Laser Guide Star Facility for LTAO and GLAO at Subaru Telescope

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ABSTRACT

In this paper, we present a laser guide star facility (LGSF) aspect of the upcoming laser tomography adaptive optics (LTAO) and ground layer (GL) AO systems at Subaru Telescope. For the LTAO system, a TOPTICA laser will be split into four beams and launched all together from one center-launched laser launch telescope (LLT). For the GLAO system, we will use one more TOPTICA laser, split each into two, and launch them by four separate LLTs from the center section of the telescope to construct a wide asterism. We expect to install the first TOPTICA laser in a single-beam configuration for single conjugated (SC) AO in 2020, a four-beam configuration for LTAO in 2022, and a wide-asterism configuration for GLAO in 2025.

Keywords: Adaptive Optics, Laser Guide Star

1. INTRODUCTION

Since its first light with 36 elements in 2000 and with 188 elements in 2006,[1] Subaru's AO facility has been providing excellent corrected seeing for many kinds of science for the past 17 years. In 2011, our AO system was further advanced by the addition of a laser guide star facility[2] (LGSF) which significantly increased the sky coverage. In the next decade at Subaru, our AO system will step forward into the next scale by introducing laser-tomography (LT) and ground-layer (GL) AO modes, whose project names are ULTIMATE-START[3] and ULTIMATE-Subaru.[4,5] ULTIMATE-START is a milestone project toward ULTIMATE-Subaru to demonstrate a multi-laser/WFS system at Subaru where we also enhance the AO correction for observations in the visible. ULTIMATE-Subaru will develop a next facility-class GLAO system at Subaru using an adaptive secondary to strengthen the extremely wide-field capability of Subaru Telescope.

2. BACKGROUND

Our first generation of LGSF[6] consists of 1) a sodium laser that is created in a temperature controlled clean room on the Nasmyth Infrared (NsIR) floor using a sum-frequency mixing of two Nd:YAG lasers at λ=1064 nm and λ=1319 nm, and 2) a 50 cm afocal laser launch telescope (LLT), which is a bean expander that consists of a parabolic primary-, a parabolic secondary-, and a flat tertiary-mirrors, installed in an octagon enclosure. The sum-frequency generation (SFG) laser is based on a solid-state technology which is usually categorized as the second generation of LGS technology. Our laser was fully developed by the collaborative effort of Subaru Telescope and Riken, the largest research institution in Japan whose research topics cover from biology to photonics. The laser beam from NsIR is transferred all the way to LLT behind the secondary mirror by an optical fiber, is collimated in the LLT enclosure, and expanded by LLT.

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At its best condition in 2011, the laser power was 4W at LLT and R=10.7 on sky; however, 8 years later in 2019, the laser brightness became significantly lower and was 0.4W at LLT and $R > 14$ on sky (Figure 1). This significant reduction of brightness not only include the aging of the laser and the relay fiber but also the degradation of Subaru telescope's primary/secondary/tertiary mirrors. In addition to the low brightness, more and more frequent maintenance work became required to stabilize the laser (e.g., the time for the laser power to stabilize increased from ∼2h to >6h). To increase the brightness and reduce operation complexity, we started LGSF upgrade project in 2018. The plan is to replace the SFG laser with a new, more powerful, and simple operation TOPTICA laser[7] and increase the LGS brightness to $R < 8.5$ on-sky (magenta triangle in Figure 1). This magnitude includes the effect of the expected secondary mirror recoating in 2019. Using this powerful laser, the future plan is to split the beam into four to perform laser tomography (LT) AO (ULTIMATE-Start project, §2.1) in 2022. Once we purchase one more laser, which can be another TOPTICA, and splitting each to two, GLAO (ULTIMATE-Subaru project, §2.2) will be performed in 2025. The expected on-sky brightness of ULTIMATE-Start and ULTIMATE-Subaru cases are shown as cyan downward triangle and green diamond in Figure 1.

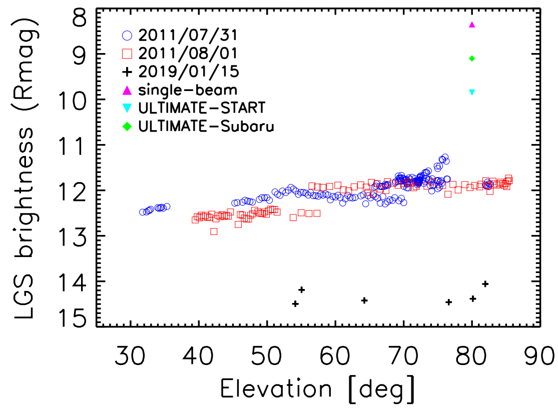

Figure 1 On-sky brightness of the Subaru's first and future LGSs. Blue circles and red squares were measured when it was installed in 2011. Black pluses were measured 8 years later in 2019. Expected new laser brightness in single-, four-, and ULTIMATE-configurations are shown as magenta upward triangle, cyan downward triangle, and green diamond, respectively. The expected values are estimated from 2011 values where the coating on the telescope mirrors were younger.

2.1 ULTIMATE-START

ULTIMATE-Start[3] will demonstrate a multi-laser/WFS system at Subaru while providing an interesting science capability during the transition phase to ULTIMATE-Subaru. For this project, the TOPTICA laser beam will be split to four and launched all together from the same existing LLT behind the secondary mirror. The details of the four-beam configuration is described in §3.2. In addition to the LGSF upgrade, four new Shack-Hartmann WFSs will be installed behind the existing AO188 so that we will recycle many existing components in AO188 to minimize the additional development required. The separation of the beams on sky, we call it asterism, is adjustable between $r = 5"$ to 15" so that two different AO experiments can perform: Small asterism to perform LTAO to enhance the AO correction for observation in visible, and large asterism to perform a part of GLAO to be used as a platform for future Subaru facility AO system. The details of the ULTIMATE-Start project can be found in Ref. 3.

2.2 ULTIMATE-SUBARU

ULTIMATE-Subaru[4] is a project that develops one of three main wide field instruments of 2025 and beyond at Subaru. The project has two main components to build: 1) A brand new facility class AO system that embraces the GLAO technique using an adaptive secondary mirror, and 2) a brand new very wide field (14'×14') designated IR imager. For GLAO, four beams will be launched from four separate LLTs located on the front and rear sides of center section (CS) and create $D = 4'$ to 20' asterism on sky. While Hyper Supreme Cam (HSC) and Prime Focus Spectrograph (PFS) will provide wide field optical imaging and optical multi-fiber spectral data, ULTIMATE-Subaru will provide wide field IR science to strengthen the extremely wide-field capability of Subaru. The details of ULTIMATE-Subaru can be found in Ref. 4

Table 1. Configuration summary

	SCAO	LTAO	GLAO
Number of LGS	1	4	4
Number of laser	1	1	2
Power per beam	> 20 W	> 5 W	> 10 W
On-sky brightness (Rmag)	< 8.5	< 10.0	< 9.25
Number of LLT	1	1	4
LLT location	Center launch	Center launch	Side launch
Asterism rotation	N/A	Fixed with respect to sky	Fixed with respect to telescope
Asterism radius	N/A	Adjustable bertween 5" to 15"	2', 3', 5', 10'
WFS system	Current curvature WFS in AO188	Additional 4 SHWFSs behind AO188	New 4 SHWFSs for GLAO system
Expected first light	2020	2022	2025

3. THREE DIFFERENT CONFIGURATIONS FOR SCAO, LTAO, AND GLAO

In the next 5 years, Subaru's LGSF will go through three upgrades: 1) a powerful single-beam configuration for SCAO, 2) a narrow, multi-beam configuration for LTAO, and 3) a wide, multi-beam configuration for GLAO. The upgrade to a brighter LGS for existing AO system will improve the performance of existing instruments, and the upgrade to the even more advanced multi-beam configuration will open up a new capability at Subaru. In this section, we describe each of the three different laser configurations for three different AO modes in details. The main parameters of three configurations are summarized in Table 1.

3.1 SCAO IN SINGLE-BEAM CONFIGURATION

The first LGSF upgrade in a series of three is a replacement of the Subaru's first generation laser with a more powerful one and increase the brightness of LGS on-sky. The expected brightness after the installation of the new laser is about $R < 8.5$ (magenta upward triangle in Figure 1). For this upgrade, we will not touch any AO system but LGSF (and of course software to interface the new LGSF). The simplified description of its configuration is on Figure 2. The configuration can be split to four sections: 1) the TOPTICA's electronic cabinet (EC) and a heat exchange unit at NsIR, 2) the TOPTICA's laser head (LH), a laser diagnostic bench, and an electronics rack at CS, 3) mirror-based relay optics along a newly designed truss, and 4) beam control optics and LLT in an LLT enclosure. In the following sub-sections, we summarize details of the new TOPTICA laser and describe current designs at different sections.

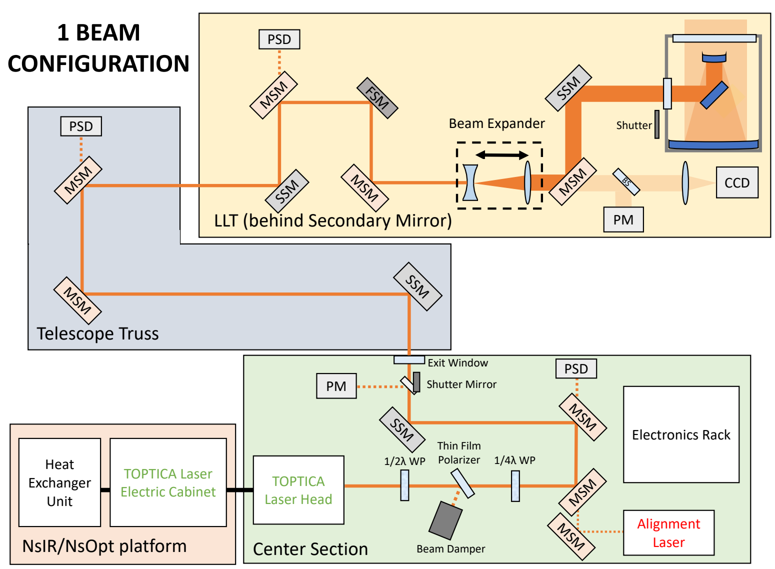

Figure 2 Single-beam configuration for SCAO. The system can be split into four sections according to the locations (NsIR, CS, Truss, and LLT) along the telescope.

3.1.1 TOPTICA LASER

Our new laser from TOPTICA uses narrow-band Raman Fiber Amplifier (RFA) technology and generates a laser beam of > 20W at 589nm.[7] The laser unit consists of two components, EC, which contains SEED laser, diagnostic modules, and power supplies (heat source), and LH in which the power amplification happens using RFA technology. EC is about $2 \times 1 \times 1$ cubic meter whose weight is $\sim$ 600kg. LH is about $0.5 \times 1 \times 0.75$ cubic meter whose weight is $\sim$ 80kg.

Both components can be operated under varying gravity, and thus mounting them to the telescope's body is a viable choice. In our case, EC will be located at NsIR floor, and LH will be installed on the front side of CS. Two are connected by an optical fiber and electric cables. Figure 3 is the CAD model of Subaru Telescope and shows the locations of the new LGSF main components, including TOPTICA's EC on NsIR and LH at CS.

The laser unit has been delivered to Hilo office in 2017 and is being used for lab experiments. The laser power has been confirmed > 22W over 12+ hours of continuous operation. We will keep it in Hilo office until all the other LGSF components are ready for installation. During this period, we will work on the development of laser control/operation software while using the beam for lab experiments, such as polarization and coating tests.

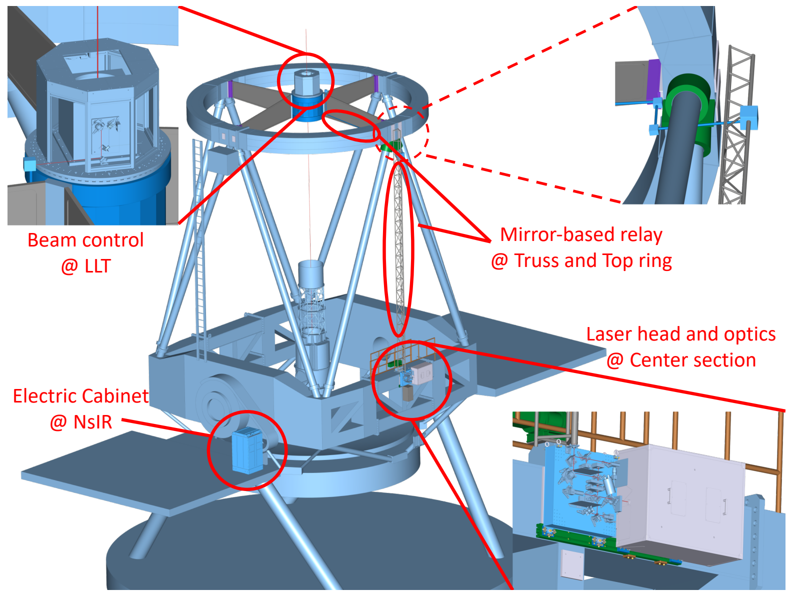

Figure 3 CAD model of Subaru Telescope and new LGSF components at NsIR, CS, TR, and LLT.

3.1.2 DESIGN

In this section, optical and mechanical designs at different locations are described. Figure 3 shows the CAD models of our new LGSF mechanical design. We are currently working with other divisions of Subaru Telescope, such as telescope and instrument divisions, to make sure our design does not interfere with the existing and future telescope's/instrument's developments. Depending on the analysis/simulation results, we may need to modify our design, especially the relay part (please see §3.1.2 for details of current plan). Otherwise the design described here are more-or-less the final version. Earlier version of design report and discussions can be found in Ref. 8.

CENTER SECTION On the front side of CS, 1) LH, which is connected by EC on NsIR through an optical fiber, 2) an optical breadboard, which holds optics and diagnostic devices, and 3) an electric rack, which contains electronics drivers and network/power switches, will be mounted. LH will be installed so that the beam points parallel to the ground. Immediately in front of LH, the beam enters the breadboard where a 1/2 waveplate (WP, A in Figure 4) and a polarizer (B in Figure 4) on rotation stages control the output power, and another 1/2 WP and 1/4 WP (D and E in Figure 4) on rotation stages control the polarization of the beam. As the TOPTICA laser power can only be controlled between 12W and $\sim$ 23W using the provided software, the power control system is necessary for alignment and maintenance purpose. The polarization control is used to create a circular polarization on-sky to maximize returning flux (see Ref. 9 and reference therein).

When the shutter is closed, the beam goes to a power meter (K in Figure 4) and a sodium reference cell (Na cell, L in Figure 4). The Na cell is a glass tube that contains Na molecular compounds inside. When it is heated to a specific temperature, Na is vaporized inside the tube and glows when $\lambda = 589$nm beam enters the cell. This is the same (de)excitation mechanism why we can use Na lasers to create LGSs on sky. The Na glow is brightest when the laser beam is tuned to a particular excitation energy/wavelength, and thus monitoring the brightness of the glow using a CCD (M in Figure 4) is an alternative way of tuning the laser's wavelength to using provided software.

There is another position where an extra LH can be installed. On Figure 4, it is shown at the bottom of the figure where an orange beam is hitting mirrors P and Q. The mirror C on Figure 4 is on a translation stage, and by moving it in and out of the path, either TOPTICA laser from the right or another laser from the bottom can be selected. At this second LH position, we will initially install an alignment laser. This extra port will also be used as an experimental port. ANU is currently developing and testing a fourth generation sodium laser based on semiconductor technology (after dye, solid-state, fiber technologies). The details of the ANU laser and its technology can be found in Ref. 10. Once ANU finishes the off- and on-sky tests of their prototype laser at Mount Stromlo observatory, the ANU laser will be delivered to Subaru and installed to this experimental port for apple-to-apple performance comparison to the TOPTICA laser. An additional interesting experiment we are planning to do is to combine two laser beams to one to increase the final laser power. By replacing mirror C with a polarizing beam splitter cube, we can combine the TOPTICA and ANU laser beams (albeit with orthogonal laser polarizations).

A. ½ waveplate
B. Thin film polarizer
C. 1"mirror
D. ½ waveplate
E. ¼ waveplate
F. 1" mirror
G. Position sensitive device
H. Slow steering mirror
I. Shutter
J. 1" mirror
K. Power meter
L. Sodium cell
M. CCD
N. Beam dumper
O. Wavefront sensor
P. 1" mirror
Q. 1" mirror
R. Wavefront sensor

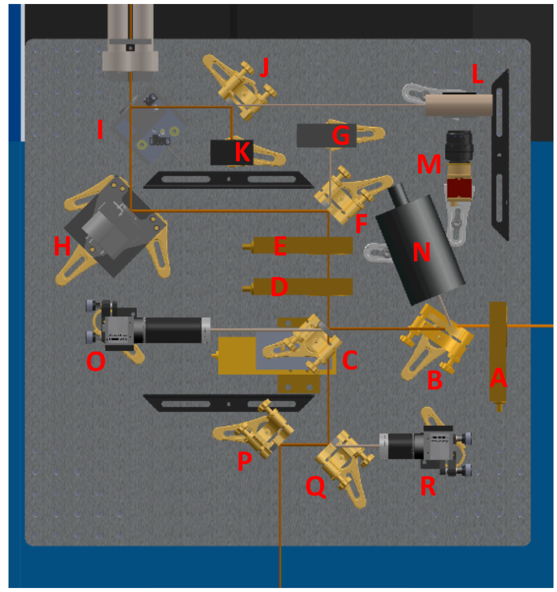

Figure 4 Diagnostic bench at CS. The power and polarization are controlled by WPs and polarizer while the beam power, wavelength, and quality are monitored and tuned by a Na cell, PM, and WFSs.

MIRROR-BASED RELAY The biggest challenge with this upgrade is the switching from a fiber relay to a mirror-based relay. Our old laser beam was generated in a clean, temperature-controlled room on NsIR and transferred to LLT behind the secondary mirror by an optical fiber. The great thing about the fiber relay is its light weight, physical flexibility, and thus an easy installation. However, it cannot transfer the very high power beam, like our new laser beam, and thus we need to design and build a mirror-based relay. The difficulty of a mirror-based relay is that because the laser beam can only travel in a straight line, every time beam hits an existing structure, an additional mirror needs to be installed to change the light path, and at the end, the entire path needs to be well covered by a laser-safe material, which is usually a metal. A metallic structure, especially when it is long and big, is quite heavy, and adding such extra weight to our existing telescope requires careful vibration and balance analysis.

Figure 5 shows zoomed in images of Subaru CAD along the relay path. Panel A shows the top half of the diagnostic bench installed at CS and a triangle shaped interface block in between the bench and the relay truss structure. The relay truss is the three gray tubes above the triangle block that are standing upward. Because the truss at this location is more than 8 m long, we have chosen to go with a triangle structure. The right most tube in this figure is the path of the laser beam. Panel B shows the front side of the top ring (TR) where the relay truss tubes are fastened by the other triangle block shown under the brown square box. The gray box toward the bottom of the figure contains a motorized slow steering mirror (SSM) and a position sensitive device (PSD). Up to this point, the laser beam is pointing upward, and using this SSM, the beam is now pointing toward LLT from the underneath of TR. The brown box is another electric rack that contains another set of power/network switches and SSM driver. Panel C shows the back side of Panel B. A manually steerable mirror (MSM) shown on the right middle side of the figure reflects the beam upward again to send the light to the another MSM that is installed on a side of the secondary mirror spider.

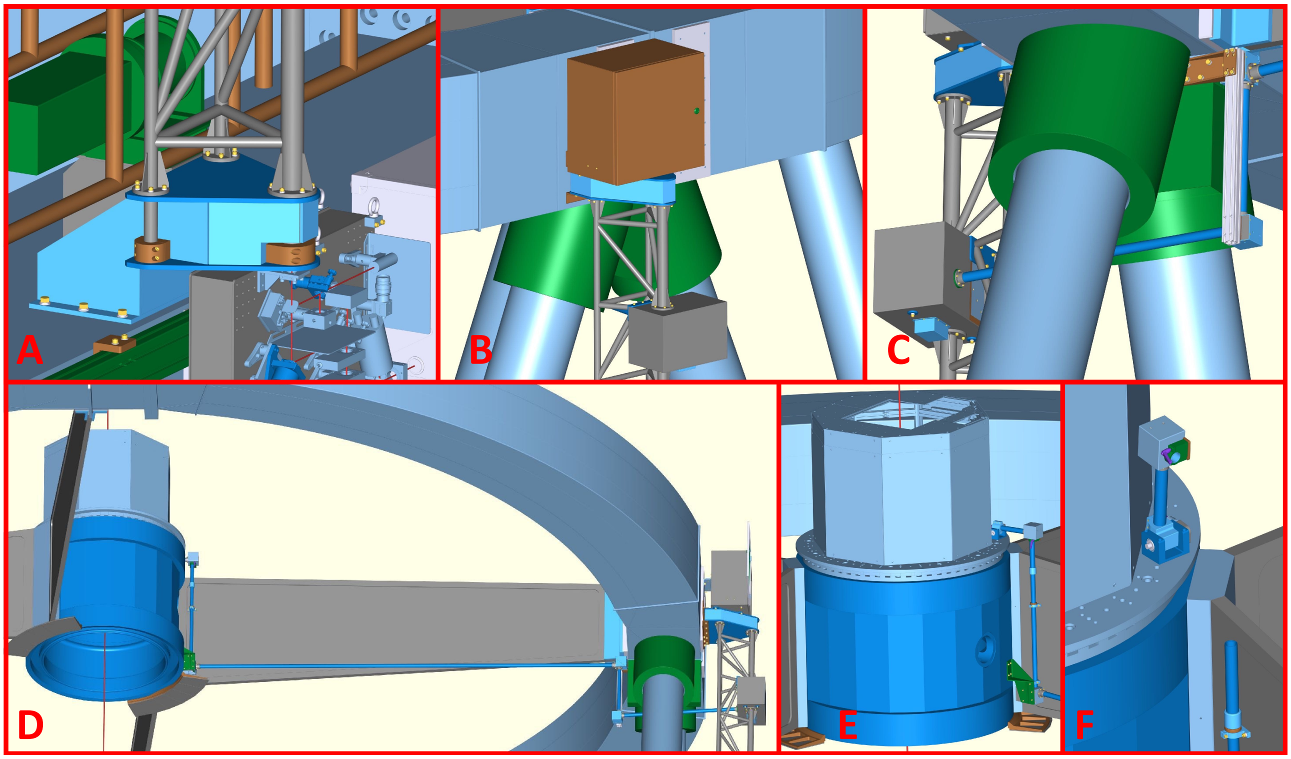

Figure 5 Zoomed images of our new relay structure at different locations. (A) Interface between the diagnostic bench and the relay truss at CS. (B) Front side of TR looking from outside to inside. (C) Front side of TR looking from inside to outside. (D) TR in a wide field view. (E) Secondary mirror and LLT. (F) Lever system for removable LLT.

Panel D shows TR of the telescope in a wide view. The beam that is folded by three mirrors at the front side of TR goes straight line along the spider and hits the other MSM located in a green box at the bottom of the spider right next to the secondary mirror. This mirror sends the light upward to go behind the secondary mirror to LLT. Panel E shows the secondary mirror (deep blue) and LLT (light blue above the secondary mirror). A unique feature of our LLT is that because Subaru Telescope operates prime focus instruments about two weeks every month, the secondary mirror needs to be removed every month along with LLT. This adds an extra requirement to our relay design that the last path needs to be retractable and repeatable for the removal and installation work. Our design uses a lever system shown in panel F. The beam that is pointed upward by the last mirror on the spider is folded by an mirror that is installed in a box sitting at the end of the lever system. When LLT is installed behind the secondary mirror, the lever is pulled down and connected to the extendable tube installed on the spider. When the secondary mirror is removed, the lever is pushed up and is removed all together with LLT. Nothing can extend further than the LLT's base plate (shown as a circular light blue/gray colored mounting plate underneath LLT on pane E) during the removal work, and thus this lever system is a viable choice.

Between the elevation 90° and 15°, the relative positions of the front side of CS and TR shifts about 3.5 mm and tilts about 100 arcsec due to the gravity vector changes. To compensate this changes over the course of operation, SSMs, PSDs, and some locations extra CCDs, are installed throughout the relay path. The details of deflection measurements and its control system will be reported in future papers.

LASER LAUNCH TELESCOPE Our LLT component consists of an octagonal enclosure (the light blue structure above the secondary mirror in Panel E of Figure 5) and a 50 cm launching telescope inside. This enclosure and launching telescope are the same ones used with the first generation of our laser unit. All the previously used optics and electronics will be removed from the enclosure to be ready for new installation. In this enclosure space, there are two main components, a fast steering mirror (FSM) and a beam expander (BE). FSM is there to compensate the tip and tilt (TT) component of aberration seen by the high order WFS. Our current AO system has the high order TT corrector in the WFS path, but we will switch the correction in the laser path.

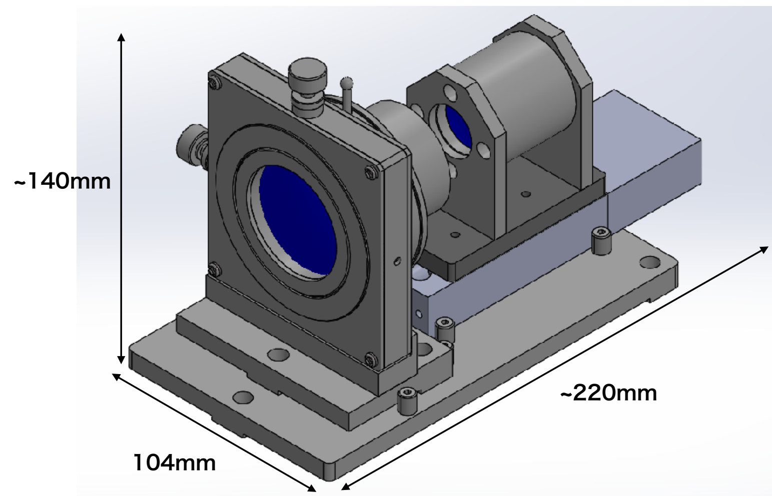

Figure 6 Our custom-made BE when it is mounted. After considering requirements from both single- and four-beam configurations, our BE consists of three lenses on a translation stage whose Gaussian magnification is 6.

Our BE was designed to work with both single- and four-beam (see §3.2) configurations. Most requirements and constraints came from the four-beam configuration, including that BE should 1) magnify a Gaussian beam by a given factor, 2) tolerate the incident beam angle up to the largest asterism planned, which is $\pm 0.2°$ at the entrance of BE, 3) be able to correct the defocus created due to the temperature change from -10°C to +10°C by a simple movement when lenses are mounted on aluminum stages, and 4) have a wavefront error well within $1/4\lambda$ after considering typical manufacturing and alignment tolerance. We considered several different magnifications between 5 and 8 and picked the best BE that fulfill the requirement above. The final design is composed of a set of three custom-made lenses, 1" biconcave lens, 1.5" meniscus lens, and 2" meniscus lens, where the temperature effect can be compensated only by the smallest lens on a translation stage. Our design has a magnification of 6 so that when it is combined with LLT of a magnification 12.5, the final beam size at the exit of LLT is $D = 225$ cm at $1/e^2$ of a Gaussian. The mechanical and optical designs of BE are shown in Figure 6 and as a part of Figure 7, respectively.

3.2 LTAO IN FOUR-BEAM CONFIGURATION

Next upgrade in line is a multi-laser system for LTAO. In this configuration, the TOPTICA laser beam is split to four, and all four are launched together by one LLT behind the secondary mirror. Compared to the SCAO configuration (Figure 2), the only change in LGSF appears in the optics located in the LLT enclosure. The optical design of LLT enclosure are shown in Figure 7, and its descriptions of components are summarized in Table 2.

Because we split one beam to four, the on-sky LGS brightness is four times fainter compared to the single-beam case, but they are still bright enough, especially compared to our old laser ($R < 10$, cyan downward triangle in Figure 1). Increasing the asterism brightness by combining the TOPTICA and ANU laser beams as described in §3.1.2 will be very valuable in the LTAO configuration.

The laser beam is transferred up to the LLT enclosure in exactly the same way as SCAO case. Once the beam enters the LLT optical bench, the beam is split to four equal powers by a set of beam splitters. Each beam has its own 1/4 WP on a rotation stage so that their circular polarizations are individually controlled. Two SSMs per beam, in total 8 SSMs, control the separation of the four beams to create narrow- and wide-asterism on sky. We call this set of 8 SSMs an asterism controller. Since we will use the same single BE as SCAO case for all four beams, the four beams in any asterism need to be overlapped at the entrance of BE. However, considering the smallest beam separation at asterism controller being the size of a mirror, i.e., 0.5", and the planned beam separation of $D = 10"$ to 30" on sky, the required distance from the asterism controller to BE is about 3.5 m. This is too long to fold inside the given space in the LLT enclosure. To relax this requirement, A prism wedge is designed to be installed to shrink down the beam separation angle. After the separation of the four beams

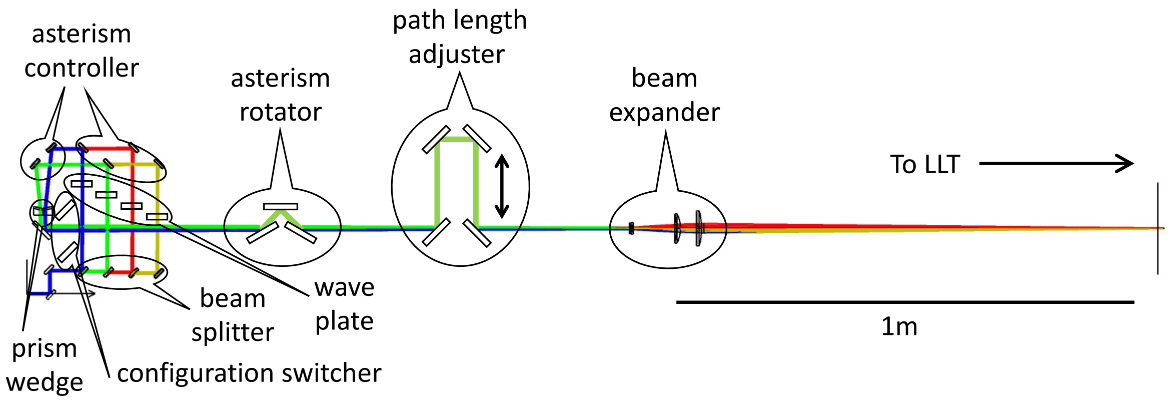

Figure 7 Conceptual optical design of a multi-beam configuration for LTAO. Descriptions of different components are summarized in Table 2.

Table 2. Optics in LLT enclosure for four-beam configuration

COMPONENTS	DESCRIPTION
Configuration switcher	Switchers 4- or 1-beam configuration by inserting/removing mirrors
Beam splitter	Splits the laser into four beams
Wave plate	Controls polarization of each beam
Asterism controller	Adjusts separation of beams from 10" to 30" on sky
Prism wedge	Shrinks beam separation to shorten optical path
Asterism rotator	Rotates the position of the beams on sky for WFSs
Path length adjuster	Adjusts optical path lengths for different beam separation
Beam expander	Expands all four beams by a factor of 6 at once

are narrowed, the beams enter a K-mirror (we call this an asterism rotator), where the positions of four beams on-sky are rotated to compensate the sky rotation with respect to the telescope (and thus WFSs). Right in front of BE is a set of mirrors on translation stages. We call this unit a path length adjuster as its purpose is to change the optical path length according to the different asterism size so that the four beams still overlap at the entrance of BE. A configuration switcher, which sits right before the beam enters the set of beam splitters, is a set of two mirrors on a translation stage. When the mirrors are not in the path, one beam becomes four beams, and when the mirrors are in the path, the beam bypasses everything else but the asterism rotator, path length adjuster, and BE and eventually goes to LLT as a single beam.

3.3 GLAO IN ULTIMATE-SUBARU CONFIGURATION

The final stage of a series of LGSF upgrades is an ULTIMATE-configuration, where we will purchase one more TOPTICA laser, split each beam to two, and separately launch from four LLTs installed around CS. For this configuration, each laser has ~ 10 W, and thus the estimated on-sky brightness is $R < 9.25$ (green diamond on Figure 1). The simplified description of the ULTIMATE-configuration is shown in Figure 8.

The reason why we need four separate LLTs, unlike LTAO case, is that GLAO requires wide-asterism (up to $D = 20$' separation) that cannot be launched simultaneously from one LLT. Because we need four LLTs, we cannot install them behind the secondary mirror in the same way we did in the previous cases, thus four LLTs are installed around CS. This actually reduces the complication of the relay path and a requirement of LLT removability. Figure 9 shows a current design of LLT, LH, diagnostic bench, and electronic rack when they are installed on Subaru Telescope. A model of a person is included to show the scale of components.

To have one designated LLT per beam, we need to purchase four new LLTs. Our plan is to use ANU LLTs that are currently being developed at ANU. The LLTs shown on Figure 9 are the ANU LLTs. The ANU LLT is a

320mm-diameter aperture, 500mm-high compact afocal reflective on-axis beam expander. This LLT is currently tested on-sky along with ANU laser at Mount Stromlo Observatory.

3.3.1 OPERATION CONSTRAINT

The top screen of Subaru Telescope consists of three panels and sits right below the dome slit to prevent the stray light and falling object to hit the primary mirror. All three panels are normally retracted to the stow position during the observation (Figure 10). On Figure 10, the telescope's front side is in the right, and the rear side is in the left. At this top screen location, the laser beams launched from the rear side of the telescope are fully vignetted by the top screen when the telescope is pointing zenith. To avoid the vignetting, the telescope must be tilted by > 10.6 degrees (thus elevation < 79.4 degree). The situation is slightly better when all panels are fully retracted instead of at stow position. The rear beams are still completely vignetted at zenith but the amount needed to be tilted is now > 9.7 degrees (elevation < 80.3 degrees). To further improve the situation, one possibility is to move the panel A to its front side limit while keeping the panel B to its rear side limit. In this configuration, the required tilt is only 3.2 degrees and thus elevation 86.8 degrees, but it adds a lower elevation limit of 66.5 degrees, and moving panels adds about 10 minutes overhead.

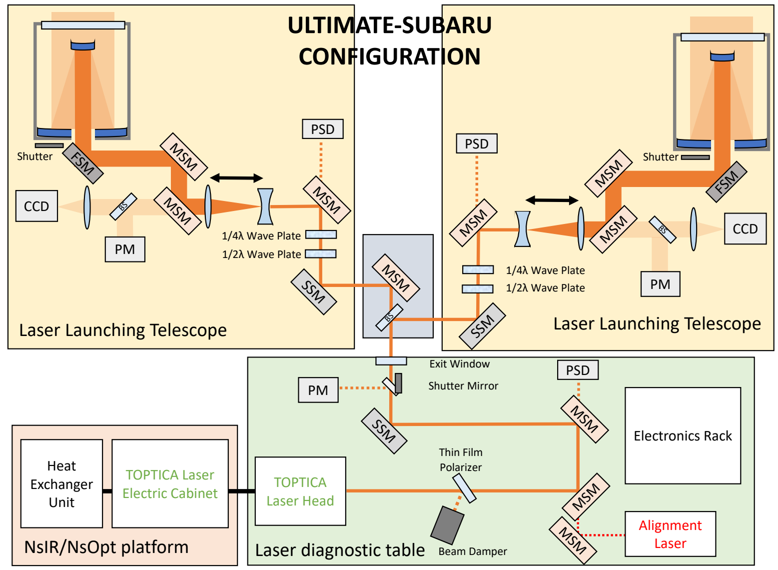

Figure 8 ULTIMATE-configuration for GLAO mode. This is the final stage of many upgrades and is used with a brand new GLAO system and a brand new wide-field imagers developed under ULTIMATE-Subaru project.

Using the statistical data of the current Subaru instruments in 2015 and 2016, the probabilities of observing the target at $EL > 80°$ is 1.4% for HSC (1.5 degree FoV seeing-limited optical imager), 0.5% for MOIRCS (IR seeing-limited imager and spectrograph), and 3.4% for HDS (high-dispersion seeing-limited optical spectrograph).

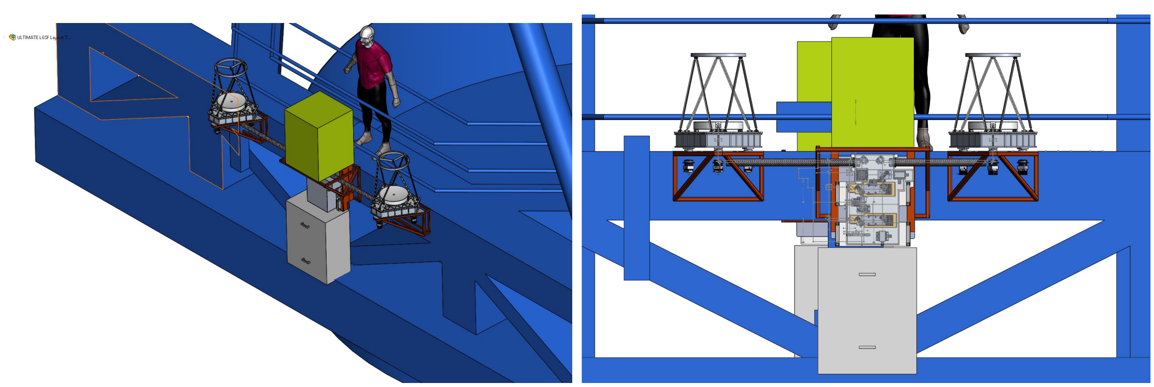

Figure 9 Current design of LLT, LH, diagnostic bench, and electronic rack when they are installed on Subaru Telescope in ULTIMATE-configuration. Two sets are installed on the front and other two are on the back side of CS. LLTs shown here are ANU LLTs. A model of a person is included to show the scale of components.

We are currently looking into solutions to this top screen vignetting problem, including modification to the top screen. However, the statistics show that the chance of needing to observe such high elevation is low, and the constraint on the laser propagation has only a small effect on the GLAO operation anyways.

4. SUMMARY

In this paper, we summarize the current designs of our new LGSF in three different stages. The first upgrade to a brighter laser is expected to be commissioned in summer 2020. Immediately after the commissioning, we will move on to the second project which advances our laser system to be a multi-beam system. The multi-beam configuration need to be ready by the time of the new SHWFS delivery, and we are aiming to have first light in 2022. In 2025, our new facility class GLAO system that is equipped with a brand new deformable secondary mirror is expected to be ready for engineering, and the commissioning of the final LGSF configuration should coincide with it. Designing and building three different configurations is a lot of work within a rather short period of time, but it is at the same time a very exciting period to see the rapid changes of capabilities at Subaru Telescope.

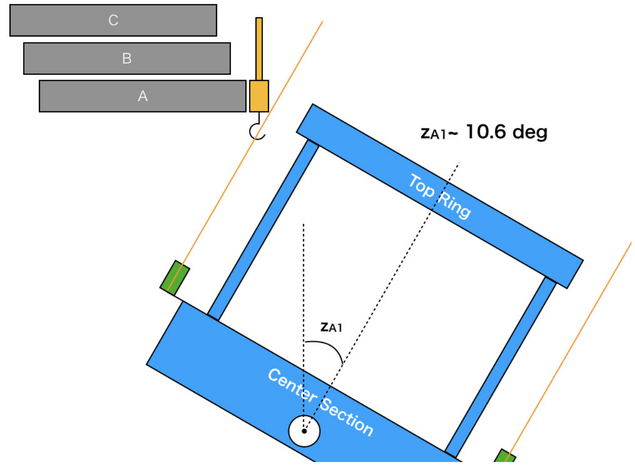

Figure 10 Schematic view of the top screen when it is at the stow position. In this figure, the telescope front side is right, and the rear side is left. To avoid vignetting of the rear laser beam by the top screen, the telescope needs to be tilted by > 10.6 degrees (elevation < 79.4 degrees).

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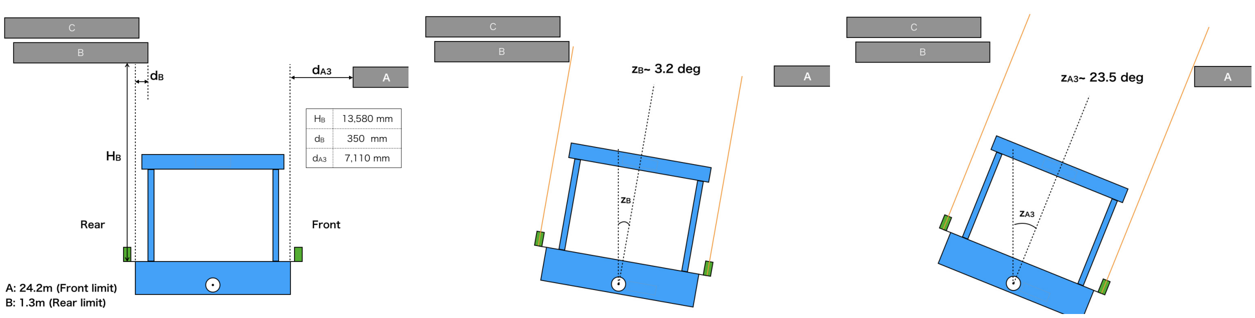

Figure 11 Configuration of the top screen when the panel A and B are at its front and rear side limits, respectively. In this configuration, operational elevation is between 66.5° and 86.8°.

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