Next Generation Adaptive Optics System

KAON 686

NGAO Laser Launch Facility System Performance

Preliminary Design

Nov 4, 2009

VersionV1.1

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REVISION HISTORY

Revision	Date	Author (s)	Reason for revision / remarks
1.0	Oct 19, 2009	All	Initial release
1.1	Nov 04, 2009	JC	Added KAON #

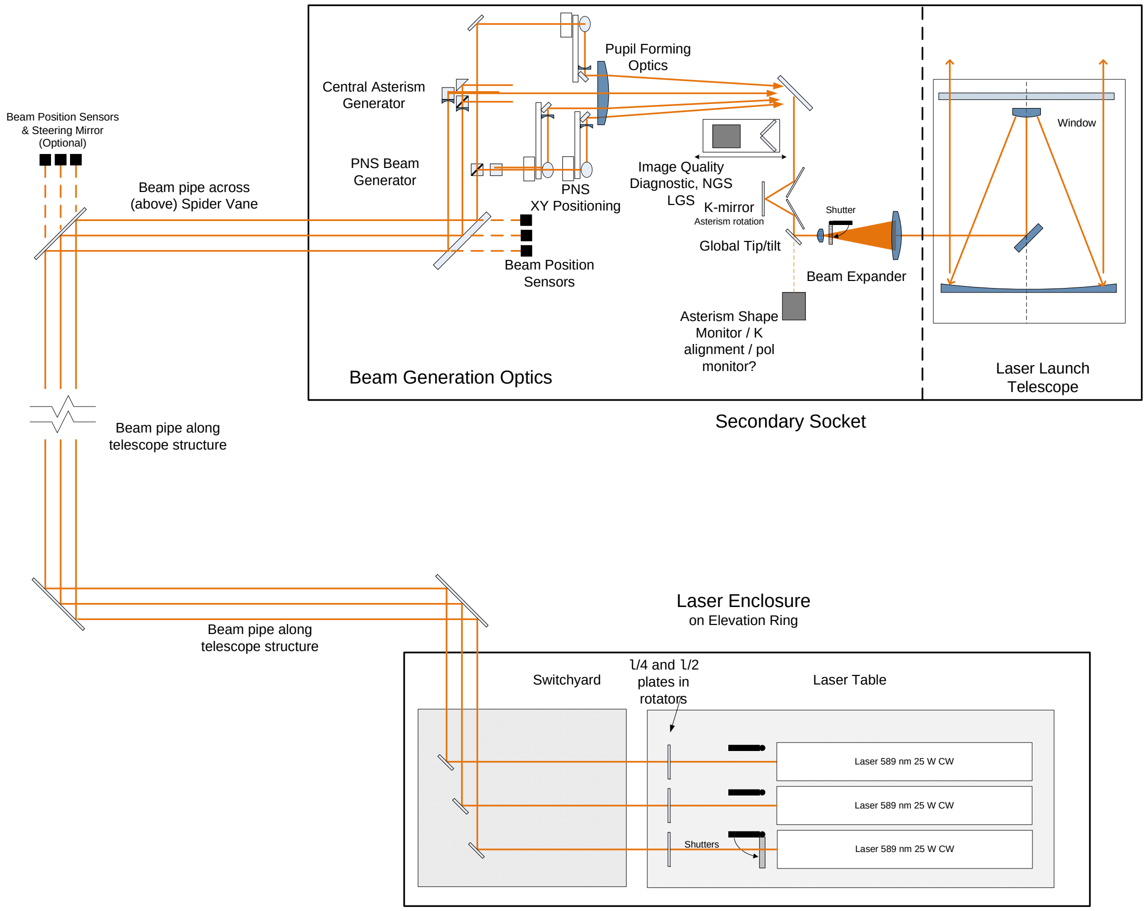
TABLE OF CONTENTS

1 INTRODUCTION

As part of the Next Generation Adaptive Optics System (NGAO), a Laser Launch Facility (LLF) System is needed to generate and propagate the laser beams. The LLF is made up of three subsystems: Beam Generation System (BGS), Beam Transport Optics (BTO); and the Switchyard (SYD). This document provides the preliminary design performance of the three subsystems and examines the overall performance of the LLF. A section will also be devoted to understand further work to be done to complete the LLF.

2 System Performance

2.1 System Overview



2.2 Throughput

Due to the number of surfaces in the LLF the system throughput has a strong sensitivity on the coating quality and surface cleanliness. As a result, good quality coatings are required along with procedures and design features to minimize the accumulation of dust and dirt on the surfaces. Periodic cleaning will be necessary so the coatings should also be hard to prevent damage.

For the throughput analysis below, the NGAO standard values were used. These are:

- Laser line coating reflectivity = 0.994
- Laser line AR coating transmissivity = 0.996
- Transmission due to dust/dirt accumulation = 0.995

As the mechanical design is finalized, the dust and dirt contribution can likely be modified somewhat. The entire system will be enclosed with a light overpressure of filtered air, but there will still be some dust infiltration during maintenance and during the cleaning process itself. As a further dust reduction measure, some surfaces may be enclosed in a secondary enclosure. An example of this would be including a dust tight shroud between the two lenses in the BGS beam expander. This would allow reducing the dust scatter allowance for the inner two surfaces below the NGAO standard 0.5%. The LTA will also be a sealed enclosure with no planned access so the dust contribution to its internal surfaces will also be better than 0.5%.

In the table below, there are two overall values for the throughput, one for the "clean" state and one including the dust contribution. The total throughput will be monitored with power meters at the laser unit outputs and as close to the BGS output as possible. When the total throughput approaches the dusty value given below, the optics would be cleaned to restore the throughput to higher levels.

Table 1. PNS throughput.

Element Name	Number of Surfaces	Reflec./Trans. per Surface	Dirt and scatter	Total Element, Clean	Total Element, Dirty
Switchyard					
Laser Enc. Laser 1 Mirror	1	99.40%	0.50%	99.40%	98.90%
1/2 Wave Plate	2	99.60%	0.50%	99.20%	98.21%
1/4 Wave Plate	2	99.60%	0.50%	99.20%	98.21%
Laser Enc. Steering Mirror	1	99.40%	0.50%	99.40%	98.90%
BTO					
Entrance window	2	99.60%	0.50%	99.20%	98.21%
M1-M6	6	99.40%	0.50%	96.45%	93.60%
BGS					
Astr. Gen. B.S. 1	2	99.60%	0.50%	99.20%	98.21%
Astr. Gen. B.S. 2	2	99.60%	0.50%	99.20%	98.21%
Astr. Gen. Mirror 1 - 4	4	99.40%	0.50%	97.62%	95.68%
Astr. Gen. Negative lens	2	99.60%	0.50%	99.20%	98.21%
Astr. Gen. Pupil Imaging lens	2	99.60%	0.50%	99.20%	98.21%
Fold	1	99.40%	0.50%	99.40%	98.90%
K Mirror assembly	3	99.40%	0.50%	98.21%	96.74%
Global TT mirror	1	99.40%	0.50%	99.40%	98.90%
Beam Expander Telescope Lens 1	2	99.60%	0.50%	99.20%	98.21%
Beam Expander Telescope Lens 2	2	99.60%	0.50%	99.20%	98.21%
LTA fold	1	99.40%	0.50%	99.40%	98.90%
LTA					
Launch Tel. Input Win. Surf 1	1	99.60%	0.50%	99.60%	99.10%
Launch Tel. Input Win. Surf 2	1	99.60%	0.05%	99.60%	99.55%
Launch Tel. Tertiary	1	99.60%	0.05%	99.60%	99.55%
Launch Tel. Secondary	1	99.60%	0.05%	99.60%	99.55%
Launch Tel. Primary	1	99.60%	0.05%	99.60%	99.55%
Launch Tel. Output Win.	1	98.00%	0.05%	98.00%	97.95%

Surf 1					
Launch Tel. Output Win. Surf 2	1	98.86%	0.34%	98.86%	98.52%
LLT Secondary Obscuration				95.50%	95.50%
				Clean	Dirty
TOTAL Throughput				75.71%	62.53%

Table 2. Central asterism throughput.

Element Name	Number of Surfaces	Reflec./Trans. per Surface	Dirt and scatter	Total Element, Clean	Total Element, Dirty
Switchyard					
Laser Enc. Laser 1 Mirror	1	99.40%	0.50%	99.40%	98.90%
1/2 Wave Plate	2	99.60%	0.50%	99.20%	98.21%
1/4 Wave Plate	2	99.60%	0.50%	99.20%	98.21%
Laser Enc. Steering Mirror	1	99.40%	0.50%	99.40%	98.90%
BTO					
Entrance window	2	99.60%	0.50%	99.20%	98.21%
M1-M6	6	99.40%	0.50%	96.45%	93.60%
BGS					
Beamsplitter	2	99.60%	0.50%	99.20%	98.21%
Mirror 1 - 3	3	99.40%	0.50%	98.21%	96.74%
Negative lens	2	99.60%	0.50%	99.20%	98.21%
Pupil Imaging lens	2	99.60%	0.50%	99.20%	98.21%
Fold	1	99.40%	0.50%	99.40%	98.90%
K Mirror assembly	3	99.40%	0.50%	98.21%	96.74%
Global TT mirror	1	99.40%	0.50%	99.40%	98.90%
Beam Expander Telescope Lens 1	2	99.60%	0.50%	99.20%	98.21%
Beam Expander Telescope Lens 2	2	99.60%	0.50%	99.20%	98.21%
LTA fold	1	99.40%	0.50%	99.40%	98.90%
LTA					
Launch Tel. Input Win. Surf 1	1	99.60%	0.50%	99.60%	99.10%
Launch Tel. Input Win. Surf 2	1	99.60%	0.05%	99.60%	99.55%
Launch Tel. Tertiary	1	99.60%	0.05%	99.60%	99.55%
Launch Tel. Secondary	1	99.60%	0.05%	99.60%	99.55%
Launch Tel. Primary	1	99.60%	0.05%	99.60%	99.55%

Launch Tel. Output Win. Surf 1	1	98.00%	0.05%	98.00%	97.95%
Launch Tel. Output Win. Surf 2	1	98.86%	0.34%	98.86%	98.52%
LLT Secondary Obscuration				95.50%	95.50%
				Clean	Dirty
TOTAL Throughput				76.78%	64.37%

2.3 Projected Spot size

The controlling specification is for spot size at the sodium layer, not a native wavefront error. The spot size at the sodium layer is a combination of a few factors. The output of the LLF is a Gaussian beam and the waist size and location determine the ideal spot size. This ideal spot size is then degraded by the laser beam quality as described by M^2, the wavefront error in the LLF, and the wavefront error due to atmospheric turbulence.

It is relatively easy to determine the spot size based on the output beam parameters, however determining the degradation due to the atmospheric terms is much more difficult. The current spot size analysis first finds the ideal, unaberrated spot size from Gaussian beam propagation relationships. Then, the contributions from the laser beam quality, the projection optics wavefront error, and the atmospheric tip/tilt corrected wavefront error are combined into a M^2 value. The ideal spot size is then multiplied by the M^2 value to find the final spot size at the sodium layer. The procedure used to convert the total wavefront error into an M^w value, however, is a rough approximation at best. Currently, Chris Neyman and Thomas Stalcup are working on a more detailed simulation of the expected spot size which will be used to finalize the allowable wavefront error in the LLF optics. It is worth noting that since the majority of the wavefront error in the LLF is due to figure errors in the many optical surfaces and not due to aberrations in the design, it is easy to decrease the total wavefront error with tighter figure tolerances with the side effect of increasing the cost.

Table 3. Wavefront error for PNS.

Element Name	Number of Surfaces	PV error (waves @ 632.8 nm)	Per surface RMS WFE (nm)	Per Element RMS WFE (nm)
Switchyard				
Laser Enc. Laser 1 Mirror	1	0.050	10.5	10.5
1/2 Wave Plate	2	0.100	21.1	29.8
1/4 Wave Plate	2	0.100	21.1	29.8
Laser Enc. Steering Mirror	1	0.050	10.5	10.5
BTO				
Entrance window	2	0.100	21.1	29.8
M1-M6	6	0.050	10.5	25.8

BGS				
Astr. Gen. B.S. 1	2	0.100	21.1	29.8
Astr. Gen. B.S. 2	2	0.100	21.1	29.8
Astr. Gen. Mirror 1 - 4	4	0.050	10.5	21.1
Astr. Gen. Negative lens	2	0.100	21.1	29.8
Astr. Gen. Pupil Imaging lens	2	0.100	21.1	29.8
Fold	1	0.050	10.5	10.5
K Mirror assembly	3	0.050	10.5	18.3
Global TT mirror	1	0.050	10.5	10.5
Beam Expander Telescope Lens 1	2	0.100	21.1	29.8
Beam Expander Telescope Lens 2	2	0.100	21.1	29.8
Beam Expander design	1		33.5	33.5
LTA fold	1	0.050	10.5	10.5
LTA				
Launch Tel. Input Win.	2		2.9	4.2
Launch Tel. Tertiary	1		5.9	5.9
Launch Tel. Secondary	1		36.8	36.8
Launch Tel. Primary	1		49.1	49.1
Launch Tel. Output Win.	2		11.8	16.7
Total			123.4	nm

Table 4. Wavefront error for central asterism.

Element Name	Number of Surfaces	PV error (waves @ 632.8 nm)	Per surface RMS WFE (nm)	Per Element RMS WFE (nm)
Switchyard				
Laser Enc. Laser 1 Mirror	1	0.050	10.5	10.5
1/2 Wave Plate	2	0.100	21.1	29.8
1/4 Wave Plate	2	0.100	21.1	29.8
Laser Enc. Steering Mirror	1	0.050	10.5	10.5
BTO				
Entrance window	2	0.100	21.1	29.8
M1-M6	6	0.050	10.5	25.8
BGS				
Beam splitter	2	0.100	21.1	29.8
Mirror 1 - 3	3	0.050	10.5	18.3
Negative lens	2	0.100	21.1	29.8

Pupil Imaging lens	2	0.100	21.1	29.8
Fold	1	0.050	10.5	10.5
K Mirror assembly	3	0.050	10.5	18.3
Global TT mirror	1	0.050	10.5	10.5
Beam Expander Telescope Lens 1	2	0.100	21.1	29.8
Beam Expander Telescope Lens 2	2	0.100	21.1	29.8
Beam Expander design	1		20.6	20.6
LTA fold	1	0.050	10.5	10.5

LTA

Launch Tel. Input Win.	2		2.9	4.2
Launch Tel. Tertiary	1		5.9	5.9
Launch Tel. Secondary	1		36.8	36.8
Launch Tel. Primary	1		49.1	49.1
Launch Tel. Output Win.	2		11.8	16.7

Total

116.3 nm

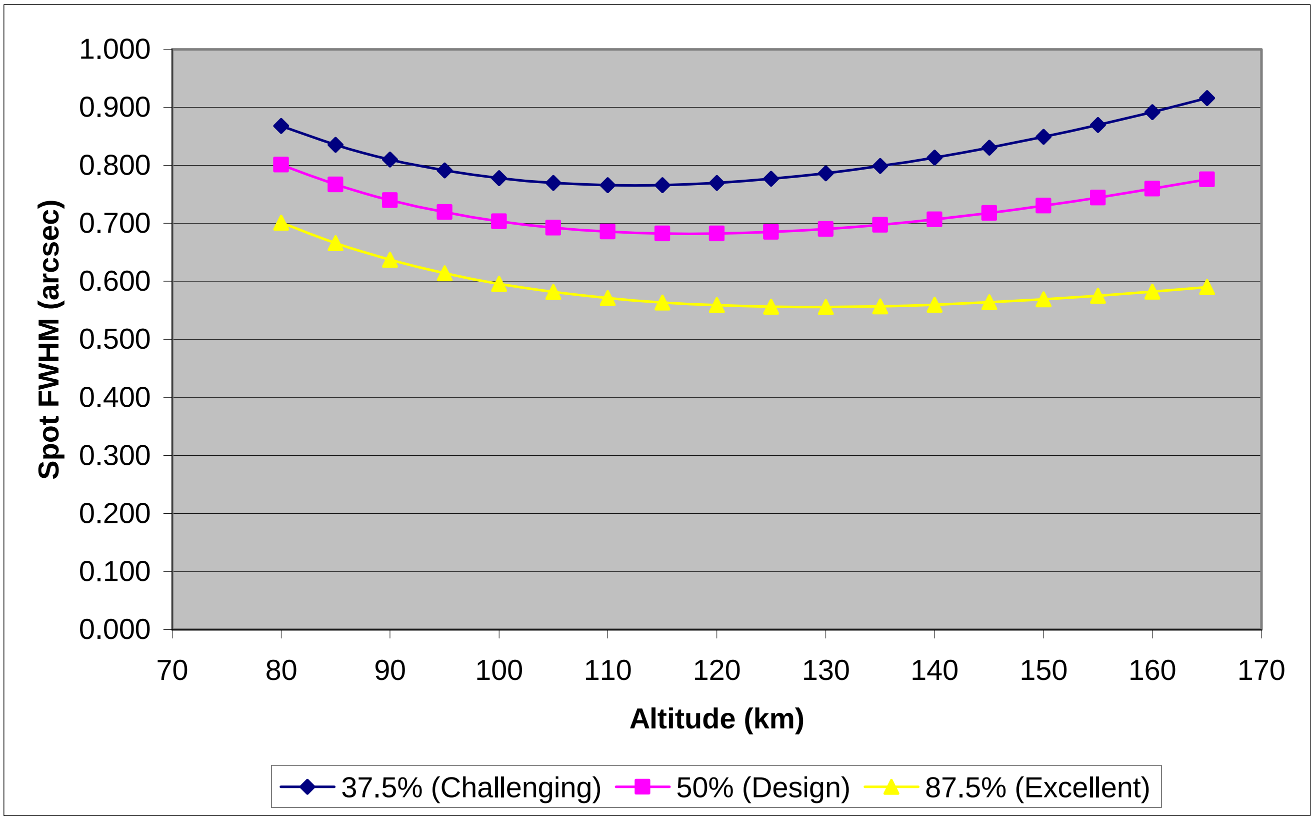


Figure 1. PNS spot size versus altitude for seeing percentiles of 37.5%, 50%, and 87.5% corresponding to r0=0.14, 0.16, and 0.22 m at a wavelength of 500 nm.

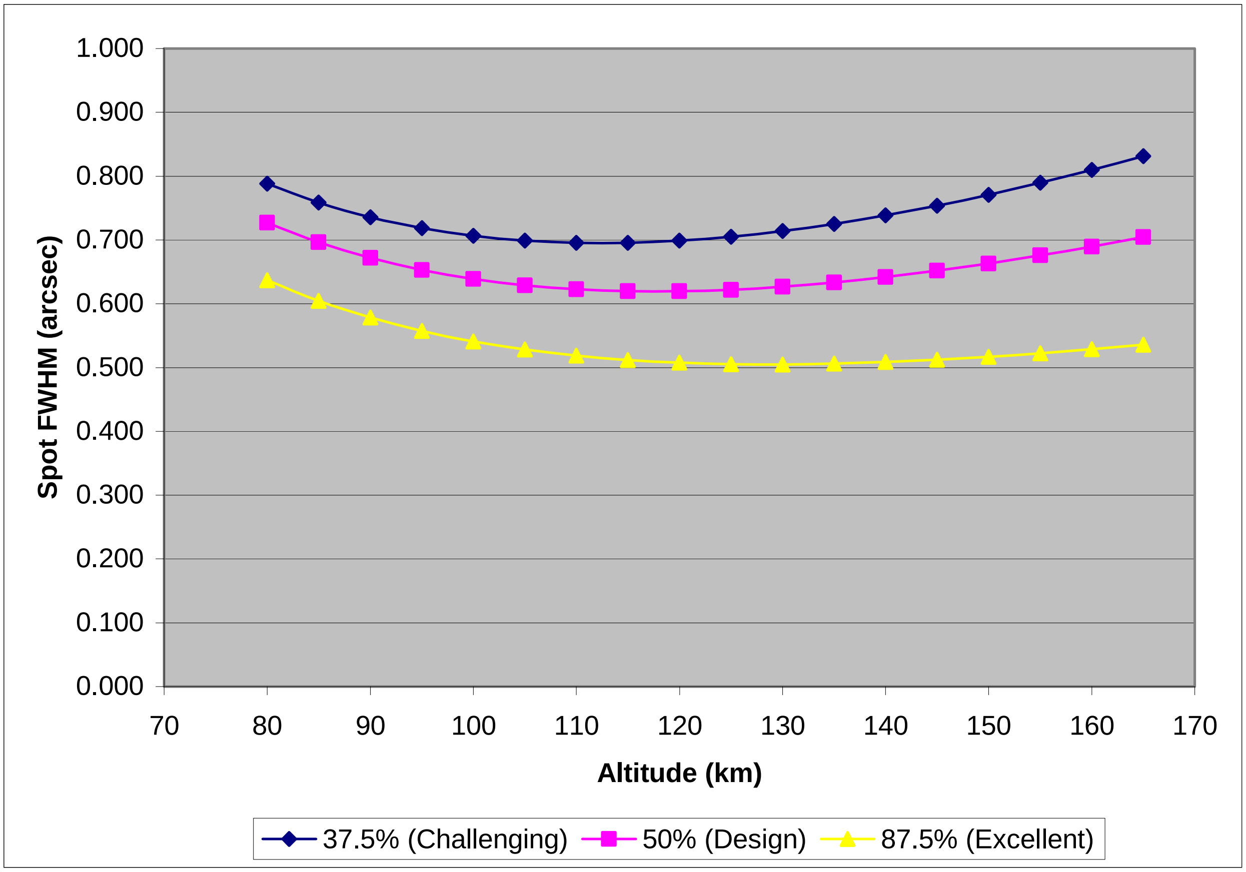


Figure 2. Central asterism spot size versus altitude for seeing percentiles of 37.5%, 50%, and 87.5% corresponding to r0=0.14, 0.16, and 0.22 m at a wavelength of 500 nm.

2.4 Focus Error

Due to the short focal lengths and high magnification elements in the various beam expander units in the LLF, small changes in element spacing can have a large effect on the projected beam parameters. While these errors can be compensated with an active focus system based on temperature sensors and lookup tables, the sensitivity is such that careful attention must be paid during the design to focus errors. Prior to the PDR, a detailed focus error budget will be prepared.

2.5 Pointing Error

A full pointing error budget will be produced prior to PDR. This will take into account both the mechanical performance of the various element mounts as well as the positioning accuracy of the motion stages and expected errors in telescope flexure correction.

2.6 Polarization Control

The output of the LLF is required to be circularly polarized with an accuracy of 98%. The specified output from the laser heads is linear polarization. This linear polarization will be converted to circular polarization by using a quarter-wave plate. Unfortunately, the polarization state of the beam will change slightly after every reflection so it is not possible to simply produce circular polarization in the laser enclosure and transmit it through the rest of the LLF.

It is possible, however, to control the polarization state of the beams in the laser enclosure such that the initial polarization state compensates for the polarization change in the rest of the LLF resulting in a circularly polarized output. This is complicated, however, by the fact that after the beam splitters in the BGS each beam will experience a slightly different angle of incidence on every element after the pupil forming lens. The polarization properties of dielectric mirror coatings have a dependence on angle, so therefore each of the seven output beams will acquire a slightly different polarization state after traversing the BGS. If the polarization dependence on angle is small enough the error may not be significant, however if this is not the case then the polarization control will have to be moved such that there is a controller for each of the seven individual projected beams. Given the current layout of the BGS this is easy for the three PNS beams, however the central asterism generator will have to be slightly modified so that there is an area with enough clearance for the rotation stage required for the polarization control. This should be possible without adding any more surfaces to the current design.

Prior to the PDR, data on the polarization properties for the specific coatings being considered will be obtained and used to generate an error budget for the polarization control.

Element Name	**Requirement**	**Design**
The LGS facility optical transmission shall be greater than or equal to 75% at a wavelength of 589 nm. The requirement is for all optics from the output of each Laser Unit to the sky. It includes all transmission losses in the Beam Transport System and the Laser Launch Telescope. It also includes losses from the Laser Launch Telescope secondary obscuration. PNS	60%	62.53%
Wavefront Error PNS	?	123.4
The LGS facility optical transmission shall be greater than or equal to 75% at a wavelength of 589 nm. The requirement is for all optics from the output of each Laser Unit to the sky. It includes all transmission losses in the Beam Transport System and the Laser Launch Telescope. It also includes losses from the Laser Launch Telescope secondary obscuration. Central Asterism	60%	64.37
Wavefront Error Central Asterism	?	116.3
The LGS spots at the sodium layer shall be less than or equal to 0.9 arc seconds (TBC) without considering the effects of atmospheric turbulence.	0.9 arcsecond	0.8
The blind pointing of the LGS asterism shall be less than 10 arc seconds rms (TBC) with a goal of 1 arc second rms (TBC).	1 arcsecond	TBD
The Beam Transport System shall accept three input beams of diameter 3 mm from each Laser Unit. The Laser Unit will deliver a collimated beam with an output beam waist diameter at 1/e2 equal to 3.0 mm plus/minus 0.1 mm. Output beam waist location: 0.0 m plus/minus 0.5 m with		Yes

respect to the output aperture of each Laser Unit.		
The Laser Launch Telescope shall have an output Gaussian intensity profile with a 1/e2 diameter of 0.3 m (TBC).	0.3 m	0.36 m
The Beam Transport System mirrors used for off loading up-link tip tilt correction shall have a range of 30 arc seconds (TBC) and a positioning tolerance of 0.3 arc seconds (TBC).		Range: +- 60 arcseconds Accuracy: 0.05 arcseconds
The Beam Transport System shall be provided with 1500 Watts of 120 VAC power.		< Req
The LGS Facility shall produce a return flux of 740 ph/cm2/sec (TBC) for each of the 4 LGS in the on axis fixed asterism (science asterism) and 495 photons/cm2/sec (TBC) for each of the 3 LGS in the movable asterism. These flux values are measured at the Keck Telescope primary mirror (i.e. the pupil) when the laser projection system is pointed at zenith. This requirement assumes a sodium column density of 3e9 atoms/cm2, mean distance to the sodium layer of 90 km, a one-way atmospheric transmission of 89.6%, and laser beam powers of 9.4 W and 6.25 W respectively. Return flux variations will result from changes in the sodium column density and the direction of the earth's magnetic field.		
The laser beams leaving the Laser Launch Telescope shall be circularly polarized to greater than or equal to 98% (TBC). The handedness, right or left, is arbitrary (TBC) but the beams should be fully polarized to the value given in one or the other of these states.		
The LGS Facility mass shall conform to following weight limits. The maximum weight of the LGS Facility on the azimuth rotating part of the telescope shall not exceed 10,000kg. The maximum weight of the LGS Facility on the elevation moving portion of the telescope shall not exceed 1700 kg (elevation ring mounting). The maximum weight of the LGS Facility in the top-end module (secondary) shall not exceed 150kg. All mass values are (TBC).		TBD; based on lasers as well
The LGS Facility shall maintain the asterism orientation and shape to 1 arc second (TBC) rms. The asterism orientation must be maintained as the telescope tracks astronomical targets for periods up to one hour (TBC).		By Design
The projected (up-link) tip tilt residual for each LGS shall be less than or equal to 0.5 arc seconds rms (one sigma) on-axis (TBC). This includes the residual from atmospheric turbulence, wind shake, and vibrations. The correction of this residual motion shall be performed on the return trip (down-link) by the AO System Real Time Controller and fast steering mirrors location inside the laser guide star wavefront sensor optics.		TBD

The LGS Facility shall be capable of correcting for the effects of flexure between the telescope top end structure and the elevation ring structure by up to 20 mm (TBC) in translation (perpendicular to the primary mirror optical axis) and 2 milliradians (TBC) in tilt (relative to the primary mirror optical axis) over elevation angles between 0 and 90 degrees.	From KAON TBD, flexure = 3mm	Yes, by design

Table 5: System Performance

3 PLANS TO COMPLETE PRIOR TO PDR

The focus of the remaining work is to complete the design and reduce the risk currently presented at the mini-review. The following items are listed as further actions necessary to complete the design prior to the PDR:

- Examine the clearance issues at L4 and at the secondary socket for the Short Relay Design
- Examine the vibrations currently on the Keck II telescope and its impact to the design
- Understand the total weight of the BGS to ensure it will not impact the launch telescope performance
- Complete the implementation of diagnostics for the BGS.
- Complete the polarization control system.
- Produce a focus error budget
- Produce a pointing error budget