

# ULTIMATE-START: Tomography AO experiment on Subaru: latest progress and future plan

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Make Subaru as sharp as ELTs !

## ABSTRACT

We present the current status of the ULTIMATE-START (Subaru Tomography Adaptive optics Research experiment) project, an on-going laser tomography adaptive optics (LTAO) project on the Subaru telescope. The main purpose of this project is to realize high Strehl Ratio AO correction not only in NIR bands, but also in visible bands above 600nm. The LTAO system will be operated by four 32x32 Shack-Hartmann wavefront sensors (SH-WFSs) and four LGSs. The LTAO WFSs will be installed behind AO188, which is the current facility AO system on the Nasmyth platform of the Subaru telescope. We will use the low-order WFS and DM of AO188 for Tip-Tilt measurements with a NGS and wavefront correction, respectively. The DM of AO188 was replaced with a 3228 element DM. Assembling of the LTAO WFS system has completed in 2022. Currently WFS data acquisition and tomographic wavefront estimation are under testing in Hilo. A new laser launching system has been installed. The single LGS with 22W laser source is already available for open-use observations, and the four LGS system, which can make an asterism with 10-40 arcsec diameter, will be installed in late-2024. The first light of the entire LTAO system is planned in early 2025.

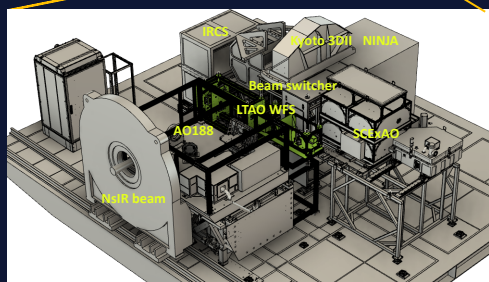
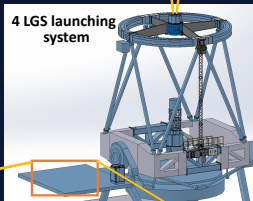
## OVERVIEW

ULTIMATE-START is an upgrade project of current AO188 LGS system to implement LTAO mode by installing the LTAO WFS unit behind AO188. It is also a prototype to develop key technologies (multiple LGSs and WFSs, real-time system, and tomographic WF estimation) for future GLAO system (ULTIMATE-Subaru). 3 new key components of the LTAO system are

- \* 4 LGS launching system with 20W laser
- \* LTAO WFS unit with 4 SH-WFSs
- \* 3228 actuator DM in AO188

The corrected output beam will be fed into the Beam switcher system, which will feed 4 instruments with switching.

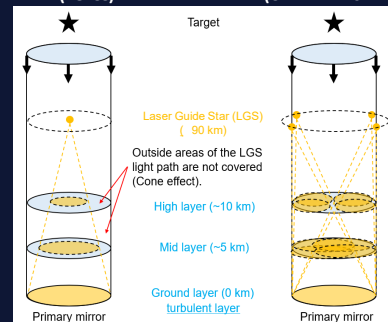
LGS asterism  
( $\Phi$  10"-40")



- ✓ Laser Tomography Adaptive Optics (LTAO)

Current LGS-AO system (AO188)

New LTAO system (ULTIMATE-START)



4 LGSs made by new high brightness fiber laser (20W TOPTICA laser).

3D structures of turbulence layers can be estimated by using tomography method from measurements of the four LGSs.

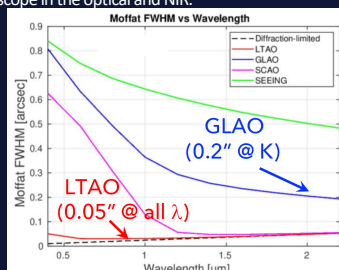
Integrating along the target light path to estimate the optimal correction for the target

- ✓ Specifications of the LTAO WFS system

Number of LGS	4	Pixel per subap.	6.93
Asterism diameter	10" - 40"	WFS pixel scale	0".99/pixel
LGS brightness	> 5W (R-0.5 mag)	Number of NGS	1
LLT location	center launch	NGS WFS (low-order)	2x2 SH-WFS in AO188
LGS WFS	4 SH-WFSs	Wavelength for NGS WFS	< 575 nm
Frame rate	up to 800 Hz	Wavelength for science path	> 600 nm
Number of subap.	32 x 32	Science path FoV	< 65°
WFS subap. FoV	6".84		

- ✓ LTAO performance simulations

- Run full LTAO simulation and compare the LTAO performance with the current performance of AO188 LGS mode (SCAO).
- In optical wavelength, AO performance by LTAO is significantly improved compared to the AO188 SCAO model. LTAO will achieve the close to diffraction limit of the Subaru telescope in the optical and NIR.



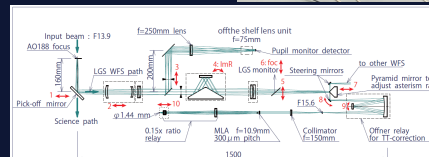
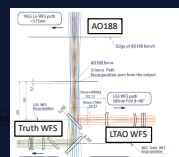
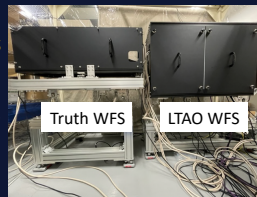
Expected FWHM versus wavelength of current AO system (SCAO) and the LTAO

## CURRENT STATUS

- ✓ Wavefront sensor unit with 4 SH-WFSs

- Four SH-WFSs and a truth-WFS, which calibrate the LGS WFSs by observing an NGS, are shipped to Hawaii in Aug. 2023, and alignment and testing works are on-going in Hilo.
- The units will be installed to NsIR in summer 2025.

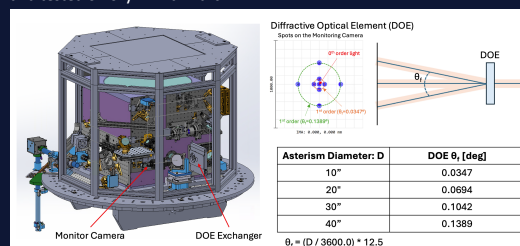
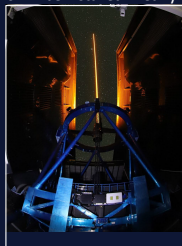
LTAO WFS unit



Optics design of pick-off optics (left) and fore optics with a SH-WFS (right) (Ref.1)

- ✓ Launching system of 4 laser guide stars

- The 4 LGS optical and opto-mechanical designs were finalized by utilizing 4 diffractive optical elements (DOEs) that split the single TOPTICA 20W laser beam into 4 with the asterism diameter of 10, 20, 30, and 40 arcsec.
- There is no interference with the existing optics or opto-mechanics at this location (enclosure panel needs to be modified to allow connecting the power/communication cables).
- Optical fabrication is ongoing, to be completed by the end of February. Opto-mechanical fabrication and assembly completed. The DOEs will be installed in early March and tested on-sky in mid-March.



(Left) First launch of the new 20W laser on March 3rd, 2022. (Right) Opto-mechanical design of the LLT upgrade for splitting the single laser beam into 4. DOEs are used to split one beam to 4 beams.

- ✓ AO188 upgrade with 3228 element DM (New tech. for ELTs !)

- ALPAO 3228 element DM is installed in AO188 (AO3K).

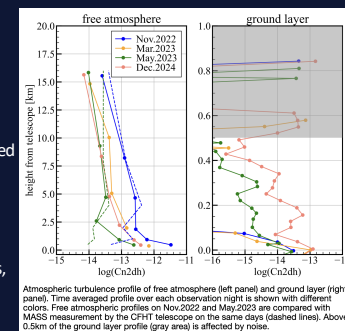
ALPAO 64x64 DM (3228 usable actuators)



- ✓ SHARPEST: Turbulence profiling with Shack-Hartmann WFSs



- SHARPEST is an activity to measure the atmospheric turbulence profiles using two Shack-Hartmann sensors with 2 cm sub-apertures. Free atmosphere is estimated from the spatial frequency of the stellar scintillation (SH-MASS). Ground layers are measured from the correlation measured by two SH sensors (SLODAR).
- Four half nights of engineering observations have been carried out using the Subaru Telescope.
- The free atmospheric profile is generally consistent with the CFHT-MASS results, from which the typical profile assumed by LTAO can be constructed.
- The results of the ground layer profile includes telescope dome seeing.



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