing problems immediately.

9.2.10 Wave-Front Correction System

For WFC monitoring and control purposes, the OCS makes available a "Wave-Front Correction" Ops GUI with the following functionality:

- Select and execute routine high-and low-order WFS calibrations (e.g. dark, gain).
- Select and execute an operating mode of WFC.
- Enable/disable Deformable Mirror (DM).
- Enable/disable Tip-Tilt Mirror (TTM).
- Allow to set DM unflat/flat.
- Allow to offset the lock point of high- and low-order WFC.
- Report current WFC lock point information to other systems.
- Change update reference image method.
- Update the reference image used by the high-order WFC.
- Change the reference image update period.
- Select and execute routine Limb Tracker calibrations.
- Enable/disable the Limb Tracker (when using 5 arcmin or 2.8 arcmin occulter).
- Change set point to allow for over and over-occulting during limb tracking.
- Select and change FOV of WFC Context Viewer (i.e. 30 arcsec, 60 arcsec).
- Select and execute routine WFC Context Viewer calibrations.
- Enable/disable Quasi-static correction of active Optics (aO engine).
- Enable/disable boresight stabilization of active Optics (aO engine).

The "Wave-Front Correction" Ops GUI provides access to and allows controlling the WFC system independent from Observing Programs, i.e. when in the OCS's manual control.

The interaction with and control of the wave-front correction system and its different components (i.e. mostly the low-order adaptive optics system (LOAO), the high-order adaptive optics system (HOAO), and the "limb tracker") during and in preparation of science operations (see Executing Observing Programs) is crucial. Therefore, the "Wave-Front Correction" Ops GUI is interactive (live) during automatic control of the OCS.

It is expected that much of the details of this Ops GUI are subjected to change and evolving over time.

9.2.11 Instrument Control System

For instrument control purposes outside of an individual instruments capability (i.e. when Observing Programs are executed in the OCS's automatic control), the OCS makes available an "Instrument Control System" Ops GUI with the following functionality:

- Display a list of all Instrument Programs associated with a selected Observing Program.
- Display the (execution) status of all Instrument Programs associated with a selected Observing Program.
- Cancel/abort the execution of a specific Instrument Program on a per instrument basis during Observing Program execution (i.e. without interfering with the execution of the Observing Program and the execution of other Instrument Programs).
- Cancel/abort the execution of all Instrument Programs that belong to a specific instrument during Observing Program execution (i.e. without interfering with the execution of the Observing Program and the execution of other Instrument Programs).

The "Instrument Control System" Ops GUI displays all Instrument Programs part of an Experiments Observing Program. These Instrument Programs are displayed in a tree structure separated by instrument. Highlighted or selected Instrument Programs and their details are viewed through individual instrument tabs (see Sect. 9.2.8 Instruments).

In case the selected Instrument Program is part of an Experiments Observing Program, only some pre-defined parameter fields and their values are editable and changeable, and when saving those changes, the Instrument Programs ID remains un-changed. During Observing Program execution, any Instrument Programs parameters are inaccessible for changes (even the allowed pre-defined ones, no on-the-fly changes).

Furthermore, during Observing Program execution, the "Instrument Control System" Ops GUI allows to cancel or abort all of an instruments Instrument Programs without affecting any other instrument participating in the Observing Program execution. The reasoning is that if an instrument fails it must be possible to stop the instrument as soon as possible without spending time on bringing up an ``Instrument Engineering GUI" and/or leaving all ``Instrument Engineering GUIs" open/up all the time.

9.2.12 Facility Control System

For monitoring and changing the thermal conditioning of the observatory, the OCS makes available a high-level "Facility Control System" Ops GUI with the following functionality:

- Provide selection of and allow changing the operating mode (i.e. housekeeping, observing) of the Facility Management System (FMS).
- Provide selection of and allow changing the observing type (i.e. on-disk, coronal) of the FMS.
- Provide selection of and allow changing the observing mode (i.e. automatic, manual) of the FMS.
- Display set times for sunset (current day) and sunrise (following day).
- Display status of the air knife.
- Display status of the vent gates.
- Display status of Universal Power Supply.

It is expected that much of the details of this Ops GUI are subjected to change and evolving over time.

9.3 Telescope Control System

The TCS provides a "TCS Operations GUI" made available through the OCS. Any expected interaction with the TCS during routine operations is through the "TCS Operations GUI". For all other instances and for testing TCS interfaces with TCS subsystems and the OCS, the TCS provides a "TCS Engineering GUI".

9.4 Wavefront Correction System

The WCCS provides a "WFC Operations GUI" made available through the OCS. Any expected interaction with the WFC system during routine operations is through the "WFC Operations GUI". For all other instances and for testing the WCCS interfaces with TCS subsystems and the OCS, the WCCS provides a "WCCS Engineering GUI".

9.5 Instrument Control System

The ICS provides an "ICS Operations GUI" made available through the OCS. Any expected interaction with the ICS during routine operations is through this "ICS Operations GUI". For all other instances and for testing ICS interfaces with the OCS and the instruments, the ICS provides an "ICS Engineering GUI".

9.6 Camera Software System

For engineering purposes and for testing its interfaces with the instruments and the DHS, the CSS provides a "CSS Engineering GUI".

9.7 Data Handling System

The DHS provides a "DHS Operations GUI" made available through the OCS. Any expected interaction with the DHS during routine operations is through this "DHS Operations GUI". For all other instances and for testing DHS interfaces with DHS subsystems, the OCS, and the cameras, the DHS provides a "DHS Engineering GUI".

10 Instruments and Cameras at the DKIST

10.1 Facility Instrument

A *Facility Instrument* is an instrument that is permanently installed and fully integrated into the DKIST's control system architecture (OCS, ICS, CSS, DHS) and has the full Common Services Framework (CSF) functionality. DKIST operations staff operates and maintains a Facility Instrument. During normal Science Operations, the Facility Instrument is either automatically or manually controlled through the OCS. During automatic control of the OCS, its operation is facilitated through the execution of an Observing Program part of a specific Experiment that can be traced back to an approved Proposal. All data from a Facility Instrument is associated with an ID that unambiguously identifies the data (including complementary data, i.e. necessary calibrations) and its source Experiment and Proposal. During manual control of the OCS, its operation is completely independent from any Experiment and Observing Program and facilitated through the execution of an Instrument Program.

The Facility Instrument is available to any Investigator during service and access time. All data from a Facility Instrument is openly available to the public (or otherwise as regulated by a data policy).

The *Facility Instrument* should make available an Instrument Performance Calculator (IPC) for Investigators during Proposal Preparation and a set of plug-in tools for monitoring data and quality assurance purposes during data acquisition. The instrument builder should provide the IPC and the initial set of plug-ins.

10.2 Instrument Sets

Many Proposals are expected to request the parallel use of more than one Facility Instrument. It seems therefore useful to introduce a common term and concept for those instruments. An *instrument set* is the combination of all instruments that participate in the same Experiment related to one source (one approved proposal). An *instrument set* can be one instrument only. The *instrument set* includes only facility instruments.

10.3 Visitor Instrument

A *visitor instrument* (or instrument component) is an instrument that is only temporarily installed at the DKIST. The DKIST supports visitor instruments as regulated by policy.

10.4 Instrument Development

The DKIST supports the development of new DKIST facility instruments as regulated by policy.

10.4.1 Support for Instrument Developers

In order to ease the development of new facility instruments and their integration, the DKIST provides a collection of software components (base components) to the developers as part of the DKIST standards. The base components include controllers for I/O (motion, digital sensors), controllers for coordination (management, sequencing, scripting, and multi axis), hardware connections (various motion control boards, I/O boards, etc.). The base components, however, are extensible: instrument developers who develop new controllers or connections in support of their own requirements may submit these to DKIST for inclusion into the standards list.

10.5 Facility Cameras

Commercially available science cameras typically differ significantly with respect to detector and sensor architecture and associated software libraries. Hence, any new camera may involve a substantial software development effort for the potential user. In order to minimize or even avoid this effort, the DKIST facility cameras are controlled by a common software architecture that is able to harness internal differences between individual cameras yet provide a common interface to the user. Facility cameras controlled by this camera software system (CSS) look identical to external systems. The CSS provides the capability to tailor the camera to the demands of individual instruments. These demands are reflected in the CSS.

The DKIST CSS interfaces with the data handling system (DHS) that is responsible for all data distribution and storage.

The DKIST facility cameras are able to synchronize with modulation optics which requires a very tight timing, with latency and jitter specifications that are beyond what can be typically found in network communications. It is possible to synchronize the facility cameras to a specific time and to a specific modulation state.

The facility cameras support at a minimum the following functionality:

- Binning: allows grouping and combining of pixels into a single super pixel (accomplished either by hardware if available, and/or software).
- Region-Of-Interest: allows read-out of a defined subarea of the sensor.
- Exposure time: allows changing the exposure time.
- Frame rate: allows changing the frame rate.