Keck Adaptive Optics Note 744

Keck Next Generation Adaptive Optics:
Science Operations Tools Preliminary Design

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1. Introduction

The purpose of this document is to define the concepts for the tools that will be used to calibrate NGAO, to plan observations, to operate NGAO, and to observe. Operating NGAO and observing will occur concurrently. Where beneficial, NGAO will build upon science operations tools developed for the current LGS-AO system on Keck 2. The current tools work well, but several are prototypes that were pressed into service. The NGAO tools will incorporate features from the current system's tools, which reflect valuable operational experience, but will be the product of a more careful and methodical "interaction design" process. We assume there will be a keyword-like interface available to system experts to script calibration steps, observing simulations, and non-standard observing. This implies that functionality will not require any of the GUIs described below.

2. Vision Summary

2.1 Tools

Four or five top-level tools comprise the NGAO Science Operations Tools Suite. In the current system, planning is divided between the web-based AO Guide Star Tool, to find NGS, and the stand-alone OSIRIS Observing Planning GUI (OOPGUI), to define observing sequences. These functions may be combined into an NGAO Planning Tool, or left separate as the Acquisition Planning Tool and the Observing Planning Tool. For further discussion, we will assume separate tools. The other three stand-alone tools will be the Execution Client, the Observer's Status Display, and the Operator's Status and Control Display. We highly recommend that the current ethos of separating form and function be continued.

1. The web-based Acquisition Planning Tool will inherit strongly from the AO Guide Star Tool used by the current LGSAO system. The planning tool will require an internet connection to provide catalogs and images and will produce a data product that inherits strongly from the current LGS starlist format and will be compatible with the MAGIQ acquisition and guiding system of the telescope. This data product will be compatible with the Execution Client and will be executed as an acquisition sequence.

2. The Observing Planning tool will inherit many features of the OOPGUI and will be a stand-alone tool. It will allow the observer to define an observing sequence that includes configuring the science instrument, data taking, dithering, and offsetting. It will produce a data product that is compatible with the Execution Client and will be executed as an observing sequence.

3. The Execution Client will inherit many features of the OSIRIS Data Execution Client (ODEC) and will be the main interface to the Multi-System Command Sequencer (MSCS). The Execution Client will read in all sequences (calibration, acquisition, setup, and observing) and output them in a common format to the MSCS.

4. The Observer's Status Display will inherit from the Laser User Interface (LUI) tool developed for the current system; it provides the information needed for filling out log sheets, for making tactical observing decisions, and for automatically answering observer's questions as to why a certain step in the acquisition sequence is taking longer than usual. Although targeted toward the needs of the observer, the Observer's Status Display will be useful to the NGAO operator under nominal operating conditions. Initially, the NGAO operator may be a separate position, but eventually could be the observing assistant (OA) or support astronomer (SA).

5. The Operator Status and Control Tool will incorporate the functionality of an alarm handler along with direct status and control functions needed to optimize performance and troubleshoot fault conditions. We envision this tool to use a simplified light path to aid in troubleshooting.

Figure 1 provides a view of how each of the Science Operations Tools, outlined above, will interact with underlying software systems.

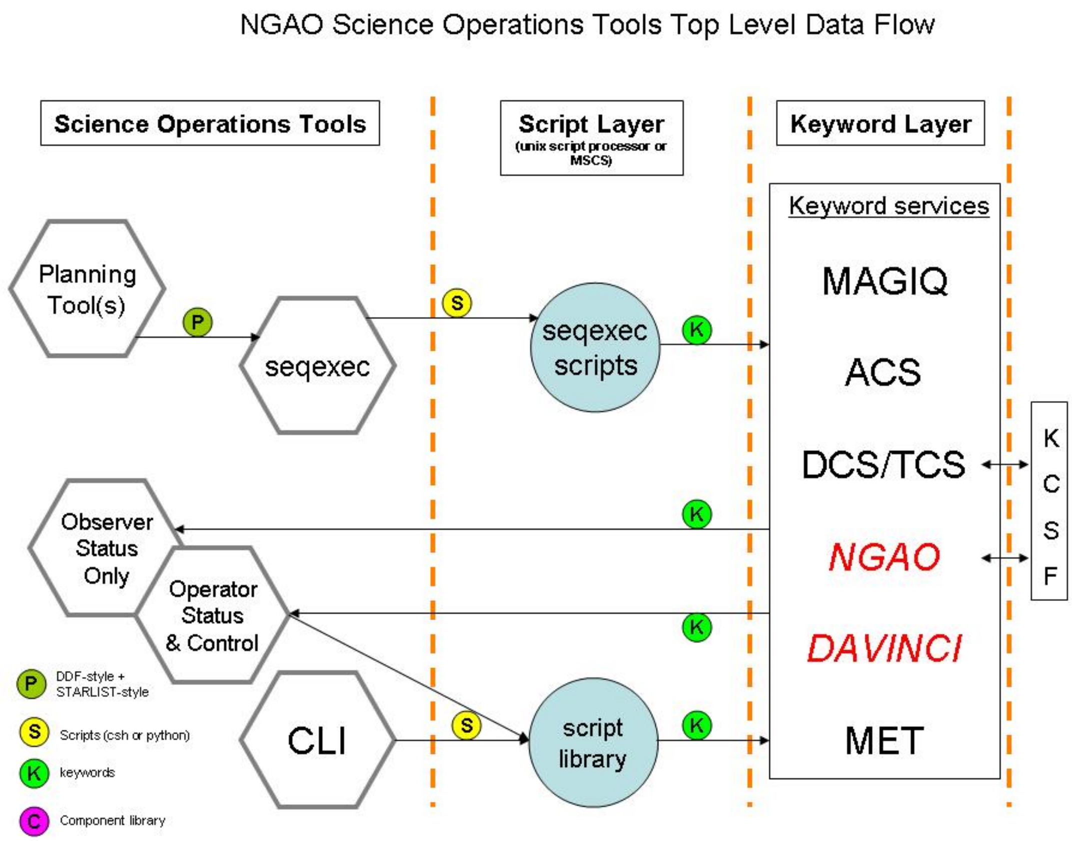


Figure 1: Top level view of the science operations tools (hexagons on the left), the lower tier comprised of scripts and existing telescope acquisition software (blue circles second from left), the lower keyword-services tier (second from right), and the underlying control system implemented via KCSF (far right).

In addition to the five top-level tools, the NGAO Science Operations Tool suite will provide tools to coordinate targets with the Laser Clearinghouse (LCH), to optimize NGAO given observing conditions and NGS "constellation", and to characterize the point spread function (PSF) as a function of time, field position, and wavelength.

2.2 Roles

The current AO system and science instruments are calibrated by a SA. The AO system, which includes the LGS, is operated by the OA during the night with backup from the SA. The science instrument is operated by the observer during the night. Behind the scenes, AO experts define calibration sequences and assist the SA with advanced troubleshooting. This is the goal of the operations model for NGAO, but likely will not happen before commissioning.

AO Expert:

- Defines calibration sequences and procedures
- Defines quantitative measures to monitor system performance
    - Strehl ratio or encircled energy
    - Current performance vs. expected performance given current conditions
    - Field-dependent PSF
- Defines methods to optimize system performance
- Assists SAs with advanced troubleshooting
- May assist with nighttime operations initially

Support Astronomer (SA)

- Calibrates NGAO and science instrument(s) for nighttime use
- Coordinates nighttime operations
- Assists OA with nighttime operations of NGAO including basic troubleshooting
- Coordinates advanced troubleshooting

Observing Assistant (OA)

- Operates the telescope
- Operates NGAO
- Performs basic troubleshooting at night

Observer

- Operates the science instrument(s)

The interferometer currently uses NGS AO mode simultaneously on both telescopes. The two AO systems are calibrated, included image sharpening on the interferometer's angle tracker camera, prior to observing. The AO white light source and acquisition camera are also used for interferometer daytime alignment purposes. Nighttime operation of the AO systems is done by the OAs. The Interferometer operator or specialist may identify AO problems at times, and in some cases the interferometer specialist may have more information or expertise to resolve problems than the OA. The interferometer will be used with LGS AO on both telescopes starting in 2011 and additional AO support may be needed for these observations.

2.3 Division of Effort

The software tools described here will require the effort of different development teams.

- NGAO Software UI team (with input and direction from SAs)
    - Acquisition Planning Tool
    - Observation Planning Tool
- NGAO Software Controls team (with input and direction from SAs and AO experts)
    - Multi-System Command Sequencer (MSCS) and GUI interface (Execution Client)
    - Alarm Handler
    - Operator's Status and Control Display
- Support Astronomers
    - Provide input and direction to all Science Operations Tools
    - Maintain laser clearinghouse coordination tools

2.4 Scope

The image display tool for the science instrument for NGAO will not be described. Especially for IR instruments, the image display tool has been the responsibility of the instrument team. Examples include Quicklook (QL) for NIRSPEC and NIRC2 and Quicklook2 (QL2) for OSIRIS. In addition to displaying incoming science images, these tools often have additional functionality that satisfies some of the Science Operation Tools Functional Requirements. We assume that the following Functional Requirements will be satisfied by the DAVINCI image display tool:

ID	Short Name	Description	Comments
FR-1913	Image Size and Profile Measurements	The acquisition system shall include tools to measure the FWHM and ellipticity of images, and to provide a profile of these images.	To be provided by DAVINCI image display tool. QL/QL2 do this via 2D Gaussian fit
FR-2206	Quick look data reduction tool	A quick look data reduction tool shall be provided for semi-realtime analysis of the NGAO imager and IFU data.	Equivalent to OSIRIS Online Reduction Pipeline
FR-2209	Semi-real-time SNR calculator	Provide a semi-real-time tool to determine point-source SNR from an image or IFU slice.	To be provided by DAVINCI image display tool. QL/QL2 do this via aperture photometry
FR-2210	Semi-real-time Strehl calculator	Provide a semi-real-time tool to determine point-source Strehl from an image or IFU slice.	NIRC2 has a stand-alone tool for this. Features could be included into DAVINCI image display tool
FR-2211	Semi-real-time Ensquared Energy calculator	Provide a semi-real-time tool to determine point-source ensquared energy from an IFU slice.	Possible substitute for IFS Strehl tool (FR-2210). Could be included in DAVINCI image display tool
FR-2213	Data quality assessment tool	Provide a semi-real-time tool to assess the quality of the science data.	Redundant? See other FRs in this table
FR-2231	Acquisition and AO control user interface	Provide a user interface for NGAO acquisition and AO control, including science instruments.	Acquisition interface will be Execution Client; AO control provided by Operator's Status and Control Display; Science instrument control provided by DAVINCI team

3. Calibrations

Calibrations may fall into several categories including: 1) Calibrating NGAO to provide optimized closed-loop image quality; 2) calibrating PSF as a function of position, wavelength, and observing conditions; and 3) calibrating wavelength and flat field stability for the science instrument.

We will leave the definitions of which NGAO calibrations are necessary to AO experts, but will describe some features that are needed. Calibration sequences may be stand-alone scripts or could be a configuration sequence that is loaded into the Execution Client. Whatever implementation is chosen, the goal of calibrations is that it can be done by a SA following a reasonable procedure. Once calibrations are completed, there should be an observing simulation sequence that allows one to verify point source image quality on the science instruments.

Requirements Compliance:

ID	Short Name	Description	Comments
FR-2214	PSF calibration tool	Provide a tool/method to provide a PSF estimate versus field position for each NGAO imager or IFU image to a TBD performance level.	Heavily dependent on FR-2197 PSF performance documentation. Category

			2 above
FR-2218	Calibration sequences	Provide a sequence(s) to perform all required calibrations of the NGAO facility including science instruments.	Categories 1 and 3 above

4. Planning

Planning observations using NGAO consists of two main tasks: defining acquisition sequences and defining observing sequences. The NGAO planning tools will meet the defined requirements while the goal for NGAO planning tools should be to have the observer plan their observations enough so that the observers are efficient at the telescope, but not restrict them so much that small changes are difficult.

The planning tools for NGAO should build upon the excellent AO Guide Star Tool and OSIRIS Observer Planning GUI, OOPGUI (see appendix II-A, (i) and (iv)). The AO Guide Star Tool is a web-based utility that displays survey images and catalog positions of possible guide stars. Observers can determine whether a guide star is within reach of the system and add it to their starlist. Once complete, the observer may submit their starlist via this tool in the proper format. The OOPGUI is a java-based tool that allows observers to visualize their OSIRIS dither pattern on a grid representing the sky. Once defined, this dither pattern can be saved as an xml file or sent directly to the OSIRIS Data Execution Client, ODEC (see appendix II-A, (ii)).

The acquisition planning and Observation Planning Tools could be combined into one tool or kept separate. If combined, one would need to pick an implementation. If kept separate, the two tools must use the same format of text file such that one can pass starlists and observing sequences between the two tools. Regardless, some new features are required for these tools.

4.1 Acquisition Planning

Acquisition planning is the process of choosing the required natural guide stars (NGS); typically three for LGS AO science observations or one for NGS AO science. The output of such planning will be a Keck-formatted starlist with flags as described below that the Execution Client can use to configure NGAO for acquiring each target (as described below). In addition to the features of the AO Guide Star Tool, the Acquisition Planning Tool (see appendix III-A) will have the ability to:

- Load images from surveys other than DSS (SDSS, Pan-STARRS, LSST)
- Load user-supplied images
- Search online image archives and create links to images (HST, Subaru, etc.)
    - often, these archives do not serve images like DSS, but rather allow registered users to download raw or reduced FITS files
- Cross-check available catalogs to flag:
    - high proper motion stars
    - galaxies
    - magnitude or coordinate disagreements among catalogs
- Provide access to an online ephemeris calculator such as JPL Horizons for nonsidereal targets
- Perform rudimentary color transformations to estimate magnitudes in the proper band if no measurements are available
    - given Rmag, b-v, and b-r, one can, for example, estimate Jmag and Hmag assuming the star is “normal”
- Overlay brightness and accuracy of astrometry onto images
- Allow users to upload their own catalog information in either absolute or relative coordinates
- Estimate the AO performance (Strehl ratio, encircled energy, field dependent PSF) given median conditions with the selected NGS “constellation”
- Estimate the time required to acquire and optimize NGAO with the selected NGS “constellation”

Requirements Compliance:

ID	Short Name	Description	Comments

FR-2194	Photometric and astrometric catalogs	Provide photometric and astrometric catalogs in support of observing preparations.	Acquisition Planning Tool will provide “access” to existing catalogs
FR-2195	Ephemeris calculator	Provide access via the web to ephemeris calculators for small solar system bodies and planets, and for satellites of the giant planets in support of observing preparations.	MAGIQ UI has a similar feature that should be straightforward to implement in Acquisition Planning Tool
FR-2196	Strehl performance documentation	Provide plots of Strehl versus seeing conditions, guide stars brightness, guide stars off-axis distance, wavelength, sodium return, etc. for the NGAO imager.	From commissioning data
FR-2197	PSF performance documentation	Provide images of PSFs versus seeing conditions, guide stars brightness, guide stars off-axis distance, wavelength, sodium return, etc. for the NGAO imager.	From commissioning data (will require significant on-sky time)
FR-2198	Ensquared energy performance documentation	Provide plots of ensquared energy versus seeing conditions, guide stars brightness, guide stars off-axis distance, wavelength, sodium return, etc. for the NGAO IFU.	From commissioning data
FR-2202	Acquisition performance documentation	Document the required acquisition time (from end of slew to start of science exposure) for various science cases.	From commissioning data
FR-2217	Configuration sequences	Provide a sequence(s) to configure the NGAO facility including science instruments for each required observing configuration.	Acquisition Planning Tool will output an acquisition sequence that will configure NGAO
FR-2220	Acquisition sequences	Provide an acquisition sequence(s) to perform all required acquisitions of the NGAO facility including science instruments	Output of Acquisition Planning Tool
FR-2228	Setup User Interface configurations	Provide a user interface to setup the NGAO facility including science instruments into the required observing configurations.	Covered jointly by Acquisition Planning Tool and Observation Planning Tool
FR-2238	NGS star finder	Provide a tool to identify suitable NGS for NGS and LGS observations with NGAO, and to generate star lists.	

4.2 Observation Planning

Observation planning will define the observing sequence that the Execution Client can use to collect data. An observing sequence can include instrument configuration(s) such as pixel scale, filter, integration time(s) and dither and offset patterns. The output from such planning will be a text file that will be readable by the Execution Client which will communicate with the MSCS. In addition to the functions provided by the OOPGUI, the Observation Planning Tool will have the ability to:

- Read the starlist (acquisition sequence) and import target and NGS positions
- Load a sky survey image (DSS, SDSS, Pan-STARRS, LSST)
- Load a user-supplied image
- Overlay the dither pattern on the sky image (this is the most requested feature of the OOPGUI)
- Estimate the SNR and precision of astrometry and photometry of an observation given median conditions, the predicted NGAO performance, the source flux, and the total integration time
- Estimate the total integration time needed to obtain the required SNR given median conditions, the predicted NGAO performance, and the source flux

- Estimate the companion sensitivity of an observation given median conditions, the predicted NGAO performance, the source flux, the companion separation, and the total integration time
- Alert user if dither sequence does not dwell long enough for TWFS optimization (NGS mode only)

The Gemini Observing Tool, OT (see appendix II-A (iii)) provides a similar paradigm to that used by OOPGUI and ODEC. As with the OSIRIS tools, one tool, the OT, is used to generate the sequence, while a second tool, seqexec (not shown), is used to execute it. For this case, the hierarchical list is displayed in the former (planning) tool, however. For OSIRIS, the hierarchical list is displayed in the Execution Client. Another fundamental difference between the Gemini and OSIRIS paradigms: the OT includes target acquisition information in addition to instrument sequencing. There also exists a key similarity between the two packages: the format used for passing information from the planning tool to the execution tool is XML. The NGAO tools will incorporate the best features from these two proven paradigms.

Requirements Compliance:

ID	Short Name	Description	Comments
FR-2190	Throughput and emissivity performance tool	Provide a tool to estimate throughput and emissivity in support of observing preparations.	Required for SNR calculations; from commissioning data
FR-2191	Imaging simulation performance tool	Provide a tool to simulate imaging observations sensitivity, contrast and resolution in support of observing preparations.	Required for SNR and companion sensitivity calculations; from commissioning data
FR-2192	IFU sensitivity simulation performance tool	Provide a tool to estimate the sensitivity of IFU observations in support of observing preparations.	Required for SNR calculations; from commissioning data
FR-2199	Astrometric performance documentation	Provide plots of astrometric performance and stability versus the relevant parameters including Strehl, stellar magnitude and off-axis distance, and crowded versus non-crowded fields.	From commissioning data
FR-2200	Photometric performance documentation	Provide plots of photometric performance versus the relevant parameters including Strehl, stellar magnitude and off-axis distance.	From commissioning data
FR-2201	Companion sensitivity performance documentation	Provide plots of companion sensitivity versus distance from the primary star versus the relevant parameters including Strehl.	From commissioning data
FR-2203	Zero-point magnitude documentation	Provide the zero-point magnitudes for the NGAO imager and IFU.	Required for SNR calculations; from commissioning data
FR-2204	Signal-to-noise ratio documentation	Provide plots of point source SNR versus exposure time for the imager under various conditions.	Required for SNR calculations; from commissioning data
FR-2212	Observing sequences tool	Provide a tool(s) to simulate, prepare and run the observing sequence for each target.	
FR-2221	Observing sequences	Provide the observing sequence(s) to perform observations with the NGAO facility including science instruments.	
FR-2228	Setup User Interface configurations	Provide a user interface to setup the NGAO facility including science instruments into the required observing	Covered jointly by Acquisition Planning Tool and Observation

		configurations.	Planning Tool
FR-2229	Setup User Interface calibrations	Provide a user interface to setup the NGAO facility including science instruments for calibrations.	
FR-2232	Observing sequences user interface	Provide a user interface for NGAO observing sequences including science instruments.	
FR-2239	Performance prediction tool	Provide a tool to support performance predictions that integrates all of the prediction tools.	
FR-2240	Observation planning and efficiency tool	Provide a tool to support observation planning including observation efficiency calculations.	Efficiency can be included in SNR calculations as is done for NIRC2

5. Operations

5.1 Acquisition

5.1.1 Current System

The current AO Acquisition Tool (see appendix II-B (ii)) reads in a Keck-formatted starlist and monitors the currently selected telescope target. It matches the current telescope target to a TT star in the starlist and calculates the offset from the TT star to the science target. Science targets are denoted with an “lgs=X” flag, where “X” can be either “1” for an LGS target or “0” for an NGS target. TT stars are denoted with either “vmag=” or “rmag=” flags and “b-v=” or “b-r=” flags. Science targets may be their own TT stars in the current system.

5.1.2 NGAO

NGAO will require 3 TT NGS stars for each science target and will directly acquire the science target instead of acquiring the TT stars first; however, we think using the Keck-formatted starlist model should be kept for NGAO. The Execution Client will use the starlist as the acquisition sequence. The planning tools will output the proper format to make this process straightforward for the observer. In addition to the astrometric coordinates of the science target and the TT stars, the observer will be required to define the position angle on the sky with the flag “pa=” for the science target and the magnitude and color estimates for each TT object. The observer will also need to identify one of the TT stars as the TTFA object via a flag “ttfa=1”. For example:

```
NGC 6240         16 52 58.898 +02 24 03.44 2000.0 lgs=1 pa=35
   tt000         16 53 01.214 +02 24 14.11 2000.0 ttfa=1 b-r=1.55 b-v=0.86 jmag=11.96
   tt001         16 53 00.447 +02 23 20.24 2000.0 b-v=0.63 jmag=15.12
   tt002         16 52 58.912 +02 24 47.80 2000.0 b-r=1.08 rmag=16.31
   tt003         16 52 55.871 +02 23 31.24 2000.0 b-r=1.18 b-v=0.66 jmag=16.05
   tt004         16 52 56.933 +02 24 01.23 2000.0 b-r=0.6 jmag=15.2 hmag=14.7
```

All information needed to configure the AO system is given in the above example. We know we are in LGS mode and we can calculate the offsets in arcseconds that each probe arm is from the science target. We have defined which offset should be associated with the TTFA LOWFS and how to adjust the positions of the LOWFS probe arms due to DAR once the science wavelength is known. Using these data and the PA on the sky, we can position the LOWFS probe arms for acquisition. We include 5 TT stars in our example because sometimes TT stars as selected from catalogs are not single stars, but rather are close binary systems or galaxies that render them unusable. We include color information for all TT stars in case the defined TTFA star is unusable. This implies that the acquisition sequencer needs to allow the operator to redefine the TTFA and other LOWFS stars in real time.

With proper IR NGS catalogs, one should only need to provide the “jmag=” and “hmag=” flags in the starlist for proper LOWFS configuration. At first glance, the visible color and brightness information may seem extraneous; however, according to KAON 567, GSC2.2 is likely to be the NGS catalog at NGAO first light. Because this catalog is in the visible, NGAO will need to use visible magnitudes and colors and the assumption that the NGS is a normal star to extrapolate brightness information in the IR (J- and H-bands). In fact there may be no IR all-sky catalog that will go deep enough for NGAO even after several years of operation. Additionally, the current WFS and STRAP have a color dependent effective wavelength. We do not know if the LOWFS detectors will have a similar property or if the effect will be large.

5.2 Operational Status

5.2.1 Current System

For the current system, there are several GUIs that display operational status (see appendix II-B (i) – (vi)). These include the SC GUI (stage faults), LUI (laser on/off, loop status, etc.), DM screens (laser on/off, laser permissives), WFS Intensity Display (light on WFS), TT Graphs (TT performance), AO Acq (FSM/TSS positions), and many others. Their strengths and weaknesses are outlined in detail on a Twiki Page. Essentially, we look forward to a more integrated system for displaying the status of NGAO.

5.2.2 NGAO

With several more wavefront sensors, NGAO will have to manage screen real estate better than the current system. Displays of all WFSs likely will not be possible, but may need to be “popped up” if a problem is suspected. The simple LUI display should be repeated and should be the front end to a more elaborate GUI that would help with troubleshooting (as described below). The basic display will be the Observer’s Status display; the more elaborate display will be the operator’s status and control display. The Observer’s Status display may include the helpful TT graphs. The Operator’s Status and Control display will show a stylized light path of the AO bench, LGS facility, and science instrument. These light paths may be in separate windows or tabs if space is at a premium. Stages will be labeled and display a summary of their status. If selected, more detailed information for that stage can be displayed in something like a DM screen format. We strongly recommend that an interface in the form of the SCGui is not repeated.

One idea for displaying multiple WFSs includes displaying the mean intensity of all LGS WFSs. The operator would be alerted if the difference of an individual WFS and the mean WFS rose above a threshold.

Requirements Compliance:

ID	Short Name	Description	Comments
FR-2231	Acquisition and AO control user interface	Provide a user interface for NGAO acquisition and AO control, including science instruments.	Acquisition interface will be Execution Client; AO control provided by Operator’s Status and Control Display; Science instrument control provided by DAVINCI team
FR-2233	Status and graphs user interface	Provide a user interface for NGAO status and graphs, including science instruments.	Observer’s Status Display
FR-2234	Advanced monitoring user interface	Provide a user interface for NGAO advanced monitoring, including science instruments.	Operator’s Status and Control Display. Will also interface with alarm handler (see Troubleshooting)

5.3 Observing

NGAO will have a Multi-System Command Sequencer (MSCS) that will provide overall coordination control among the AO system, LGS facility, telescope, and science instrument. Development of the MSCS is the responsibility of the NGAO software controls team; however, a tool is required that allows intuitive access for observers to submit sequences to the MSCS. We envision this tool, the Execution Client, would also be used for acquisition and calibration sequences.

The NGAO Execution Client will be able to read in the all products of the Acquisition Planning and Observing Planning Tools and send these to the MSCS in the form of a common structure. These include NGAO calibration sequences, configuration sequences, acquisition sequences, and observing sequences.

One model would be the OSIRIS OOPGUI/ODEC combination. In this model, NGAO users would interact with the planning tools and then send their sequence to the Execution Client. One important feature would be added to the NGAO Execution Client that is absent in the ODEC; observers could change the order of their observing sequence on the fly to respond to changing observing conditions such as LTCS or US StratCom laser shutter events.

The keyword interface gives users the ability to quickly and easily change parameters (such as a filter position) from nearly any terminal. Keywords are most valuable for staff as they can script new capabilities as they become available and necessary. This flexible and powerful interface will be kept for NGAO.

Requirements Compliance:

ID	Short Name	Description	Comments
FR-2216	Setup sequences common structure	Provide a common structure for science operations setup sequences	Generally part of an acquisition sequence, but can include calibration setups
FR-2219	Observing sequences common structure	. Provide a common structure for science observing sequences	All science operations tools will be able to exchange starlists, sequences, and any other configuration data among them.
FR-2227	Setup User Interface common structure	Provide a common structure for the setup user interfaces.	All science operations tools will be able to exchange starlists, sequences, and any other configuration data among them.
FR-2230	Observations User Interface common structure	Provide a common structure for the observing user interfaces.	All science operations tools will be able to exchange starlists, sequences, and any other configuration data among them.
FR-2231	Acquisition and AO control user interface	Provide a user interface for NGAO acquisition and AO control, including science instruments.	Acquisition interface will be Execution Client; AO control provided by Operator’s Status and Control Display; Science instrument control

			provided by DAVINCI team

5.4 Optimization

The current AO system queries the telemetry database to obtain system performance information; however, this data is rarely used to adjust AO control loop parameters such as frame rate or loop gains. Instead, operational experience has created lookup tables of control loop parameters based upon characteristics such as (natural and/or laser) guide star brightness.

The NGAO system may require more adjustment as the multiple NGS and LGS create a new phase space. These tools will need to be developed once NGAO is on-sky.

This most closely relates to FR-2223; however, there are many unknowns for how this will work.

5.5 Laser Clearinghouse Coordination

We expect NGAO to have similar restrictions on laser propagation as does the current system. Currently, observers must submit their starlist to Keck 4 days prior to their observing run. SAs process this starlist from the Keck format to the US Strategic Command Laser Clearinghouse (LCH) format according to an interface control document (ICD) agreement via standalone csh and IDL scripts. The SA must submit the list to LCH 3 days prior to the observing run. After the cleared list is returned to Keck, the SAs process the cleared list from LCH into formats suitable for humans, a standalone GUI called Spiral Tool, and a redundant "backend" tool.

During the night, the Spiral Tool warns of upcoming satellite closures, then automatically opens the AO control loops and shutters the laser to avoid unpermitted propagation. If the Spiral Tool fails (it never has) the redundant "backend" tool will also shutter the laser. Additionally, there is a Laser Traffic Control System (LTCS) that monitors the Az/El of each participating telescope on Maunakea and will shutter the laser if another telescope has priority.

These tools have proven to be very reliable and we intend to keep them (or their functionality) in the era of NGAO. We note that AO control loops and laser propagation are controlled via keywords.

Requirements Compliance:

ID	Short Name	Description	Comments
FR-2241	Laser clearinghouse coordination tool	Provide a tool to support target list coordination with the Laser Clearinghouse.	process_list, process_spiral, spiral.csh, LTCS

5.6 Troubleshooting

The troubleshooting tools stand to benefit the most with the careful design process in place for NGAO. Troubleshooting tools encompass alarm handlers to detect problems, a GUI to show the error to the operator, and procedures to recover from problems. The current AO system has no integrated alarm handler, but rather a collection of tools that detect some faults. Anecdotally, when used with the current AO system, the standard Keck alarm handler detects too many false alarms to be useful. As the MSCS coordinates control among the AO system, LGS facility, telescope, and science instrument, it should be the primary handler of alarms (FR-2225). We envision that the NGAO alarm handler will communicate with the NGAO Operator's Status and Control display. When an alarm is triggered, the NGAO Operator's Status and Control display will expand to show the location of the error and a link to the troubleshooting procedures. As described above, the stylized light path of the NGAO Operator's Status and Control display should shorten the learning curve for NGAO and allow more efficient operations.

Requirements Compliance:

ID	Short Name	Description	Comments
FR-2224	Alarm handler and troubleshooting sequences common structure	Provide a common structure for alarm handler and troubleshooting sequences	Alarm handler will communicate with Operator's Status and Control Display
FR-2226	Troubleshooting sequences	Provide a troubleshooting sequence(s) to perform all required troubleshooting of the NGAO facility including science instruments	These may be procedures that are developed as NGAO operates
FR-2234	Advanced monitoring user interface	Provide a user interface for NGAO advanced monitoring, including science instruments.	Operator's Status and Control Display. Will also interface with alarm handler
FR-2235	Optimization and troubleshooting user interface	Provide a user interface for NGAO optimization and troubleshooting, including science instruments.	Focus on troubleshooting. UI is the Operator's Status and Control Display; Science instrument troubleshooting may be procedures

5.7 Observer Tools

The current LUI provides observers with traffic signals to indicate good or bad performance. This simple interface should be kept as the Observer's Status display with minor additions. In addition to the information provided currently, we should provide users with seeing estimates or measurements and a comparison of the current performance compared to predicted performance in real time.

Requirements Compliance:

ID	Short Name	Description	Comments
FR-2233	Status and graphs user interface	Provide a user interface for NGAO status and graphs, including science instruments.	Observer's Status Display

6. Post-observing

Knowledge of the point spread function (PSF) is a requirement for nearly all NGAO science cases. The details of PSF reconstruction will be left to another document, but the PSF (measured, reconstructed, or estimated) must be a data product of NGAO. The format of the PSF may be a simulated image or spectrum from the science instrument. This PSF must be known as a function of time. Observers will also want a time series of conditions (seeing and weather), measured versus predicted performance, and a list of calibration files they need to reduce their data. Scalar information can be saved in FITS headers while other supplemental data can be included in a subdirectory of the data directory. We do not discuss a science instrument data reduction pipeline here.

Requirements Compliance:

ID	Short Name	Description	Comments

FR-2242	Science observation metadata	Provide a set of metadata (AKA generic data products) to be provided with science observations either as FITS header information or as supplementary data.	Other metadata will be helpful for a possible archive

7. Documentation

Documentation is vital to the successful operation of any complex system and NGAO is no exception. All Science Operations Tools will be documented. Additionally, we will adopt a rather broad definition of documentation to include procedures, web pages, planning tools, performance metrics, and system logging. We propose dividing responsibility for various documentation requirements in the following way:

AO experts

- Define and document calibration procedures
- Define performance metrics
- Log performance metrics (with SAs)
- Define and document acquisition and observing procedures (with SAs)

SAs

- Define science calibration procedures and document
- Define and document instrument performance characteristics
- Log performance metrics (with AO experts)
- Define and document acquisition and observing procedures (with AO experts)

NGAO should adopt a common log format for ease of problem investigations.

Requirements Compliance:

ID	Short Name	Description	Comments
FR-2205	Performance documentation tools	Provide the performance characterization tools, and documentation to support these tools, to allow operational personnel to periodically update the performance documentation.	Can use tools to be developed for IPM
FR-2222	Quality monitoring sequences	Provide a quality monitoring sequence(s) to perform all required quality monitoring of the NGAO facility including science instruments	Strehl and EE tools may satisfy science instrument portion of this requirement
FR-2243	Quality metrics and logged information	Log TBD quality metrics.	Suggest standard format for logs
FR-2236	Astronomer user documentation	Provide user documentation for the astronomer/observer.	Partially provided by planning tools
FR-2237	Operator user documentation	Provide user documentation for the NGAO operator(s).	Acquisition and observing procedures

Appendices

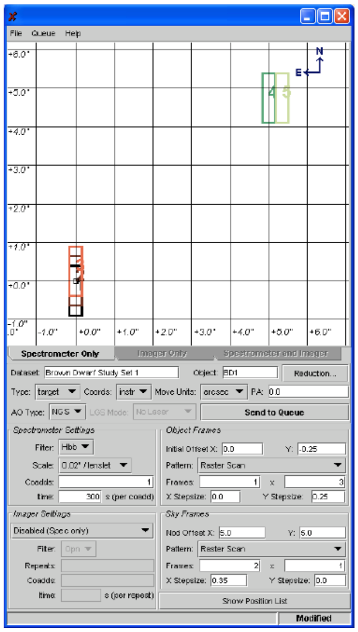
I. Mapping to Official NGAO WBS

WBS #	WBS Name	Mapping to section in this

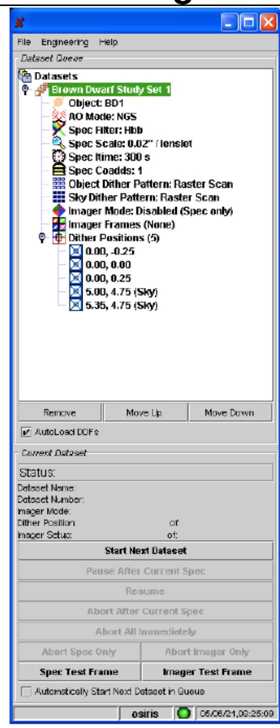
		document
1.3.7.2.1.1	UI Command Interface to MCS	Section 4.3
1.3.7.2.1.2	UI Command Interface to Pre & Post Ops	N/A
1.3.7.2.2.1	Setup UI: Common Structure	N/A
1.3.7.2.2.2	Setup UI: Configurations	N/A
1.3.7.2.2.3	Setup UI: Calibrations	Section 2
1.3.7.2.3.1	Observations UI: Common Structure	N/A
1.3.7.2.3.2	Acquisition and Control UI	Section 4.1
1.3.7.2.3.3	Observing Sequences UI	Section 4.3
1.3.7.2.3.4	Status and Graph UI	Section 4.2
1.3.7.2.3.5	Advanced Monitoring UI	N/A
1.3.7.2.3.6	Optimization and Troubleshooting UI	N/A
1.3.7.3.2.1	NGS Star Finder	Section 3
1.3.7.3.2.2	Performance Prediction Tool	N/A (TBD for section 3)
1.3.7.3.2.3	Observation Planning and Efficiency Tool	N/A
1.3.7.3.2.4	Laser Clearinghouse Coordination Tool	Not needed?

II. Sample GUI Views: Existing Tools

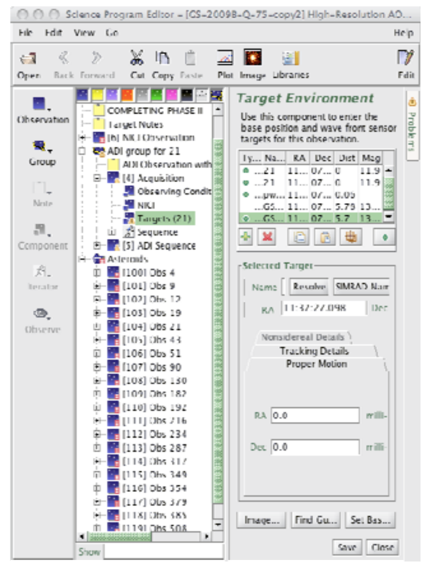
A. OOPGUI, ODEC, Gemini's 'Observing Tool' (OT), and the AO Guide Star Tool Web Page.



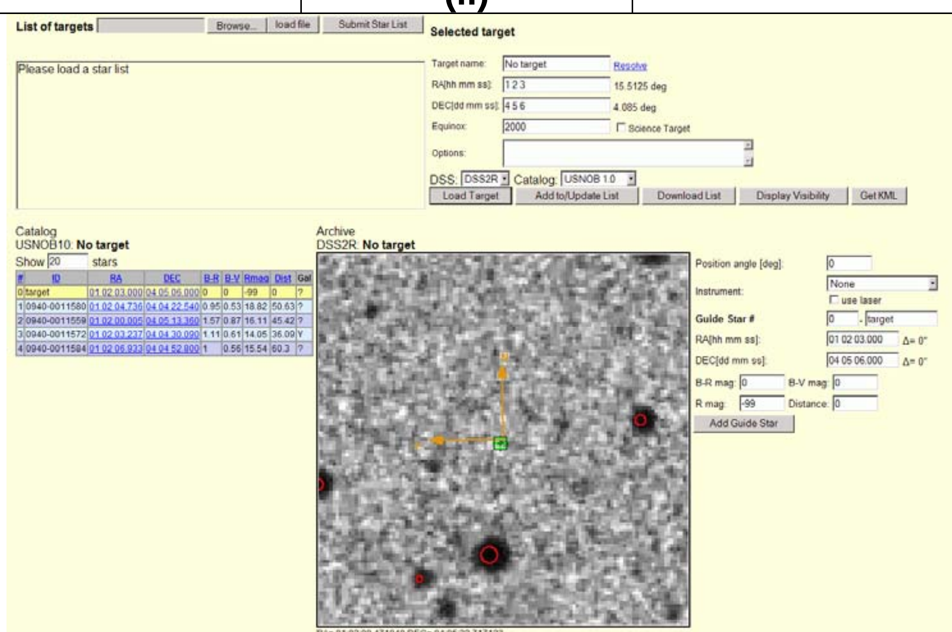
(i)



(ii)

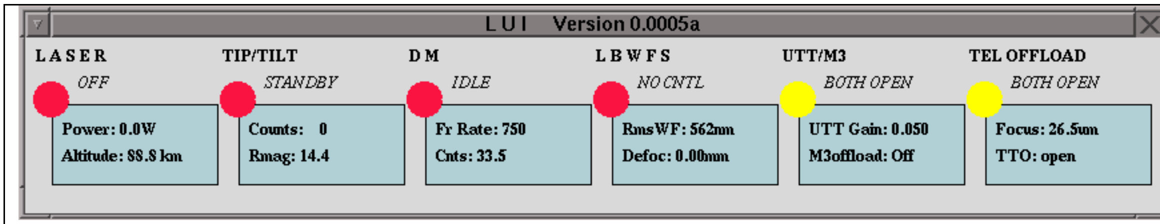


(iii)

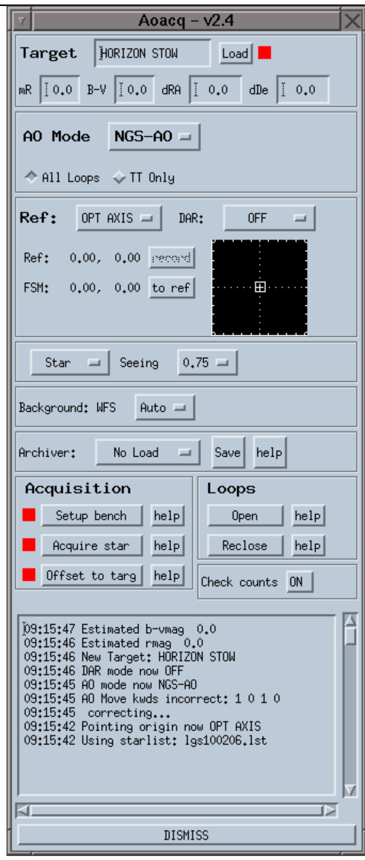


(iv)

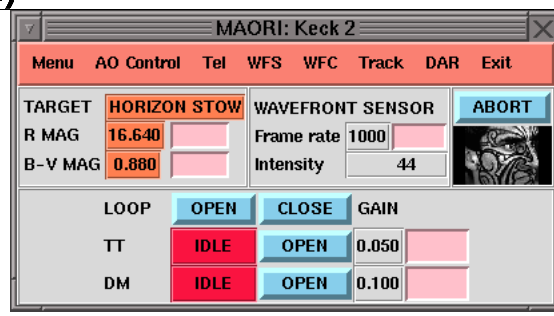
B. LUI, aoacq, Maori, SCGUI, WFI, and Strap-status.



(i)

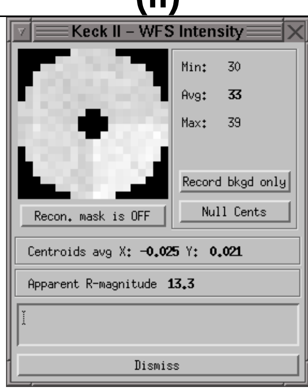


(ii)

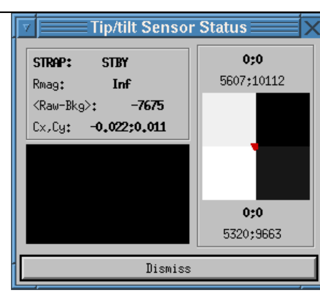


(iii)

(iv)



(v)



(vi)

III. Sample GUI Views: New Concepts for NGAO

A. Web page for guide star planning