Keck Adaptive Optics Note 771

NEXT GENERATION ADAPTIVE OPTICS: SYSTEM REQUIREMENTS DOCUMENT

PRELIMINARY DESIGN RELEASE

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1 INTRODUCTION

This document describes the requirements for the Next Generation Adaptive Optics (NGAO) system to be built for the W. M. Keck Observatory (WMKO).

The requirements in this document are intended to be at a level appropriate for the preliminary design phase. Further development of the requirements will take place in the next phase of the project (detailed design). In particular, parametric performance requirements given at this stage are intended to indicate the scope and format of the requirements, but do not in all cases establish final values for the specified parameters. In some cases, values for these parameters have yet to be established and are given as to be determined (TBD) or to be confirmed (TBC).

All of the NGAO science, system and functional requirements are maintained in a requirements database tool called Contour produced by Jama Software. Inside the database separate folders are used for the science, system, functional and Keck standards requirements, as well as folders for interfaces and NGAO controlled documents. Within the system requirements folder the requirements are organized by categories such as overall, optical, mechanical, etc. Within the functional requirements folder the requirements are organized to match the NGAO Product Breakdown Structure. The requirements from Contour were output into this document for the preliminary design review. A single requirement in the database contains the following information:

> **ID**: unique letter and number designator for requirement, all system requirements have a designator SR-#
> **Short Name**: brief name that summarizes what the requirement is about
> **Description**: statement of the requirement in a few sentences
> **Rationale**: statement of why the requirement is needed
> **Relationships**: database links to other requirements that are derived from this requirement and links to requirements that were used to develop the current requirement
> **Version History:** a list of changes including author and date.
> **Status:** requirement is draft, approved, final, etc.
> **Attachments:** hyperlinks to related electronics files inside the database or links to outside information such as the NGAO project TWiki related to that requirement

For this document only the ID, short name and description are exported from the database and included in the statement of requirement. Because the database is accessible over the internet, the process of requirements development and version control happens directly through the webpage interface. A person at any of the main NGAO partner institutions is able to have an up to date version of the requirements. Our previous method of requirements management consisted of emailing MS-words versions of a requirements document between teams. The current process is more flexible and efficient.

In all levels of the requirements, steps were taken to assure that each documented specification is traceable back to its origin or driver. The most relevant sources are the top level NGAO science

requirements and essential observatory standards but in many cases requirements are generated based on architectural design decisions, engineering best judgments, or for other reasons. Maintaining requirements traceability enables reasonable change control, so that the systems engineer is able to understand and manage the impact of descopes, engineering "push backs," error budget redistribution, etc.

A more generic set of requirements for new WMKO instrumentation is described in the projects Keck Standards section of the contour database. They are based on standards and solutions that capture the Observatory's unique knowledge and experience. The Keck Standards are based on the earlier "Instrumentation Baseline Requirements Document" KAON 572. The NGAO system requirements and functional requirements will take precedence over the "Keck standards" in the event of a conflict.

It is important to understand that at this stage of development, the requirements provide a basis for identifying the parameters that will be part of the system's specifications, but the values given are subject to change as the development continues. During the next phases of the project, work will be done to refine the requirements for review at the preliminary design review. The final requirements to be reviewed at the detailed design review will form the basis for the acceptance test criteria for the instrument.

2 SCOPE AND APPLICABILITY

This document establishes requirements for all aspects of NGAO. This document also establishes requirements for changes to related Keck telescope subsystems and software where required.

This document does not address the requirements for the science instruments that will work with NGAO, although it does cover some of the NGAO interfaces to these instruments. Separate system requirements documents will need to be prepared for the instrument as part of their design process.

3 REFERENCES

3.1 Related Documents

1. KAON 572. Instrumentation Baseline Requirements Document.
2. KAON 399. NGAO Proposal Executive Summary.
3. KAON 400. NGAO Proposal.
4. KAON 455. NGAO Science Case Requirements Document v2.0.
5. KAON 476. NGAO Science Operations Observing Model Trade Study.
6. KAON 550. System Configurations Spreadsheet
7. KAON 580. Requirements Management Software Evaluation
8. KAON 636. Observing Operations Concept Document
9. KAON 638. Requirements Approval and Change Process

10. KAON 642. NGAO Design Changes in Support of the Build-to-Cost Guidelines.
11. KAON 716. NGAO Preliminary Design Wavefront Error Budgets
12. KAON 721. Wavefront Error Budget Tool
13. KAON 722. High-Contrast Error Budget Tool
14. KAON 723. Performance Flowdown Requirements Spreadsheet
15. KAON 772. NGAO Compliance Matrix and Appendix
16. KAON 153. Coordination and Use of Laser Beacons for AO on Mauna Kea.
17. ANSI Z136.1 Safe Use of Lasers Indoors (2000).
18. ANSI Z136.6 Safe Use of Lasers Outdoors (2000).

3.2 Referenced Drawings

1410-CM0010 Primary Mirror Mapping to Deformable Mirrors
KAON 726 NGAO SolidWorks Model
KAON 727 A definitive version of the optical design file

4 REVISION HISTORY

Version	Date	Author	Reason for revision / remarks
0.1	May 24, 2010	C. Neyman	Release of draft for preliminary design phase. Requirements description, ID, and short name from Contour database. Includes science case flow down to aggregated system requirements. Removal of science requirements tables as redundant to ScRD

5 BACKGROUND

5.1 Purpose

The purpose of the background section of this document is to provide context and related information for the requirements defined in later sections of this document.

5.2 Motivation for the Development of NGAO

The Keck telescopes are the world's largest optical and infrared telescopes. Because of their large apertures, the Keck telescopes offer the highest potential sensitivity and angular resolution currently available. WMKO has already demonstrated scientific leadership in high angular resolution astronomy with the first NGS and LGS AO systems on 8-10 m telescopes. The importance of achieving the full potential of the Keck telescopes is recognized in the Observatory's strategic plan which identifies leadership in high angular resolution astronomy as a key long-term goal.

In order to maintain our leadership in this field, we must pursue new AO systems and the instrumentation to exploit them. We have examined, and are continuing to examine, a broad range of key science goals in order to identify the most compelling future science goals of our community and to determine what is needed to realize these goals. As a result, we have identified that NGAO should provide the following suite of capabilities:

- Near diffraction-limited performance at near infrared wavelengths, producing a point spread function with unprecedented precision, stability, and contrast;
- Increased sky coverage and a multiplexing capability, enabling a much broader range of science programs; and
- AO correction in the red portion of the visible spectrum (0.6-1.0 μm), delivering the highest angular resolution images available for filled aperture telescopes.

NGAO will be a broad and powerful facility with the potential to achieve major advances in astrophysics. It will provide dramatic gains in solar system and galactic science where AO has already demonstrated a strong scientific impact. NGAO will also allow for extraordinary advances in extragalactic astronomy, far beyond the initial gains being made with the Observatory's current AO systems.

The NGAO proposal (KAON 400) and NGAO proposal executive summary (KAON 399) provide more background on the motivation for the development of NGAO. Further scientific motivation is provided in the NGAO science case requirements document (KAON 455). More detailed design specific requirements will be detailed in the NGAO Functional Requirements Document (FRD) that will be released with this document as part of the preliminary design material.

5.3 Overview

The Systems Requirement Document includes high-level performance specifications that level requirements on more than one subsystem. This document also discusses significant design standards and implementation requirements that are used across the Keck Observatory. The basic organization of NGAO results in the following sections for the requirements document. Each of these sections is organized by engineering discipline. These sections are:

1. Overall
2. Optical
3. Mechanical
4. Electronic/Electrical
5. Safety
6. Software
7. Interface Requirements
8. Reliability Requirements
9. Spares Requirements
10. Service and Maintenance Requirements
11. Documentation Requirements

The AO and laser facilities and the science instruments will have to interface with the telescope structure. Figure 1 shows a schematic view of a Keck telescope. The current location for the NGAO system and science instruments is the one of Nasmyth platforms of the telescope. Nominally, we have chosen the left Nasmyth platform of the Keck II telescope as our starting point. The most likely location for the projection telescope is behind the f/15 secondary mirror in the top end of the telescope.

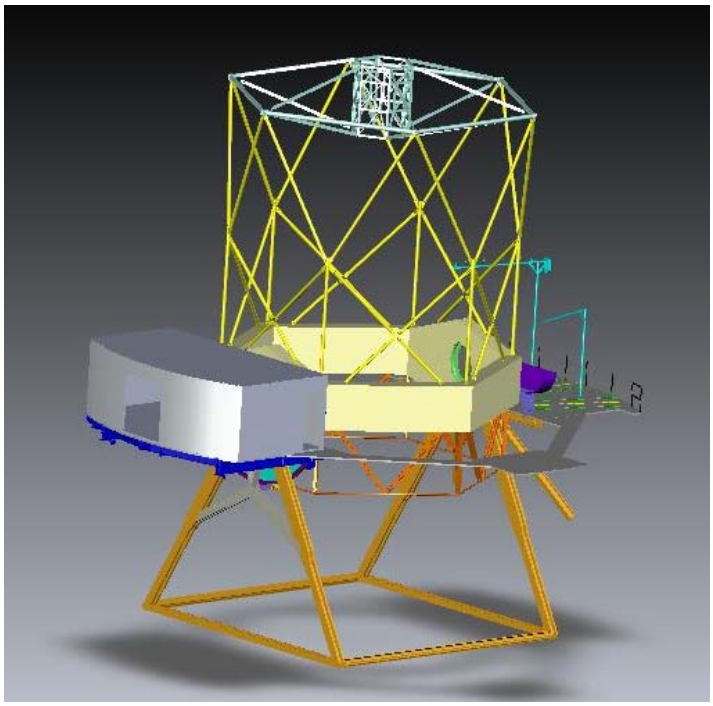

Figure 1 Keck telescope structure

6 OVERALL REQUIREMENTS

The purpose of the overall requirements section is to summarize and convey requirements that apply generally to the overall NGAO system and its accessories. These are based on the NGAO Science Case Requirements Document (SCRD) (KAON 455), various trade studies undertaken, and error budgets developed to meet these science requirements, general observatory instrument and interface requirements (KAON 572), and general observatory obligations (KAONs 428 and 153). In addition, information from the build-to-cost guidelines (KAON 642) has also been considered in the development of these requirements.

6.1 LGS Wavefront Error (SR-20)

The NGAO system shall produce a wavefront with errors less than or equal to the values shown in the table below for the corresponding science case(s) as measured at the center of the focal plane of the science instrument. Each science case has a corresponding range of zenith angles, galactic latitudes, and sky coverage as detailed in KAON 716 over which this performance must be achieved.

Key Science Driver	High-order Wavefront Error (nm)	Tip-tilt Error (mas)	Ensquared Energy	Strehl	Validation Science Band	Validation Exposure Time (sec)
Galaxy Assembly	≤170	≤5	≥50% in 50 mas, 30% sky cov'g	≥75%	K'	1800
Nearby AGN's	≤165	≤5	≥25% in 35 mas, 30% sky cov'g	≥15%	Z	900
Galactic Center	≤190	≤3	N/A (imaging) ≥35% in 35mas	≥70% at K'	K' (imaging) H (spectra)	30 (imaging) 900 (spectra)
Exoplanets	≤160	≤3	---	≥60%	H	300
Minor Planets	≤170	≤5	---	≥15%	Z	120

Table 1 LGS Wavefront Error

For further details on the observing details and other assumptions for these performance requirements, see KAON 716.

6.2 NGS Wavefront Error (SR-21)

In NGS mode, the NGAO system shall produce a wavefront with errors less than or equal to the values shown in the table below for the corresponding science case(s) as measured at the center of the focal plane of the science instrument. Each science case has a corresponding range of zenith angles, galactic latitudes, and sky coverage as detailed in KAON 716 over which this performance must be achieved.

Science Case	High-order Wavefront Error (nm)	Tip-tilt Error (mas)	Ensquared Energy	Strehl	Validation Science Band	Validation Science Exposure Time (s)
Bright NGS point source	≤130	≤3	≥40% in 35 mas	≥35%	Z	10
Io	≤140	≤4	≥40% in 35 mas	≥25%	Z	10

Table 2 NGS Wavefront Error

Note that KAON 716 predicts a H. O. WFE of 116nm for Io, but these requirements are purposely written to be more conservative.

6.3 Sky Coverage (SR-26)

The NGAO system shall be able to satisfy SR-20 (Wavefront error) over 30% of the observable celestial sphere.

6.4 Point Source Contrast (SR-98)

The NGAO system shall be able to detect point sources with brightness contrast as follows:

0.2" separation, Δ H = 10
1.0" separation, ΔH = 13
0.1" separation, ΔJ = 8.5
0.2" separation, ΔJ = 11
and a goal of ΔJ = 11 at 0.1".

6.5 Astrometric Precision (SR-47)

NGAO shall achieve an astrometric precision of 100 microarcseconds for observations taken within 120 seconds of each other and 100 microarcseconds for observations taken within 30 days.

6.6 Pointing Knowledge (SR-29)

The NGAO system, after having performed a dither (see SR-31), shall be able to determine the position objects on the science instruments to an accuracy of:

1) 4 mas for moves ≤50 mas.
2) 8 mas for moves ≤5 arcsec (goal: ≤10 arcsec).
3) 100 mas for moves ≤60 arcsec.

6.7 PSF Function Knowledge (SR-23)

NGAO shall provide an estimate of the delivered on-axis PSF to TBD accuracy at the science instrument input focal plane concurrent with every science image.

6.8 Pupil Alterations (SR-157)

The NGAO shall not alter the pupil of the telescope as seen by other science instruments when they are being used for science observations.

6.9 Telescope Down Time for Installation (SR-118)

The NGAO system shall be installable on the Keck Telescope in less than or equal to five 24-hour days of telescope downtime.

6.10 Telescope Down Time for Removal (SR-171)

The NGAO system shall be removable from the Keck Telescope in less than or equal to five 24-hour days [TBC] of telescope downtime.

6.11 AO Down Time for NGAO Installation (SR-117)

The NGAO system shall be commissioned in less or equal to 150 days [TBC].

6.12 Operating Environment (SR-254)

The NGAO system in the telescope dome shall meet all performance requirements, while the NGAO system is subjected to the operating environment conditions given in the table below.

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4300	m	
Temperature					
Range	-10	0	20	ºC	1
Rate of change	-0.8	-	0.8	ºC/h	
Humidity	0	-	90	%	2
Gravity orientation	-	-1	-	g	3
Vibration	-	-	$1x10^{-5}$	g^2/Hz	4
Acceleration	-	-	1	g	5

Notes:

1. Typical value is the average annual temperature.
2. Relative, non-condensing.
3. Normal to the earth's surface.
4. 20 Hz to 1000 Hz, 6db/oct drop- off to 2000 Hz.
5. All axes, due to telescope drive system fault conditions.

Table 3 Operating Environment

6.13 Non-Operating Environment (SR-250)

The NGAO system shall meet all of the performance specifications without repair or realignment after being subjected to any number of cycles of any of the non-operating environment conditions defined in the table below.

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4300	m	
Temperature					
Range	-10	0	30	ºC	1
Rate of change	-0.8	-	0.8	ºC/h	
Humidity	0	-	90	%	2
Gravity orientation	-	-1	-	g	3
Vibration	-	-	8.0×10^{-4}	g^2/Hz	4
Shock	-	-	15	g	5
Acceleration					
Due to handling	-	-	-	g	6
Due to seismic activity	-	-	2	g	7

Notes:

1. Typical value is the average annual temperature.
2. Relative, non-condensing.
3. Normal to the earth's surface.
4. 20 Hz to 1000 Hz, 6db/oct drop- off to 2000 Hz.
5. 0.015 second half-sine, all axes.
6. 2 g vertical, 1 g fore/aft, 0.5 g lateral.
7. 0.5 Hz to 100Hz, all axes.

Table 4 Non-Operating Environment

6.14 Transportation and Shipping Environment (SR-176)

The NGAO system shall meet all performance requirements without repair after a single shipment to the delivery location by any combination of air or surface transportation. For information, the expected conditions to be encountered during shipping are given in the table below.

Parameter	Min.	Typ.	Max.	Units	Notes
Altitude	0	-	4,572	m	1
Temperature	-33	-	71	ºC	2, 3
Temperature shock	-54	-	70	ºC	4
Humidity	0	-	100	%	5
Gravity orientation	-	-	-	NA	6
Vibration	-	-	0.015	g^2/Hz	7, 8
Shock	-	-	15	g	9
Acceleration					
Due to transport	-	-	4	g	10
Due to seismic activity	-	-	2	g	11

Notes:

1. See MIL-STD-810F Method 500 §2.3.1.
2. Maximum is for induced conditions, see MIL-STD-810F Method 501 Table 501.4-I.
3. Minimum is for induced conditions, see MIL-STD-810F Method 502 Table 502.4-II.
4. See MIL-STD-810F Method 503.
5. Relative, condensing.
6. Packaged equipment may be subjected to all possible gravity orientations during transportation and shipping.
7. 10 Hz to 40 Hz, -6dB/oct. drop-off to 500 Hz, all axes.
8. See MIL-STD-810F Method 514.
9. 0.015 second half-sine, all axes.
10. All axes.
11. 0.5 Hz to 100Hz, all axes.

Table 5 Transportation and Shipping Environment

6.15 Atmospheric Conditions (SR-124)

NGAO performance requirements for AO compensation shall be achieved during the following baseline conditions. The baseline atmospheric profile for the NGAO system is given in the table below. This profile defines the median conditions for operation at zenith. Other performance specifications, such as RMS wavefront error, are quoted at these median conditions. The overall normalization of the model is defined by a Fried seeing parameter of 16 cm at a reference wavelength of 0.5 microns. From this model we calculate the following turbulence parameters for 0.5 microns wavelength: Isoplanatic angle = 2.7 arcsec, Turbulence Greenwood frequency = 39 Hz. In addition, we have adopted a standard deviation for the Fried parameter of = 3 cm with a characteristic evolution time of t = 3 min. Mauna Kea "median" profile.

Altitude above ground (km)	**Fractional C_n^2**	**Wind Speed (m/s)**
0.0	0.517	6.8
0.5	0.119	6.9
1.0	0.063	7.1
2.0	0.061	7.5
4.0	0.105	10.0
8.0	0.081	26.9
16.0	0.054	18.5

Table 6 Atmospheric Conditions

6.16 Sodium Layer Conditions (SR-125)

NGAO performance requirements for AO compensation and LGS return shall be achieved during the following baseline conditions.

Sodium column density: 3 x 10^9 atoms/cm^2
Mean Range: 85-100 km above mean sea level (instantaneously)
Altitude of Mauna Kea: 4.123 km
Thickness of Na layer: 10 km
Return (proportional to effective cross section): 100 ph/cm2/sec/W in mesosphere at standard column density

6.17 Range of Zenith Angles (SR-276)

The NGAO system shall be operable over the telescope zenith angle range 0.5 degrees to 65 degrees.

6.18 Bright Target Limit (SR-170)

The NGAO System shall be able to operate on a point source target with a Bessel V-band filter magnitude of 5.0 and as a goal the NGAO System should be able to operate on a point source target with Bessel V-band filter magnitude of 0.0.

6.19 Science Target for TT and LO Aberrations (SR-32)

As a goal, the AO system should be able to use unresolved science objects as a reference source for tip tilt and low order aberration correction.

6.20 Modes of Operation (SR-298)

The NGAO system shall be capable of working in all configurations described in KAON 550, "NGAO System Configuration Spreadsheet", update February 2, 2010 or more current release.

6.21 Natural Guide Star Mode (SR-27)

NGAO system shall be able to operate with natural source as the sole means of providing a reference for AO correction. The reference objects include unresolved and partially resolved sources up to a maximum diameter of 4 arc seconds.

6.22 Non-sidereal Tracking (SR-34)

The NGAO system shall be able to track objects that move at non-sidereal rates with a maximum deviation from sidereal rate of 50 arcseconds per hour (14 mas/second) or less. In order to observe near-Earth objects, NGAO should, as a goal, be able to track non-siderally at 3600 arcseconds per hour (1 arcsec / second). In either case the system shall be able to track the non-sidereal target for a distance of 20 arcseconds of differential motion before need to re-point the telescope or reacquire Natural Guide Stars used by the AO system.

6.23 LGS Wavelength (SR-277)

The NGAO system shall only project lasers using the sodium D2 line with a wavelength of 589 nm.

6.24 Dithering (SR-31)

The NGAO system shall be able to:

1) Finely position (i.e., micro-dither) an object on the detector to an accuracy of 4 mas for moves ≤50 mas.
2) Reposition (i.e., dither) an object on the science instrument to an accuracy of 15 mas for moves ≤5 arcsec (goal ≤10 arcsec).
3) Offset an object or science field to an accuracy of 250 mas for moves ≤60 arcsec.

6.25 Offsetting (SR-301)

In LGS mode the NGAO system shall support offsetting to an accuracy of 6 mas rms over a 40"x40" field providing the LOWFS do not need to move outside of their 120" diameter field of regard to accomplish this offset.

6.26 Overheads for Observation (SR-30)

The NGAO system shall be able to start science data recording on a new object within 180 seconds of the end of the previous observation with the same science instrument if the telescope slew time to the next target was 60 seconds or less. If the time to slew the telescope to the next target is longer than 60 seconds then the NGAO system shall be able to start science data recording on a new object within 120 seconds of the end of the telescope slew.

6.27 Initialization Time (SR-283)

The NGAO System shall be able to be initialized in less than 4 hours prior to observing.

Discussion: For the purposes of this requirement initialized means going from the stand-by mode which the system is left at the end of the night and an operational mode where it is capable of starting night time operation.

6.28 Remote Observing (SR-33)

The NGAO science instrument shall be operable from the observatory, headquarters, all UC campuses, Caltech, and other designated institutions.

6.29 Science Instrument (SR-36)

The NGAO system shall be able to collect data in imaging mode and spatially resolved spectroscopy mode. Both modes shall cover the wavelength band 0.7 to 2.4 microns. The imaging mode shall have a field of view of at least 30" diameter and at least Nyquist sampling down to ~0.8 microns. The resolved spectroscopy mode should have multiple spatial scales with a spectral resolution of ~4000 and a maximum field of view of at least 4"x4".

6.30 Number of Science Instruments (SR-37)

The NGAO system shall be able to provide an input beam meeting all performance requirements to either of two stationary science instruments.

6.31 Switching Between Instruments (SR-68)

The NGAO system shall be able to direct the beam to any of the installed science instruments in less than 10 minutes.

6.32 Installing New Instruments (SR-272)

The NGAO design shall not preclude the day crew from removing an existing NGAO science instrument and installing a new NGAO instrument in less than 4 hours.

6.33 Number of Operators (SR-172)

Nighttime operation of the NGAO system, excluding the science instrument, shall require no more than one operator beyond the telescope observing assistant, support astronomer and any aircraft spotters. This additional operator should be able to be located at WMKO headquarters.

6.34 Internal Testing (SR-175)

The NGAO system shall use a maximum of 20 minutes of on-sky observing time per night for any required system checkouts or calibrations.

6.35 Telescope Software Simulator (SR-267)

The NGAO System shall include an internal telescope software simulator to facilitate diagnostic tests of the system when the telescope connection is not available.

6.36 Laser Beacon Maximum Power (SR-123)

The NGAO System shall project laser beacons with a total power of less than 200 W with no single laser beacon having a power of more than 50 W.

6.37 Acquisition (SR-293)

The NGAO system shall be able to acquire the targets for the NGS sensors (LOWFS, TWFS & NGS WFS), science instrument and LGS WFS sensor within the specified acquisition time (as specified in SR-30).

6.38 On-sky System Checkout (SR-296)

Any on-sky system checkouts or calibrations required at the start of nightly observing in order to achieve system performance shall not exceed 20 minutes of post 12 deg twilight time.

6.39 Long Exposure Tracking Accuracy (SR-302)

The NGAO system shall be able to track an object for 1 hour with less than 3.2 mas non-common-path image motion drift.

7 OPTICAL

7.1 Optical Transmission, Science Path (SR-22)

The NGAO system shall transmit the wavelengths between 700 nm and 2400 nm to the input of the science instruments in LGS modes, between 900 nm and 2400 nm to the input of the science instruments in NGS modes, and between 1000 nm and 3900 nm to the Keck interferometer.

NGAO transmission to the instrument science focal plane in LGS science mode shall be greater than:

min I-band (0.70 um): 25%
Z-band (0.88um): 34%
J-band (1.25um): 44%
H-band (1.65um): 47%
K-band (2.2um): 47%

upon pre-ship lab verification, and

min I-band (0.70 um): 21%
Z-band (0.88um): 30%
J-band (1.25um): 39%
H-band (1.65um): 40%
K-band (2.2um): 41

one year after first lock operation at the summit. This includes AO system and Instrument losses, but not telescope and sky transmission losses. Reduction in transmission is due to coating degradation and accumulation of contaminants.

7.2 Field of View, Science Port (SR-28)

The NGAO system shall provide the NGAO science instrument imager with an unvignetted field of view that is large enough to encompass a circle with a diameter of 40 arcseconds.

7.3 Surface Roughness (SR-297)

All optics in the science path shall have a surface roughness of TBD (by science team).

7.4 AO Background (SR-24)

The total background seen by the NGAO instruments shall be less than 6.3 photons/s/m^2/$arcsec^2$/nm at 2.209 microns and at a spectral resolution of 5000.

7.5 Opto-Mechanical Alignment to Telescope (SR-55)

The NGAO bench's optical axis shall be coincident with the telescope's elevation axis to within the following requirements:

At the telescope's focal plane on the Nasmyth platform the separation of these two axes shall be less than 1 mm.
At the telescope's pupil the misalignment of the two axes shall be less than 30 mm.
The NGAO input focal plane should be made coincident with the telescope's nominal focal plane in focus to within 2 mm.
The vector perpendicular to the NGAO bench surface should be parallel to gravity to within 2 arcminutes.

The above requirements should be met:

At all telescope elevations from zenith to 70 degrees zenith angle.
Assuming a rotator, at all rotator angles.
At all dome environment operating temperatures.

7.6 Wavefront Calibration Measurement Accuracy (SR-299)

The NGAO shall be able to measure the on-axis wavefront aberrations of the AO System and Instrument(s) with accuracy equal to 30 nm RMS within the range of spatial frequencies correctable by NGAO.

7.7 Telescope Line of Sight Jitter (SR-115)

The Keck Telescope shall have an aggregate line of sight jitter (wavefront tip and tilt) resulting from motion of the primary, secondary, and tertiary mirrors less than 0.020 arc seconds rms before correction by the NGAO.

7.8 Segment Pointing Error (i.e. Stacking) (SR-114)

The Keck Telescope segment stacking errors shall contribute less than 20 nm rms wavefront to the overall wavefront error before NGAO correction.

7.9 Segment Figure Errors (SR-113)

The Keck Telescope wavefront error of the 36 segments shall be less than 80 nm rms wavefront after warping, but before NGAO correction.

7.10 Telescope Segment Motion (SR-760)

The motion of each segment as a solid body shall be less than 0.015 arc seconds rms before correction by the NGAO.

7.11 Telescope Phasing Errors (SR-112)

The Keck Telescope shall have a phasing error of 10 nm rms wavefront or less before NGAO correction.

7.12 Dome and Telescope Seeing (SR-111)

The Keck Observatory shall provide dome and telescope seeing less than 0.1 arc seconds at 0.5 microns wavelength.

7.13 Full Pupil Illumination (SR-102)

The NGAO system shall observe the full pupil of the Keck II telescope, with the exception of the coronagraphic mode.

7.14 Pupil Rotation Compensation for Science Instruments (SR-58)

The NGAO system and science instrument combination should be capable of keeping the field or pupil fixed on the science instrument.

7.15 Field/pupil Rotation Compensation (SR-106)

In fixed field mode, the NGAO system shall maintain the field orientation on the science instrument to a level consistent with the short and long term image stability requirements defined in the error budget. In fixed pupil mode, the NGAO system shall maintain the pupil orientation on the science instrument to better than 1 degree in azimuth.

8 MECHANICAL

8.1 Vibration (observing and non observing) (SR-292)

Vibration isolations shall be employed as required to isolate sources of vibration within the NGAO system due to moving components such as fans, pumps and motors. The NGAO system shall meet all performance and operating requirements when installed in a vibration environment that conforms to the Generic Vibration Criteria Curve [1] "C" as shown in the figure below. The NGAO system shall not produce vibrations that result in rms velocities in excess of those given in curve "C" of the figure below.

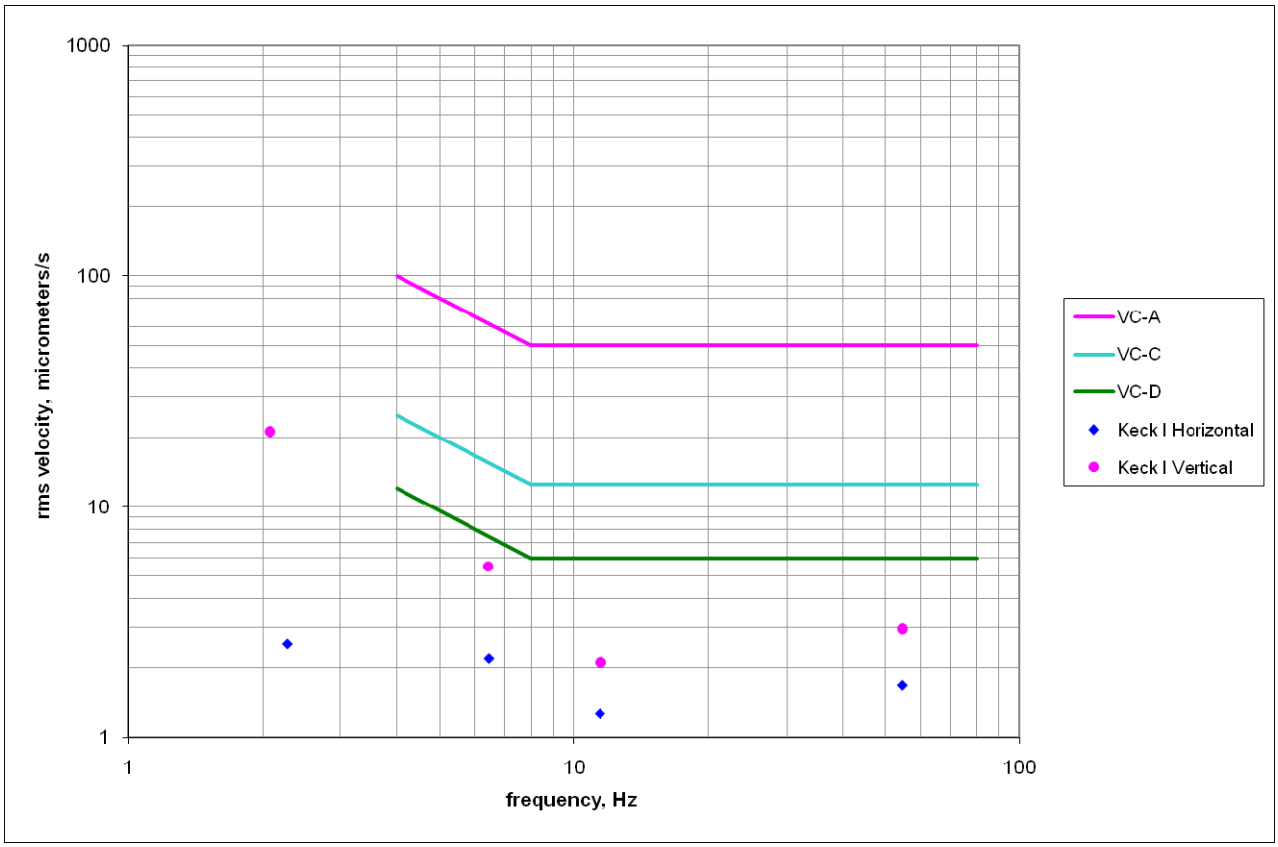

Figure 2 Vibration Spectra

[1] Gordon, Colin G. *Generic Criteria for Vibration-Sensitive Equipment.* Proceedings of the SPIE Vol. 1619, pp. 71-85, Vibration Control in Microelectronics, Optics, and Metrology. Gordon, Colin G. editor. SPIE 1992.

8.2 Thermal Dissipation into Observatory Dome (SR-65)

NGAO shall dissipate less than or equal to 100 W into the dome environment from the telescope Nasmyth platforms, less than or equal to 50Wfrom the telescope elevation ring and less than or equal to 50W from the telescope top end.

8.3 AO System Space Envelope (SR-75)

The NGAO facility must fit within the mechanical constraints of a Nasmyth platform (nominally the Keck II left Nasmyth platform).

8.4 Mass Limit for NGAO Components on a Nasmyth Platform (SR-69)

The parts of the NGAO system that are mounted on a single Nasmyth platform of the Keck Telescopes shall have a total mass less than 10,000 kg. Live load, total not to exceed 10 metric tons (10,000 kg) per each platform; this load was to be applied only at special "hard points" provided at the time of the original installation on top of the main beams of the platform. The maximum value of the concentrated design load on any one "hard point" was 5 metric tons (5,000 kg), with one such concentrated load per main beam at any one time. If components of the NGAO system are mounted on Nasmyth platforms that already contain other observatory instrumentation then the total of the existing instrumentation and the NGAO components must be less than the stated mass limits.

8.5 Mass Limit for NGAO Components on a Telescope Elevation Ring (SR-284)

The components of the NGAO system that are mounted on the telescope elevation ring shall have a total mass less than 1700 kg (TBC).

8.6 Mass Limit for NGAO Components on a Telescope Tube (SR-285)

The components of the NGAO system that are mounted on the telescope tube structure shall have a total mass less than 150 kg (TBC).

8.7 Mass Limit for NGAO Components Installed Inside Telescope Secondary Socket (SR-286)

The components of the NGAO system that are mounted inside the telescope secondary socket shall have a total mass less than 150 kg (TBC).

9 ELECTRICAL

9.1 Electrical Power Usage (SR-78)

The NGAO system, including the NGAO science instrument, shall use less than or equal to 55 kW of electrical power.

9.2 Azimuth Wrap Cabling (SR-79)

The NGAO facility cabling through the azimuth wrap must not require an area of more than TBD.

9.3 Left Elevation Wrap Cabling (SR-80)

The NGAO facility cabling through the left Nasmyth elevation wrap must not exceed an area of more than TBD.

9.4 Right Elevation Wrap Cabling (SR-81)

The NGAO facility cabling through the right Nasmyth elevation wrap must not exceed an area of more than TBD.

10 SAFETY

10.1 Laser Safety Standards (SR-15)

The NGAO System shall comply with ANSI Z136.1 and Z136.6 standards for safe use of lasers both indoor and outdoor.

10.2 Laser Aircraft Safety (SR-16)

The NGAO system shall comply with Federal Aviation Administration Advisory Circular #70-1, dated December 12, 2004.

10.3 Coordination with US Space Command (SR-17)

The NGAO system shall comply with the Laser Clearinghouse Reports Handbook Change 1, dated August 23, 2006.

10.4 Earthquake Restraints (SR-14)

The NGAO System shall be able to withstand the acceleration profile shown below without damage or severe misalignment. Restraints should be provided to prevent hardware from damaging itself or other hardware during an earthquake.

Frequency (Hz)	Acceleration (g)
0.3	0.2
0.6	2.0
2.0	5.0
5.0	5.0
15.0	1.6
50.0	1.6

Table 7 Earthquake Acceleration Profile

10.5 Emergency Stop Input (SR-209)

The NGAO system shall take necessary action to protect personnel and equipment when the observatory emergency stop signal is activated.

10.6 Laser Projection Zenith Angles (SR-278)

The NGAO system shall not project a laser at a zenith angle of greater than 65 degrees.

11 SOFTWARE

11.1 Observing Simulation and Preparation Tools (SR-40)

The NGAO system shall provide a set of tools for instrument performance simulation and observing preparations.

11.2 Data Reduction Pipeline (SR-42)

NGAO shall provide a semi-real-time level 1 data reduction pipeline for each instrument to, at minimum, perform background subtraction, cosmetic correction, and shift-and-add of images.

11.3 Image Quality Tools (SR-43)

NGAO shall provide semi-real-time tools to perform an assessment of the image quality on the level 1 data including SNR, Strehl, and encircled energy.

11.4 Archival Data Storage (SR-49)

NGAO shall archive system status, configuration, environmental, and wavefront correction telemetry to a searchable data archive.

11.5 Science Instrument Data in FITS Format (SR-19)

NGAO shall save science instrument data in FITS format.

11.6 Keck KTL Keywords (SR-82)

The NGAO system must support an interface to the Observatory standard KTL keywords.

12 INTERFACE

The interfaces for NGAO system are covered in Keck Adaptive Optics Note 741

13 RELIABILITY

13.1 System Lifetime (SR-151)

The NGAO system shall have a ≥ 10 year lifetime.

13.2 Number of Science Nights (SR-121)

The NGAO system shall be capable of collecting science quality data on 200 nights/ year.

13.3 Fraction of Time Spent Collecting Science Data for Narrow Field Instruments (SR-120)

The NGAO system shall have an observing efficiency of ≥ 70%.

13.4 Time Lost to Faults During Observing (SR-95)

The NGAO system shall lose no more than 5 percent of its total observing time to faults.

13.5 Median Time Between Faults During Observing (SR-96)

The NGAO system shall have a median time between faults of ≥ 4 hrs [TBC].

13.6 Median Time for Repair (SR-174)

The NGAO System shall have a median time for repair of TBD hours.

13.7 Operating Budget (SR-159)

The NGAO system shall have a total annual operational budget of less than or equal to 1 Million dollars per year (FY 2010 dollars).

13.8 Power Loss (SR-173)

NGAO shall be able to withstand a total and sudden loss of electrical power, without suffering damage to any or all subsystems or causing harm to personnel.

14 SERVICE AND MAINTENANCE

14.1 Installation and Removal Process (SR-295)

The NGAO system shall be implemented so that major components can be removed or installed within a 4 hour period so as to leave the telescope operational.

14.2 Maximum Engineering Nights to Maintain System (SR-122)

The NGAO facility shall require less than or equal to TBD engineering nights per year for system maintenance.

14.3 Access to Telescope for Maintenance (SR-77)

The NGAO facility must provide access for routine maintenance of the elevation bearing, elevation wrap, bent Cassegrain platform, and mirror cell stairwell.

14.4 Diagnostic Data (SR-270)

The NGAO system shall collect and store diagnostic data to provide information on system performance.

14.5 Limited Restriction on Telescope Access During Daytime Setup of NGAO (SR-109)

The NGAO system shall require less than 30 minutes of restricted access to the telescope during the daytime preceding an NGAO science night.

15 DOCUMENTATION

15.1 Drawing Standards (SR-287)

NGAO drawings shall use the metric standard with dimensions in millimeters.
NGAO drawings should conform to the following:

1. Drawings for optical components shall conform to ANSI/ASME standard Y14.18M-1986 "Optical Parts (Engineering Drawings and Related Documentation Practices)".

2. Mechanical drawings shall conform to ANSI Y14.5M-1994 (R1999) "Dimensioning and Tolerancing" and ASME standard Y14.100-2000 "Engineering Drawing Practices".

3. Each sheet shall conform to ANSI Y14.1-1995 (R2002), "Decimal Inch Drawing Sheet Size and Format". Drawing size shall be determined on an individual basis.

4. Each drawing shall have a title block with at least the following information:
- Development group
- Drawing number
- Title
- Designer
- Draftsman
- Scale
- Method for determining next higher assembly.

5. All drawings shall include parts and materials lists in accordance with ANSI Y14.34-2003, "Parts Lists, Data Lists, And Index Lists: Associated Lists". All items shall be identified with an item number or other label (with reference to the drawing number if one exists) for each part or component with all information required for procurement.

6. Assembly drawings shall include all relevant views required to clearly define the assembly including isometric and exploded views.

7. All detail drawings shall include all views, geometry, dimensions and feature controls required to duplicate the part in accordance with ANSI Y14.5M-1994 (R1999) "Dimensioning and Tolerancing".

8. Multi and sectional view drawings shall be developed in accordance with ANSI Y14.3M-1994 "Multi and Sectional View Drawings".

9. Fluid power system schematics shall be drawn in accordance with ASME Y32.10-1967 (R1994) "Graphic Symbols for Fluid Power Diagrams".

10. Dimensions and tolerances shall be indicated in accordance with ANSI 14.5M-1994 (R1999).

11. Surface finishes shall be described in accordance with ANSI 14.5M-1994 (R1999).

12. The electronic drawing format shall be at least AutoCAD 2000 (or a more current release). Drawings created with other computer aided drafting (CAD) software shall be provided in .dxf files compatible with AutoCAD 2000 (or a more current AutoDesk software release). The preferred CAD software for 3D drawings is AutoDesk Inventor or SolidWorks.

13. The electronic drawing format for electrical/electronic schematics and printed circuit board layouts and assembly drawings shall be OrCAD V9.0 or a more current release. A less desirable alternative is to provide drawings for electrical/electronic schematics and printed circuit board layouts and assembly drawings as AutoCAD 2000 (or a more current release) drawings or as .dxf files compatible with AutoCAD 2000 (or a more current AutoDesk software release).

15.2 Required Drawings (SR-288)

All drawings shall be provided as specified in the formats listed SR-287 Drawing Standards and in the native format if translated to one of the specified formats.

The following drawings should be provided:

1. As-built detailed mechanical drawings for all components not commercially available. Drawings shall provide sufficient detail to fabricate the components to original design intent.
2. As-built detailed drawings for all optical components not commercially available. Drawings shall provide sufficient detail to fabricate the components to original design intent.
3. As-built assembly drawings for all assemblies not commercially available along with appropriate detail drawings and assembly tolerances and procedures.

15.3 Documentation Package (SR-289)

The NGAO System shall be provided with a design, operating and maintenance documentation package including, but not limited to, the following:

1. System overview and design description, including details of optical design, mechanical design (including thermal and vacuum design), electrical design and software design. All design documents shall be supplied in revised form as required to reflect the delivered as-built system
2. User's manual, including but not limited to operating instructions.

3. Revised fabrication/procurement drawings, specifications, and schematics that accurately depict the as-built condition of all of the components of the NGAO system. All such drawings should be detailed enough to allow fabrication of spare parts should the need arise.
4. Optical Test data or where approved witness sample test data.
5. Bills of material including supplier information for all components of the NGAO system.
6. A maintenance manual, including all information and procedures needed to maintain and operate the NGAO system during its lifetime, including but not limited to the following:
    a. Procedures for handling, assembly, and disassembly of the NGAO system and all of its components accurately reflecting the as-built system. All assembly instructions shall be clear and include a tools list, parts lists, and check list.
    b. Routine maintenance and inspection procedures, as well as a maintenance schedule.
    c. Alignment procedures.
    d. Troubleshooting guide.
    e. Repair procedures.
7. Acceptance Test Plan documents, test procedures and all performance data and results of acceptance testing.
8. Descriptions of all recommended spare parts and procedures for removal and replacement including written procedures and assembly drawings and exploded view drawings.
9. All manufacturers' manuals and documentation for COTS components.
10. All software design documents and related documents including, but not limited to software build and install procedures, source code, release description document, software design document(s), software acceptance testing plans and software user's manual. All software design documents and related documents shall be supplied in revised form as required to reflect the delivered as-built NGAO software.
11. Safety plan and procedures.
12. Documentation of the performance modeling tools and performance budgets and their results for NGAO.

15.4 Software Documentation (SR-290)

The NGAO software is defined as all host, target, embedded controller software and data reduction software for the NGAO system. Included in this are detector controller code, code for servo controls including DSP code, motion controller code, Programmable Logic Controller (PLC) code and the like. The following software data files and documentation shall be provided

1. Source code for all NGAO software on CD/DVD.
2. Executables for all NGAO software on CD/DVD.
3. One copy of any and all software libraries required to build the NGAO software executables on CD/DVD.
4. A list of any and all code compilers required to build the NGAO software.
5. All makefiles required for building the NGAO software on CD/DVD.

6. All configuration files and all data files read by the NGAO software executables at start-up time on CD/DVD.
7. Any scripts required to run NGAO and associated data reduction packages on CD/DVD.
8. Any aliases, environment variable definitions, etc. required to correctly set up the environment to build or run the NGAO software on CD/DVD.
9. Any models developed for simulation of the NGAO including optical designs and control loop simulations should be supplied. The preferred software for optical design is Zemax. The preferred software for simulations is Matlab or IDL.
10. Full design documentation for all control loops including block-diagrams, transfer-function models of the system, performance criteria and analyses to show how these requirements are met. Models and simulations of the control loops should also be provided.
11. Documentation for the NGAO software, consisting of:
    a. Users Manual: a detailed tutorial describing how to use this version of the software.
    b. List of Source Code: A hierarchical list of all directories, source files, include files, libraries, etc that can be used as a checklist for new releases.
    c. Functional Descriptions: a description of each routine or module describing its function.
    d. Startup/Shutdown procedures: descriptions of the steps necessary to cold start the system and the steps necessary to safely shut down a running system. This document should include descriptions of any configuration files required at start-up time.
    e. Installation Manual: a detailed description of the steps necessary to rebuild and install the system from sources.
    f. Troubleshooting Guide: A description of the techniques for tracking down failures, checking system health, killing and re-starting portions of the system without a full reboot.
    g. Software Test Procedures: a detailed description of how to run the software acceptance tests.
    h. Programmer's Manual: This document shall include a description of the theory of operations; data and control flow and how standard functionality can be extended (e.g. add a new command to the API).

15.5 Electrical/Electronic Documentation (SR-291)

The following documentation for all electrical and electronic assemblies and modules in the NGAO system shall be provided in the formats listed in KS-58 (Keck Standard 58, see Contour database for details) Drawing Standards and in the native format if translated to one of the specified formats:

1. A top level system block diagram.
2. An interconnection diagram showing all interconnecting cables and connected assemblies and modules in the NGAO system.
3. An interconnection diagram showing the external connections to the NGAO system.

4. Cable drawings including cable reference numbers, pinouts, wire color codes and assembly information for all internal and external cables.
5. Schematics, assembly drawings, bills of material, printed circuit board designs and printed circuit board artwork for all custom printed circuit boards in the NGAO system.
6. Programmable device source code and binary (programming) image files for all programmable devices used on custom printed circuit boards in the NGAO system.
7. Configuration, set up and/or switch/jumper setting information for all custom components.
8. Programmable device source code and binary (programming) image files for all programmable devices used in COTS components where the programmable device source code has been modified or customized for the NGAO system.
9. Configuration, set up and/or switch/jumper setting information for all COTS components.

16 GLOSSARY

Table 8 defines the acronyms and specialized terms used in this document.

Table 8 Glossary of Terms

Term	Definition
ACS	Active Control System
ANSI	American National Standards Institute
AO	Adaptive Optics
DCS	Drive and Control System
DSM	Dual Star Module
FAA	Federal Aviation Administration
FOV	Field Of View
FWHM	Full Width at Half Maximum.
IFU	Integral Field Unit
KAON	Keck Adaptive Optics Note
KI	Keck Interferometer
LGS	Laser Guide Star
MTBF	Mean Time Between Failures
NGAO	Next Generation Adaptive Optics
NGS	Natural Guide Star
NIR	Near InfraRed
NIRC2	NIR Camera 2
NIRSPEC	NIR SPECtrometer
‘OHANA	Optical Hawaiian Array for Nanoradian Astronomy
OSHA	Occupational Safety and Health Administration
OSIRIS	OH-Suppression InfraRed Integral field Spectrograph
TBC	To Be Completed
TBD	To Be Determined
WMKO	W. M. Keck Observatory