Next Generation Adaptive Optics System

Laser Launch Facility Beam Transport Optics

Preliminary Design

KAON 662

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VersionV1.2

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REVISION HISTORY

Revision	Date	Author (s)	Reason for revision / remarks
1.0	Oct 19, 2009		Initial release
1.1	Oct 20, 2009	EW	Add KAON number (was TBD)
1.2	Nov 03, 2009	JC	Updated risk summary

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1 INTRODUCTION

As part of the Next Generation Adaptive Optics System (NGAO), a Laser Launch Facility (LLF) System is needed to propagate the laser beam. One component of the LLF System is the Beam Transport Optics (BTO). The BTO is a set of opto-mechanical devices and beam tubes that are attached to the Keck II telescope. It receives the three beams from the Switchyard and relays them to the Beam Generation System (BGS). The BTO, along with the Switchyard, ensures the laser beams enter the BGS with the proper alignment. This document provides the preliminary design of the BTO. Some sections of the document have not been completed to the level required for PDR; these sections will be completed prior to the PDR. The layout of the document is such that the context of the sections will remain the same; but more details will be provided as the project progresses from PDR to DDR.

2 REFERENCES

2.1 Referenced Documents

Documents referenced are listed in Table 1. Copies of these documents may be obtained from the source listed in the table.

Ref. #	Document #	Revision or Effective Date	Source	Title
2	KOR 90	x.x	WMKO	Keck Observatory Report
3	KAON 210	1.0	WMKO	Keck 2 Projection System Flexure
4	KAON 511	0.3	WMKO	NGAO System Design Manual
5	KAON 510	1.0	WMKO	NGAO Preliminary Technical Risk Evaluation
6	TBD	1.0	WMKO	LLF Requirements Document
7	TBD	1.0	WMKO	LLF Requirements Compliance Matrix Document

Table 1: Reference Document

2.2 Acronyms and Abbreviations

Table 2 defines the acronyms and abbreviations used in this document.

Acronym/Abbreviation	Definition
BGS	Beam Generation System
BTO	Beam Transport Optics
BTOS	Beam Transport Optical System
DDR	Detailed Design Review
IFSM	Infrared Fast Steering Mechanism
KAON	Keck Adaptive Optics Note
LE	Laser Enclosure
LGS	Laser Guide Star
LGSF	Laser Guide Star Facility
LLF	Laser Launch Facility
LRD	Long Relay Design
NGAO	Next Generation Adaptive Optics System
PDR	Preliminary Design Review
RBC	Right Bent Cassegrain
SRD	Short Relay Design

TBD	To Be Determine
WMKO	W.M.K. Observatory

Table 2: Acronyms and Abbreviations

3 OVERVIEW

The LLF layout is shown in Figure 1. This is an updated figure from one presented in the NGAO System Design Review in KAON 511. The Beam Transport Optics (BTO) includes the functions represented by the components that are not in the rectangles. The main function of the BTO is to transport the beam from the laser enclosure, along the telescope structure, to the Beam Generation System (BGS).

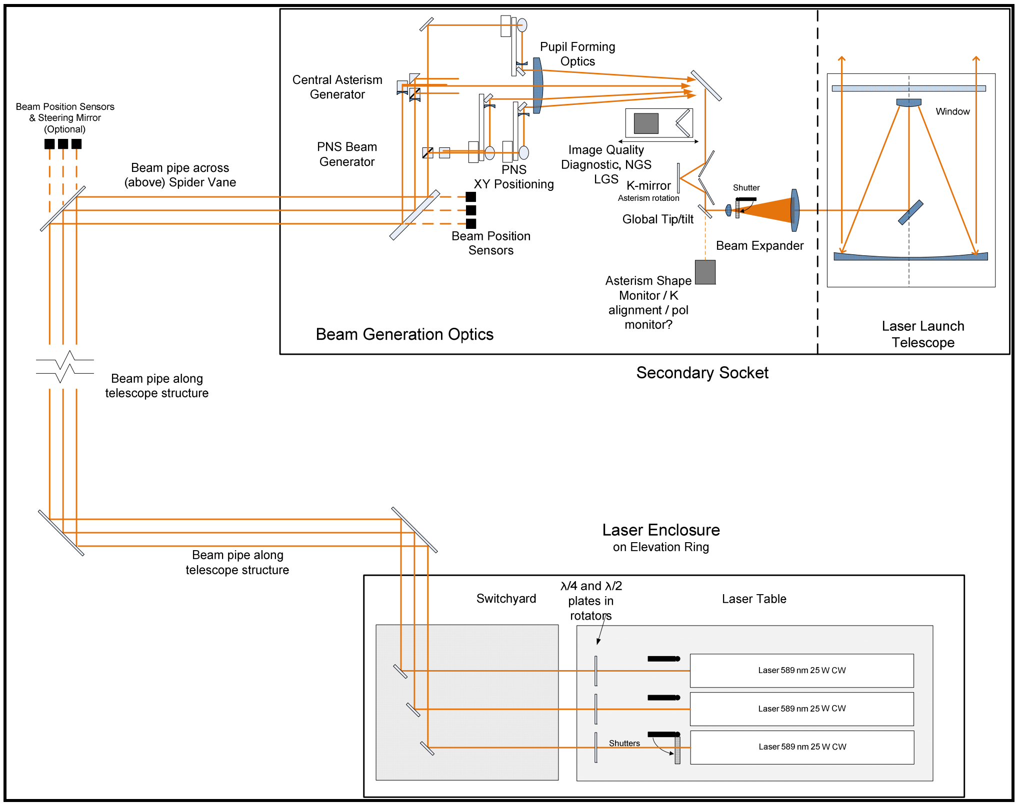

Figure 1: Laser Launch Facility Layout

The location of where the BTO fits into the overall NGAO System is shown in Figure 2. The BTO will have a mechanical interface mainly to the telescope and partially in the f/15 module to mate with the BGS.

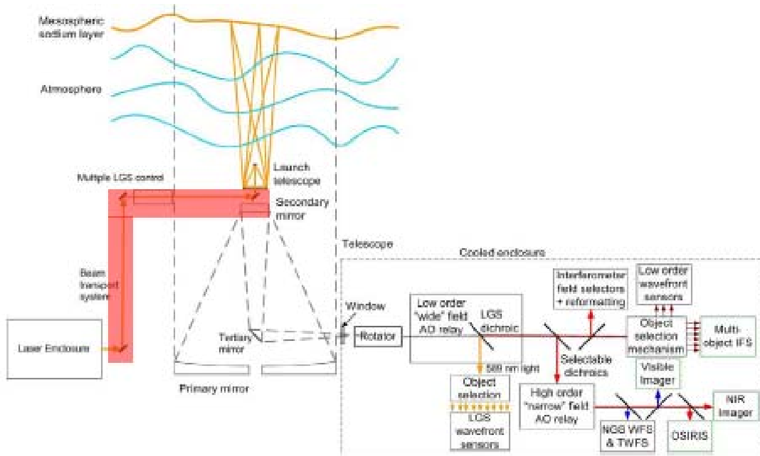

Figure 2: Laser Launch Facility BTO (shaded in red) within the NGAO System

4 REQUIREMENTS

The requirements for the Beam Transport Optical System are presented in the LLF Requirements Document. The BTO is part of the BTOS and will apply the requirements as outlined by the BTOS and the LGSF.

In addition to those in the BTOS requirement, the following requirements are being added to BTO.

Short Name	ID	Section	Category	Priority	Description
BTO Scalability	FR-	Overall	Optical	Important	The BTO optical design shall be able to be used with the existing Keck II dye laser output.

Table 3: Additional Requirement for the BTO

5 DESIGN

5.1 Opto-Mechanical Design

The main criteria for the BTO design are to maximize throughput and minimize wavefront errors by minimizing reflections, and to produce no additional vignetting of the telescope pupil. Ease of installation, alignment and maintenance are also important factors. The design will also be scalable to add additional beams if necessary. Based on these criteria, two possible designs were considered.

5.1.1 Long Relay Design (LRD)

The LRD design starts from the Switchyard located in the LE on the front section of the elevation ring. This is similar to the current location of existing output window of the Keck II laser table where the L4 launch tube starts. From there, a fold mirror (M1) will send the beam over in the +X direction to the corner of the elevation ring (Figure 3). Figure 4 shows the LRD path from the side view of the telescope. A second mirror (M2) will send the beam in the +Z and –Y direction to the spiders near the top end. The beams will run outside of the telescope pupil. At the top end, another mirror (M3) will jog the beam over to the M4 position (Figure 5), where it will follow the spider in the +Z direction to the secondary socket. The beam will follow the spider and will not vignette the telescope. Once the beam reaches the secondary socket, M and M6 will fold the beam into the BGS. The full path of the beam will be in sealed tubes to prevent stray light from affecting observations as well as for cleanliness.

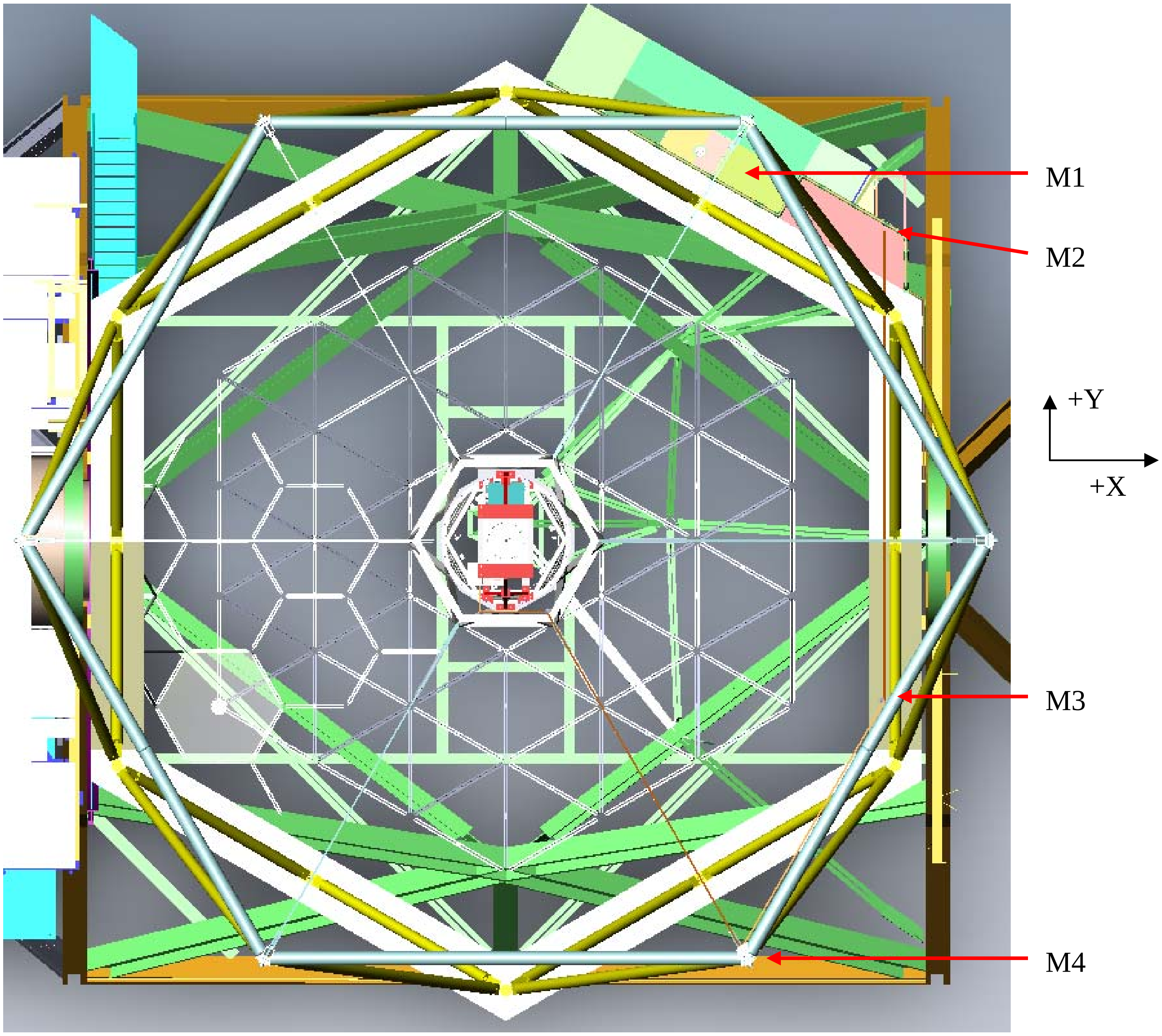

Figure 3: LRD path

The attachment points on the telescope are not clearly defined yet; however, there are several locations the beam tubes can be attached to the telescope structure. The tubes will be approximately 2”x4” leaving M1 and will be sized 1” x 3” over the spider to not vignette the telescope pupil.

There are several advantages to this design path. By having the beams approach the secondary from the spider from the -Y direction of the telescope, any structure added to the spider in the + Z direction will not collide with the Nasmyth Deck. This is not true for structure in the +Y direction. This will allow greater freedom in the size of the structures to be implemented on the telescope. Another advantage to this design is the possible need for installing a laser at the Right Bent Cassegrain (RBC) location. If a laser is installed at this location, any additional beams can join the LRD path at M4 and continue on to the BGS. The RBC location is located directly under M4 when the telescope is at zenith. This provides a scalability advantage to this design. A final advantage is entering the BGS from the -Y direction. The BGS plate will be located on the -Y direction of the launch telescope. The preferred location for the BGS is in this direction as it is easier to service and perform alignments.

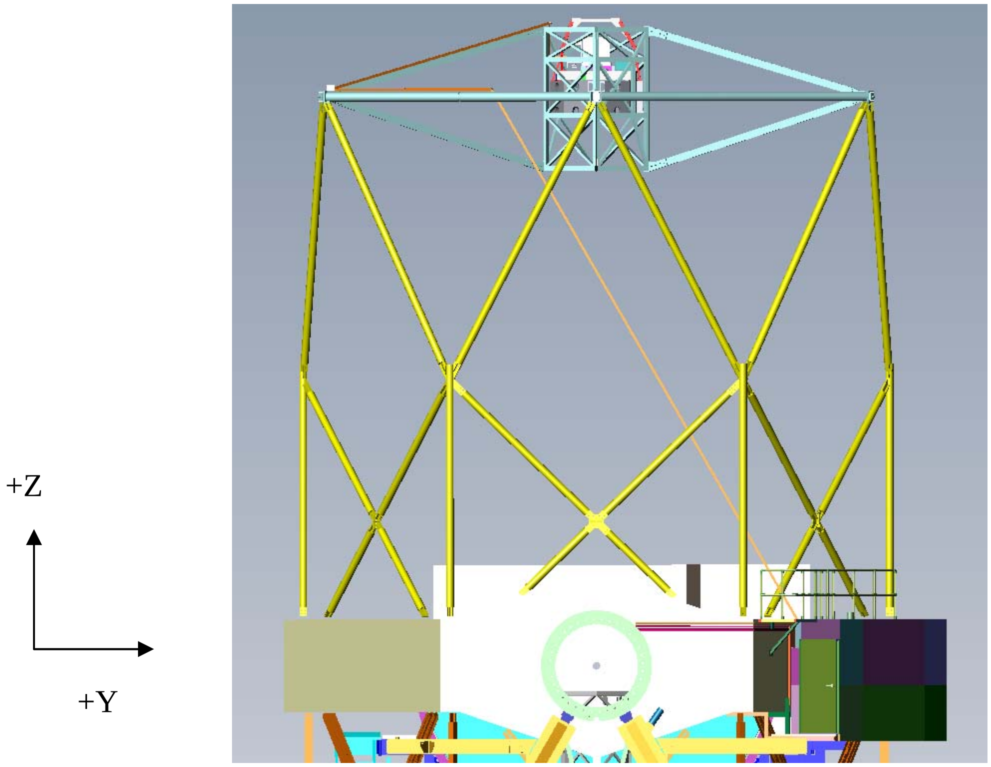

Figure 4: Side view of LRD

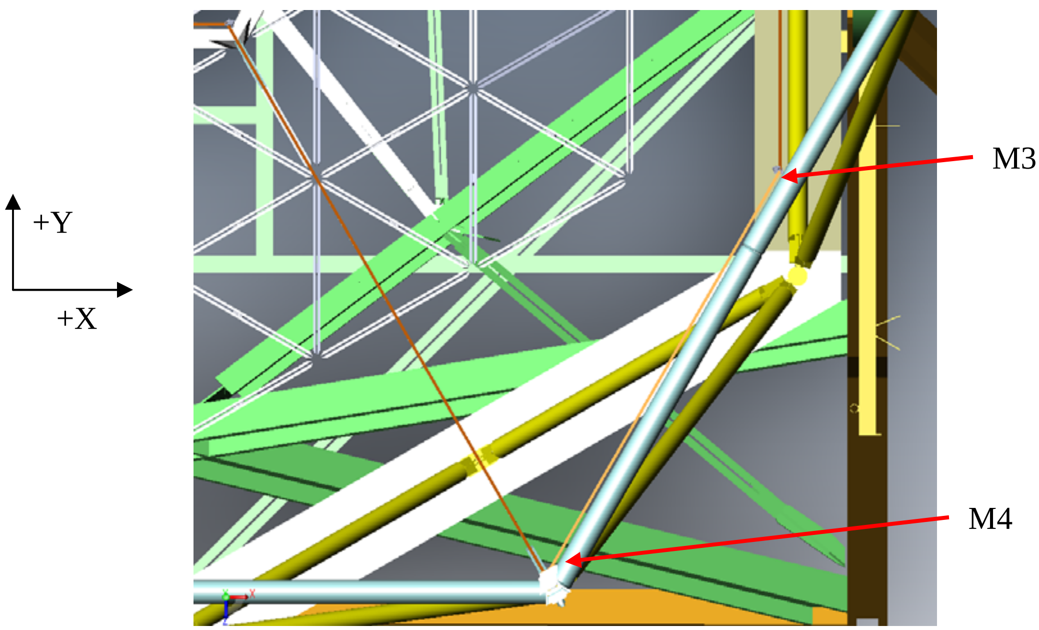

Figure 5: Leg between M3 and M4

The LRD does have one major disadvantage. From an installation and alignment point of view, it is more difficult to access the locations of M3 and M4. The LRD design, as compared to the Short Route Design (SRD), shown later, will also have tube attachments points that will have difficult access.

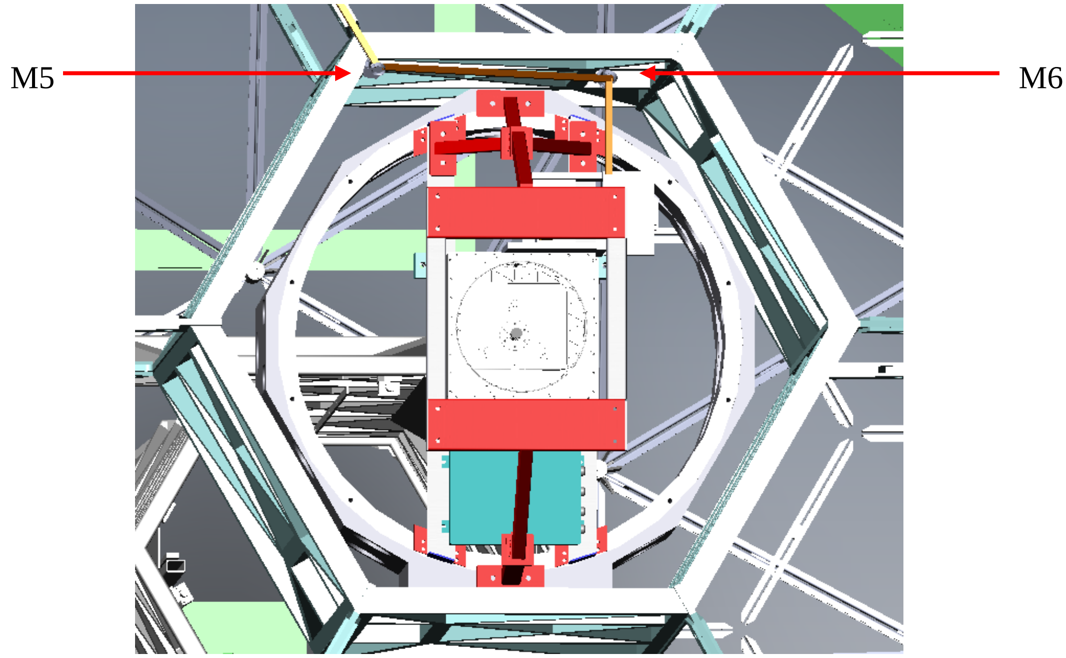

Figure 6: M5 and M6

5.1.2 Short Route Design (SRD)

The second proposed design SRD is a more direct path to the secondary socket. The SRD will exit the LE similar to the LRD; but will not require an M1. This assumes the lasers and the Switchyard can position the beam properly to the M1 near the L4 position.

The beam will travel in a similar path as the current Keck II laser up toward the L4 location from the LE. At this corner, the beam will jog onto the top of the spider and enter the secondary similar to the LRD. At the secondary, there will be a combination of three mirrors, M3, M4, and M5 to propagate the beam into the BGS. Unlike the LRD, the SRD will require an additional mirror since it is coming from the +Y direction of the telescope and the BGS is located in the –Y direction. It is possible to situate the BGS upside down on the LTA; however, this would make installation, alignments, and servicing of the BGS more difficult.

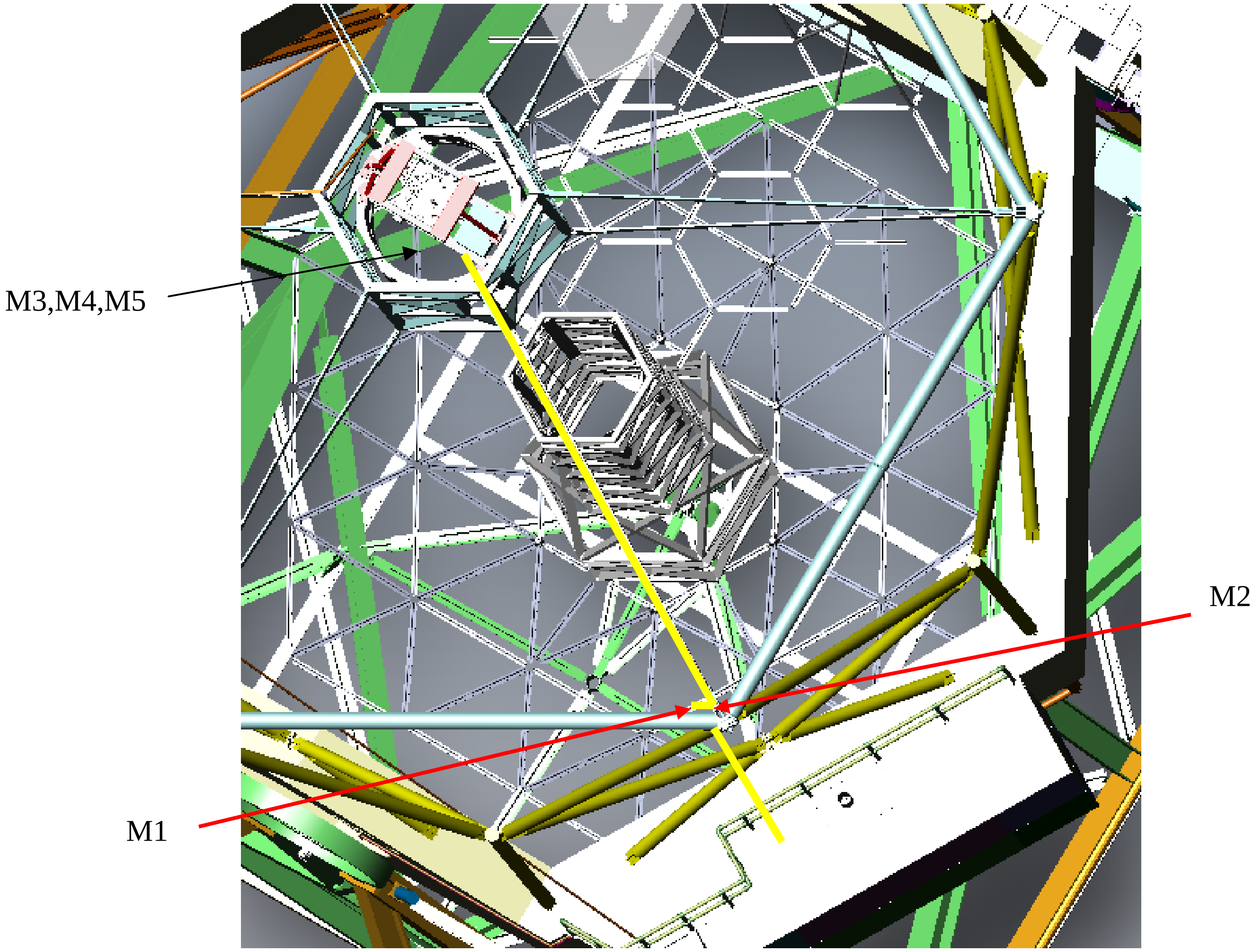

Figure 7: Short Relay Design

In addition to the obvious advantage of a shorter path to minimize angular related motion, the SRD may reduce the mirror count by one for performance. The major advantage of the SRD is the easier access to these locations for installation, alignment, and servicing. The telescope can be placed at a lower elevation to provide access to these attached points with the JLG man lift or possible a hydraulic lift since it is much closer to the dome floor. Since the L4 launch tube has similar attachment points in the existing Keck II design (Figure 8), it may be possible to reuse some of this structure.

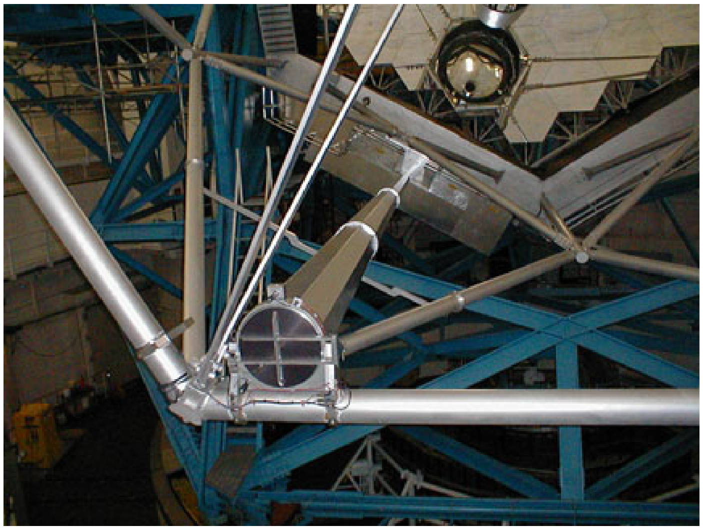

Figure 8: Current L4 beam tube

A major concern of the SRD design is pinch points along the SRD path between the telescope and the Nasmyth Deck. The amount of allowable spaces at the L4 location and the top end to attach stages are limited. At the L4, location (Figure 9), the beams are required to fold over to the +Z direction of the spiders. The current knuckle or corner structure clears the Nasmyth Deck by no more than 35 to 50 mm

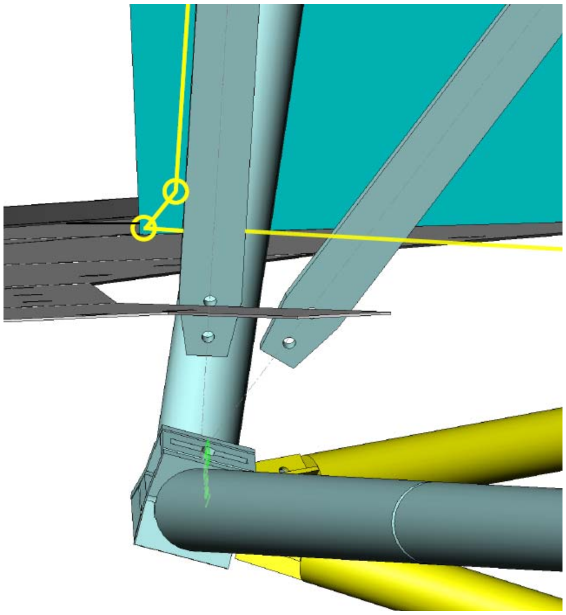

Figure 9: Pinch point at the L4 location

when the telescope is at 20° to 23° elevation. The opto-mechanical fixtures that must be located in this area has approximately 20cm in the +Z direction. Two fold mirrors and possibly a PSD are needed to be located here.

The location where the beams enter the secondary socket (Figure 10) is also limited in volume when the telescope travels to horizon near the Nasmyth Deck. This location provides slightly more space than the L4 location, approximately 30cm. In either the LRD or the SRD, there is significant infrastructure at the secondary socket that must be considered in the design (Figure 11)

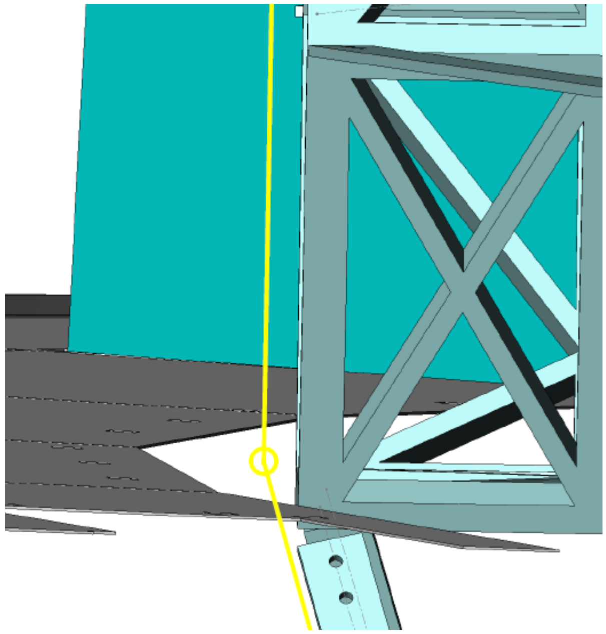

Figure 10: Pinch point at the secondary socket

Figure 11: Telescope socket infrastructure

In the SRD, to fold the beam into the BGS, an extra mirror will be needed. The beam can be placed adjacent to the launch telescope to maximize accessibility into the f/15 module for service.

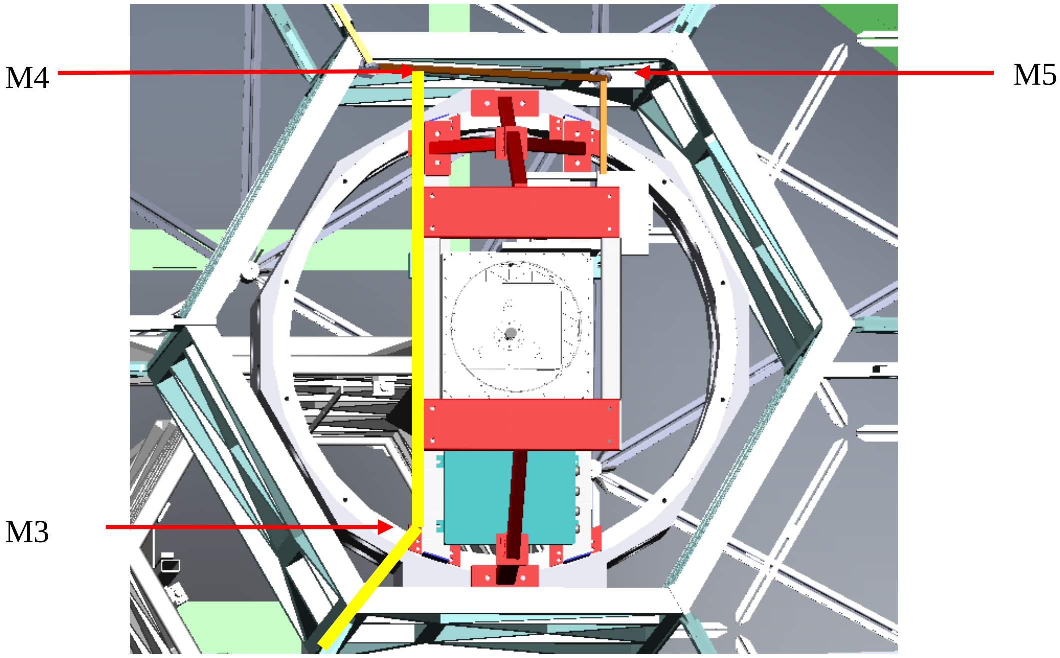

Figure 12: M3, M4, M5

5.1.3 Flexure

Understanding the telescope flexure is crucial to determine the needed motion control to assure the laser beams will enter the BGS properly at the top end. Although the telescope was designed with trusses that function as a Serrurier type telescope, the flexure impacting the laser beams will be different. The lasers will be located on the elevation ring while its initial target will be located at a corner of the top ring. The Serrurier design assumes the primary and secondary mirrors move together due to gravity.

5.1.3.1 Telescope flexure magnitude

Based on the telescope design presented in KOR 90, with a 2 ton instrument package the top ring will deflect 1.7mm due to gravity for horizon pointing relative to zenith pointing. KOR 90 also mentions a 19 arcsec tilt of the top ring about an unspecified axis, presumably close to the elevation axis. This would contribute an additional 1.2 mm of translation at the top ring. No data was provided for the corner of the top ring where the laser beams will land as they transverse toward the secondary from the elevation ring.

This data from KOR 90 does not agree with previous flexure data collected in 2001 between L3 and L4 in the current Keck 2 laser projection system detailed in KAON 210. That test measured 12 mm of motion between L3 and L4 which is much larger than the design value of 2.9 mm. To reconcile this discrepancy, more testing was performed in September 2009 and the results are detailed in KAON TBD. This new testing measured 2.9 mm of flexure between the elevation ring and the top ring.

Another potential source of flexure data is the pointing corrections currently used for the Keck II laser system. The worst case offset is approximately 19 arcseconds on sky, however as this is the sum of several factors such as internal laser flexure, residual sodium distance error, secondary tilt, telescope pointing models, and acquisition camera offsets it is not straightforward to convert this to a simple telescope flexure term.

5.1.3.2 Flexure correction system

The first consideration for the flexure correction system is how many active mirrors are required. In general, using two active mirrors would allow correcting both decenter and angular errors resulting in perfect correction of the flexure effects. If possible, however, using only one active mirror would result in significant savings for both budget and system complexity. A single active mirror could correct for changes in either position or angle, but not both simultaneously. In fact, correcting one term will potentially increase the other.

To determine the feasibility of using a single mirror corrector, the worst case system behaviour was approximated by assuming that the measured flexure amount of 3 mm from KAON TBD directly appears at the pupil forming lens in the BGS system along with an additional angular error of 19 arcseconds as described in KOR 90. From the BGS design document, the plate scale at the pupil forming lens is 0.633 mm/arcsecond. This would result in an on-sky error due to the decenter term of 3/0.633 or 4.7 arcseconds. The angular magnification of the BGS is 171, so the on-sky error due to the angular flexure term is 19/171 or 0.1 arcseconds. Therefore, without active BTO flexure control the total error should be approximately 4.8 arcseconds on sky. If a single active mirror is placed in the laser enclosure switchyard to correct this flexure, it can reposition the beam at the BGS pupil forming lens such that there is no error due to decenter. However, as it is only a single mirror it introduces an angular error in this process determined by the amount the spot moved and the distance from the steering mirror. As an estimate, assume 3 mm of spot motion 23 m away from the steering mirror, which results in an additional 27 arcseconds of angular error. The total angular error in this case is then the sum of the 27 arcseconds of error from the steering mirror and the 19 arcseconds of flexure described in KOR 90 for a total of 46 arcseconds. After accounting for the magnification of the launch optics, this results in an on-sky error of just 0.27 arcseconds. If desired, this could be reduced by commanding the spot location to some small offset from the true center position. In this case, a spot offset of 430 microns would correct for the residual 0.27 arcseconds of error.

A final consideration for the single steering mirror option is that while the spot location at one point in the BGS is stabilized, the laser footprint will still move around for other elements in the system. Since the BTO consists entirely of flat mirrors vignetting is the only concern as the spot moves around. All of the mirrors do not have size constraints and can easily be oversized by any necessary amount to allow plenty of room for the laser footprint to move around. The beam tube over the spider is the only size constrained element, but here, too, it should not be a problem. By definition, the spot position will be corrected at the BGS. The total motion of the laser footprint at the other, outer, end of the spider then depends on the angular error of the beams. For an angular error of 46 arcseconds, the beam footprint should move by just 1.3 mm. Since the beam diameter for no truncation at that point in the system is approximately 6 mm, there is plenty of room for the expected motion due to flexure inside the 25 mm beam tube over the spider. The long relay design was analyzed in more detail using zemax, and the expected motion of the laser spot at both the first mirror on the top ring and at the entrance to the spider tube is shown in Figure 13. This figure shows the zenith pointing case in blue, 3 mm of uncorrected flexure in green, and the resulting spot location after correcting the spot location at the BGS is shown in red. After the final selection of the relay path, this analysis will be performed in more detail for the chosen arrangement.

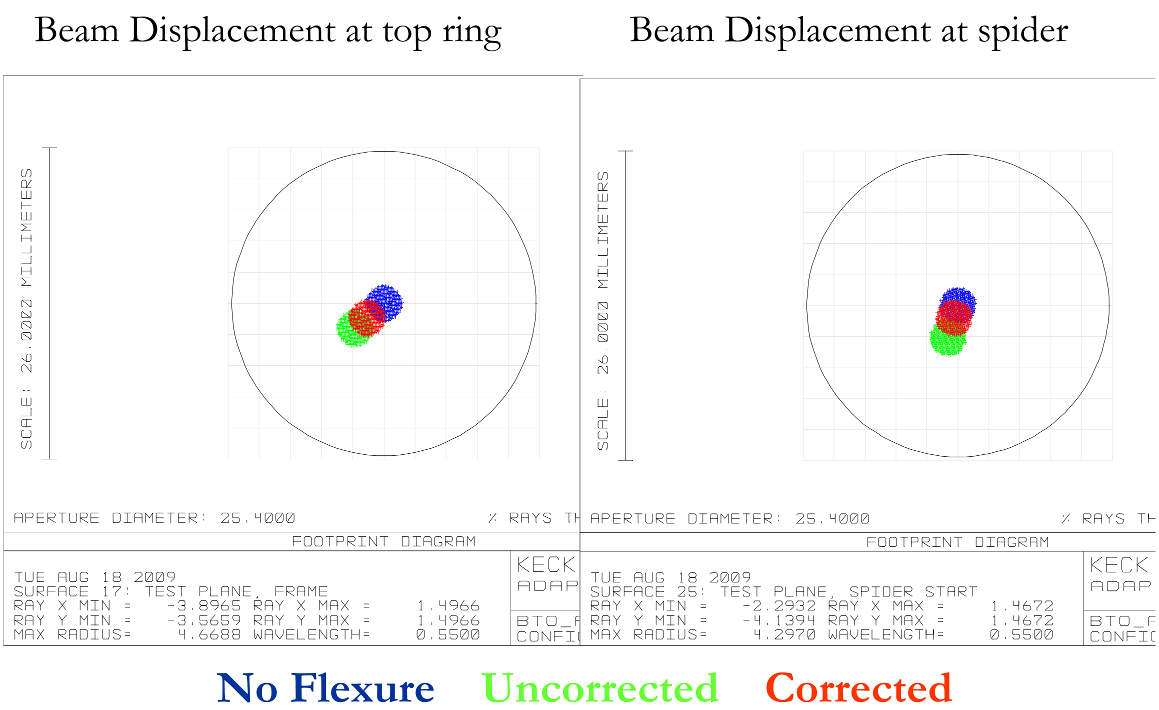

Figure 13: Beam motion for the long relay design at M3, left, and M4, right.

For the single mirror flexure correction system, the mirror would need to have enough range to move the laser spot at the BGS by 3 mm. If the separation between the steering mirror and the BGS is 23 m, this would be a total range of 27 arcseconds. To position the laser with an on-sky accuracy of 0.1 arcsecond, the required precision of the spot placement at the BGS would be 64 microns. This would imply a tilt accuracy of 0.57 arcseconds for the steering mirror. This range of 27 arcseconds and a precision of 0.57 arcseconds is equivalent to a range of 131 µrad and an accuracy of 2.8 µrad. This level of accuracy would be challenging for a mirror based on mechanical actuators, but is well within the range for a mirror using piezoelectric actuators.

Each laser will have its own steering mirror in the laser enclosure switchyard and position sensor at the BGS. This is primarily to correct for drift in the individual laser pointing from each laser head. For more detail, see the laser enclosure switchyard design document.

The expected 3 mm of flexure motion may be greater than the range of the position sensing devices used in the BGS. To ensure that the lasers are always within the dynamic range of the PSDs, the steering mirrors will use an open-loop lookup table to calculate their position whenever the PSD signal is invalid.

5.1.4 Tube Design

The BTO tubes will be of different sizes depending on its location. The tubes at the spider location in front of the pupil will be no wider than an inch so that they will not increase the pupil obscuration and telescope emissivity. The tubes exiting from the LE will be larger, at least 2”x4”; this will allow for easier handling and provide structural integrity at the attachment points. The attachment points to the telescope shall be compliant so as not to impact telescope performance. The tubes will be slightly pressurized from the LE to the BGS with a modest 1 to 2 SCFM of purge air starting at the BGS to maintain cleanliness within the tube structure. To ensure there is no turbulence due to a chimney effect, a window will be added at the LE. The Switchyard is expected to generate over 150 W of heat which will be removed by liquid cooling; however, the window will prevent any remaining heat from going through the BTO structure. The exterior of the tube shall be painted with low emissivity paint as are the trusses and spiders on the telescope. The interior of the tubes will preferably have a rough, dark finish to reduce scattered light and reflections from accidental beam-tube contact.

5.2 Scalability

The current plan is to install three 25W lasers in the existing Keck II LE. If this is unattainable, an auxiliary location may be needed to host one of the three lasers. This laser can be placed at the RBC location as mentioned earlier. In the case of the LRD, the output beam from this third laser can go directly in the +Z direction of the telescope to join the existing BTO path. This design will allow the additional beams if necessary without significant changes to the design. In the case of the SRD, laser(s) at the RBC can propagate through an identical SRD on the –Y sector of the telescope and join the laser beams coming from the LE at the secondary socket. In both cases, the two sets of beams will be combined into a single pattern in a passive box on the top ring. Since each laser will have its own flexure control system consisting of a steering mirror in the laser enclosure and position sensors at the BGS, the laser pattern at the BGS will be maintained without the use of active mirrors in the BTO.

5.3 Electronics

5.3.1 Motion Control System

Based on the flexure tests completed, no moving devices are needed in the BTO. A steering mirror in the Switchyard will provide sufficient compensation. For risk reduction, an upgrade path will be included to actuate a mirror at the M4 location of the LRD or M1 location of the SRD in the unlikely case the flexure is much larger than anticipated.

5.4 Diagnostics

The nominal LLF design places all diagnostics within the Switchyard and BGS. If the motorized stage upgrade described in section 5.3.1 is needed in the BTO due to flexure compensation, a position sensing diode will be required in the BGS to support the steering of the beams.

5.5 Safety

Since Keck II does not use the f/40 IFSM module, the f/15 will be taken out only for servicing. During these periods, the laser shutter should not open. To ensure the BTO is properly installed, interlock switches will be placed at the f/15 module/BGS end. These switches will determine the status of the f/15, BGS as well as tubes in the f/15 module. If the interlocks are not met, the laser shutters cannot be opened. Some of the interlock signals such as the f/15 module “installed” can be provided by the Keck II local controls system.

5.6 Interfaces

5.6.1 Mechanical Interface to the telescope

There will be attachment points between the tubes and the telescope similar to those for the current L4 launch tube (Figure 14). These will be modelled for the PDR. At each location where a mirror exists, an enclosure will be installed around the mirror for service, alignment and cleanliness. The enclosure will be similar to that in Figure 14.

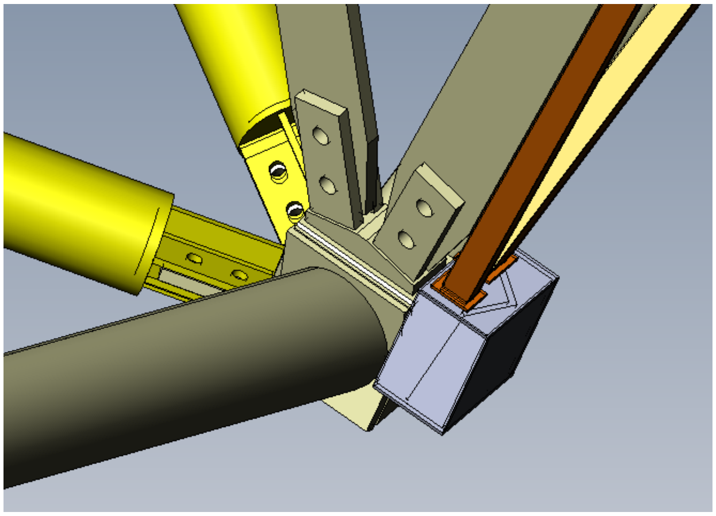

Figure 14: LRD M4 enclosure

At the secondary socket, mirrors and tubes will be attached to the telescope structure and the f/15 module. The goal is for these structures to be attached in such a manner that they will not interfere with the installation and removal of the f/15 module. It is more likely that some tube structure will require additional handling.

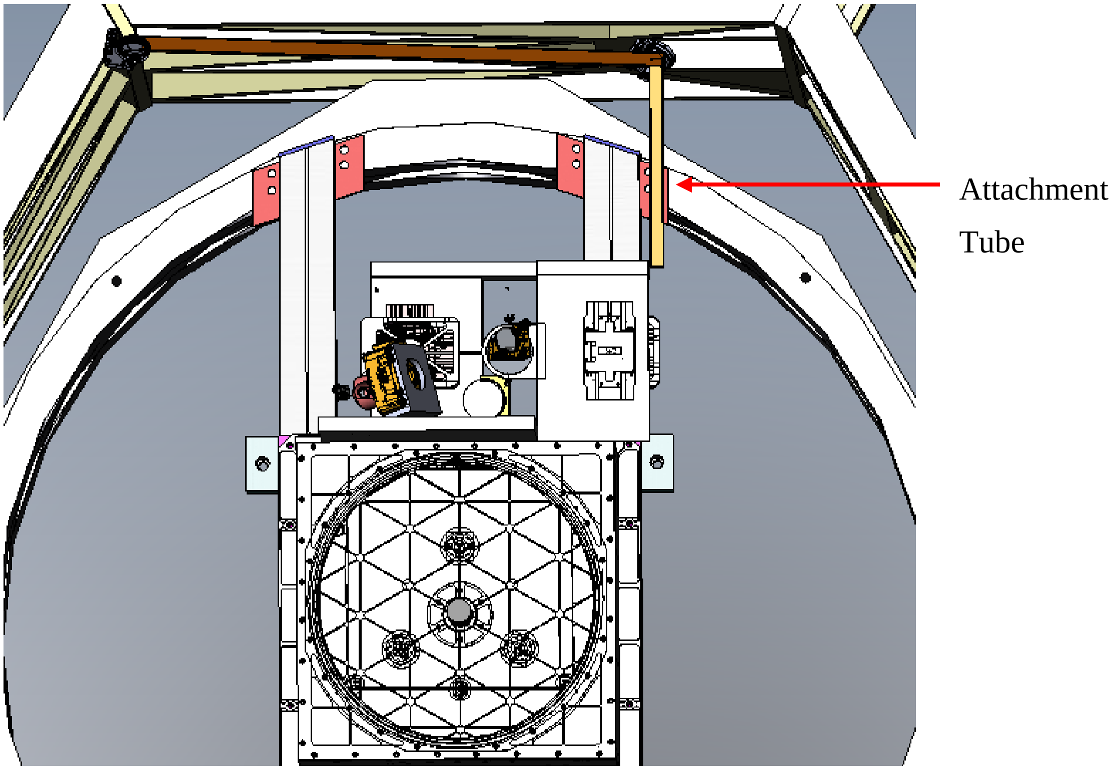

Figure 15: M5 and M6 attachment points within the LRD

5.6.1.1 Infrastructure Interfaces such as Power, Pneumatic and Glycol

No infrastructure requirements will be needed for power, pneumatic or glycol. These are available at the Switchyard and secondary socket if they become necessary in the design.

5.6.2 Internal Interfaces within the LLF

5.6.2.1 Mechanical Interface to the Beam Generation System

The BTO will attach to the BGS via a single mechanical tube structure within the secondary socket. This tube (Figure 15) will pivot onto the BGS when the f/15 module is removed from the telescope for servicing.

5.6.2.2 Mechanical Interface to the Switchyard

Unlike the BTO interface to the BGS, the mechanical interface to the Switchyard will be a permanent connection. The BTO will be attached to the Switchyard at the LE. Further information will be provided once the design matures.

5.6.2.3 Electrical Interface to the Safety System

The BTO shall have a small set of electrical signals with the Safety System. These will be two wire low voltage DC analog signals. These signals will provide status on the beam tubes in the secondary socket as well as the f/15 module status in the telescope. These interlocks are to ensure the infrastructure are in place to propagate the laser from the Switchyard to the BGS.

6 SYSTEM PERFORMANCE

6.1 Optical

6.1.1 Transmission

The total number of elements in the BTO depends on which design is chosen. It will consist of either five or six mirrors, with two transmissive surfaces for the laser enclosure window. The NGAO standard coating values are 0.994 for reflective and 0.996 for transmissive surfaces. An additional factor of 0.995 is applied to account for dust accumulation. This results in a total BTO throughput is 89.7% for five mirrors and 88.7% for six mirrors.

6.1.2 Wavefront Error

There are no powered elements, so the only source of wavefront error is random surface errors. If the surface error is 20 nm rms, 7 surfaces produces a total of 53 nm rms and 8 surfaces result in 57 nm rms. If the surface error is improved to 10 nm rms, the totals reduce to 26 and 28 nm rms, respectively. The effect of wavefront error on the final sodium layer spot size is still under investigation, but it is expected that this range of wavefront error will be acceptable.

6.1.3 Pointing Errors

See section 5.1.3.2 for a detailed analysis of the required steering mirror motion and resulting pointing errors due to telescope flexure. Another source of error not included in that analysis is the flexure of the various mirror mounts that make up the BTO, either due to the mount itself or due to local deformations in the telescope structure. The pointing error due to these motions will simply add to the total beam motion from the telescope flexure, and be corrected the same way. The mirror mount flexure will be considered during the detailed mechanical design and kept to a small enough value to meet the overall pointing specification.

6.2 Mechanical

6.2.1 Mass

The estimated mass of the BTO is shown in Table 4 and Table 5 for the two designs. With the LRD, approximately 100 Kg will need to be added to the Cassegrain location to compensate for the added mass on the telescope to balance about Z. For Y, it is relative balanced since mass will be added to both + and – Y.

Ref#	Item	Location (m from CG)	Mass (kg)	Moment (Kg*m)
1	M1, M2 section	+1	15	15
2	M2, M3 section	+6	40	240
3	M3, M4 section	+12	20	240
4	M4, M5 section	+12	10	120
5	M5, M6 section	+12	5	60
			Total	675

Table 4: LRD Mass

For the SRD, the estimated total mass to the telescope will 75 Kg. To compensate for this, 100 Kg will be added to the Cassegrain location for Z and mass must be added to counter balance in Y as well since almost all of the mass will be added in the +Y axis

Ref#	Item	Location (m from CG)	Mass (kg)	Moment (Kg*m)
1	M1, M2 section	+6	40	240
2	M2, M3 section	+12	20	240
3	M3, M4 section	+12	10	120
4	M4, M5 section	+12	5	60
			Total	660

Table 5: SRD Mass

6.2.2 Heat Dissipation and Glycol requirements

No glycol requirements are needed in the BTO.

6.3 Electrical

No electrical power will be required by the BTO.

7 Operations

7.1 Modes

7.1.1 Operational Mode

During normal operations, the BTO shall operate at full laser power with three beams operating at 25 watts of CW 589nm light. The BTO, along with the entire LLF, will maintain the beam to within 0.3 arc sec tolerance.

7.1.2 Alignment Mode

During alignment mode, the laser beams will be operated at low power 125mW initially. The power shall be sufficient to visually monitor the beam pattern on each element of the BTO.

7.2 Procedures

The following procedures shall be provided as part of future phases for the BTO.

7.2.1 Alignment

A rough alignment procedure shall be provided to set up the BTO on the telescope. This rough alignment will not require the 589nm laser. An alignment laser can be placed at the Switchyard for initial alignment. As there are no powered elements in the BTO, most of the alignment is not very critical. The goal for most of the elements is simply to ensure that there is no vignetting and the presences of a sufficient clear margin around the pattern to allow for motion due to flexure. Starting at the laser enclosure, each mirror will be adjusted to center the laser beam pattern on the next mirror in the system. The final mirror will be require more critical alignment to ensure that the laser beams are correctly placed on the position sensors. More detail of this procedure shall be provided during DDR.

A fine alignment procedure shall be provided to operate the BTO in alignment mode as specified in 7.1.2. This procedure shall take into consideration any safety issues due to the high power nature of the laser. A final procedure shall be available to the operations team during BTO handover.

7.2.2 Cleaning (Maintenance)

The BTO shall be designed for a 10 year life time. Due to the difficult access to most of the BTO devices on the telescope, the BTO shall be designed as a sealed unit to minimize particulate contamination. However, considerations shall be made in the design to allow access to clean the optics in the BTO and possibly recoat as necessary. The frequency of cleaning shall depend on how well the BTO is sealed to prevent particulates contamination. The need for cleaning will be indicated by throughput measurements of the overall system. Scheduling system cleaning based on performance metrics instead of periodic intervals will reduce both the resource requirements and the potential for damage to the system while ensuring that the overall system performance does not suffer. This procedure shall be turned over to the operations team during BTO handover. BTO cleaning will require both personnel and telescope resources to access BTO optics.

7.3 Operational Resources and Preventative Maintenance

Additional information shall be provided during DDR on required operational resources. Outside of troubleshooting of the BTO, the operations team will be required to support maintenance procedures in 7.2.

8 Development and Testing

This section will be presented at the DDR.

9 Requirements Compliance Verification

The compliance matrix will be presented as a whole for the entire LLF in the LLF Requirements Compliance Matrix document.

10 Risk and Risk Reduction Plan

Table 6 shows individual risks within BGS in accordance with KAON 510.

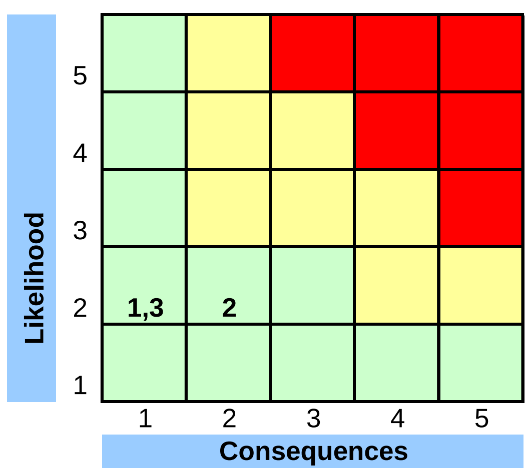

Table 6: Risk Matrix

#	Consequence	Likelyhood	Description	Status	Mitigation
1	1	2	Flexure is larger than expected	Flexure testing does not show this is the case; however, there may be flexure within the switchyard.	An additional stage will be added to compensate for this flexure
2	2	2	Vibration on the telescope	More data will be gathered to determine if this is an issue.	The steering PZT stages at the Switchyard can have an additional input to compensate for telescope motion < 60 Hz.
3	1	2	SRD allowable volume	Current models show there is sufficient space.	Final analysis will be done once the design is complete to verify sufficient volume and clearance.

Table 7: Risk Analysis

10.1 Flexure Motion

The flexure was measured from the elevation ring to a location near the L4 position. However, additional flexure may occur between the elevation ring and the Switchyard. This flexure will depend on how stiff the elevation ring is and how the Switchyard is attached. A similar test can be completed to measure the existing flexure between the laser table and the elevation ring since the Switchyard will be attached similarly. If the flexure is found to be larger than the 3mm measured, the current design will allow the addition of motors to remedy this flexure.

10.2 Vibration

The downlink tip tilt stages will remove a significant amount of the vibration on the telescope. Based on experiences on the interferometer, vibration up to 30 Hz are common on the Keck II telescope. If the downlink stages are unable to compensate, the current design of the PZT stage in the Switchyard can be used. This stage is primarily designed for steering of the beam to compensate for flexure; but can have an additional input for vibration compensation.

10.3 SRD AllowableVolume

The allowable volume for the SRD will need to be further examined. Current models show the volume is probably acceptable. The design of the stages at these locations will need to be developed to fully understand the needed volume at these locations. The design team plans to have this risk reduced by the PDR.

11 DELIVERABLES

Figure 16 shows the deliverables for the BTO.

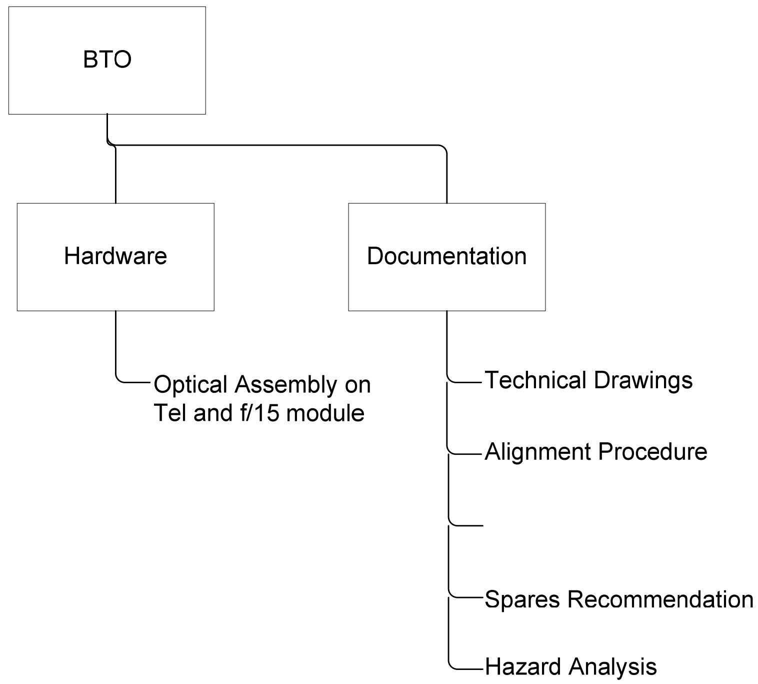

Figure 16: BTO Deliverables

12 MANAGEMENT

12.1 Budget

This section will be presented at the PDR.

12.2 Schedule

This section will be presented at the PDR.

13 PLANS FOR THE NEXT PHASE

This section will be presented at the PDR.