ULTIMATE-START:
Subaru Tomography Adaptive optics
Research experimenT

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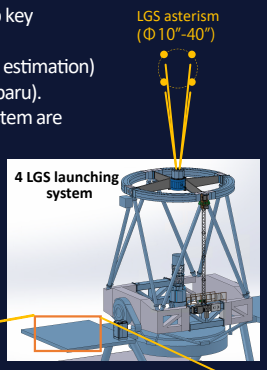
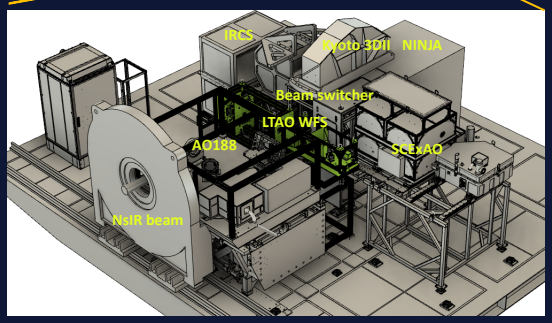
ABSTRACT

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 wavefrot correction, respectively. The DM of AO188 will be replaced with a 3228 element DM. Assembling of the LTAO WFS system has completed in 2022. Currently WFS data acquisition and tomographic wavefront estimatation are under testing. We also performed on-sky engineering observations of one prototype SH-WFS with a NGS and LGS with the Subaru telescope. A new laser lauching system has been installed. A single LGS is under on-sky performance verification for the open-use observations, and for LGS sysmtem, which can make an asterism with 10-40arcsec diameter, will be installed in mid-2024. The first light of the entire LTAO system is planned in late 2024.

OVERVIEW

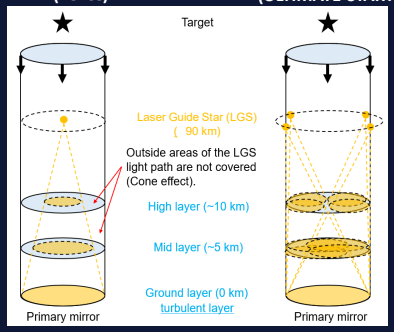
ULTIMATE-START is an upgrade project of current AO188 LGS system to implement LTAO mode by installing the LTAO WFS unit behind AO188. It is also a prototype to develop key technologies (multiple LGSs and WFSs, real-time system, and tomographic WF estimation) for future GLAO system (ULTIMATE-Subaru).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





✓ 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.

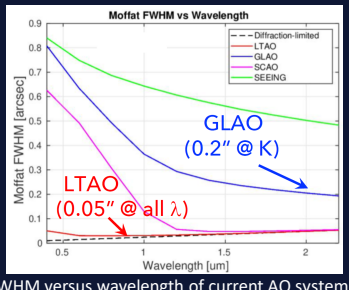
Integrating along the target light path to estimate the optimal correction for the target

✓ 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~9.5 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.

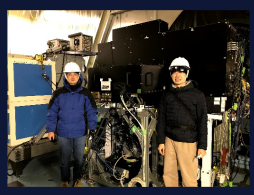


Expected FWHM versus wavelength of current AO system (SCAO) and the LTAO

CURRENT STATUS

✓ Prototype single SH-WFS on-sky testing

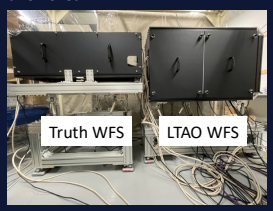
- Prototype single SH-WFS unit is under on-sky testing with new 20W laser system at the Subaru Telescope for verification of sCMOS caemra performance and the development of the control system.
- Because of the rolling shutter readout (the timing of the data acquisition is not simultaneous, center at first and upper and lower part later) of the sCMOS camera, the effect of the readout mode on wavefront reconstruction is evaluated with the on-sky measurements.
- NGS and LGS data are obtained during the engineering observations.



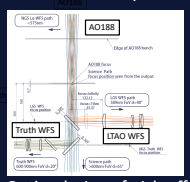
single WFS unit installed behind AO188

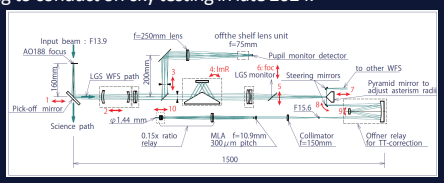
✓ Wavefront sensor unit with 4 SH-WFSs

- Four SH-WFSs and a truth-WFS, which calibrate the LGS WFSs by observing an NGS, are placed in a designed position to conduct optical alignment and tests for synchronized operation of four WFSs in Tohoku Univ.
- Image acquisition with four SH-WFSs has been successful with a light source simulating the Subaru AO188 output.
- Whole LTAO system was shipped to Hawaii in Aug. 2023 and under testing in Hilo. We are planning to conduct on-sky testing in late 2024.

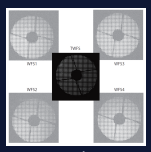


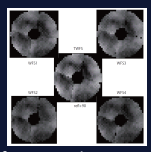
LTAO WFS unit in Tohoku Univ. Lab.





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

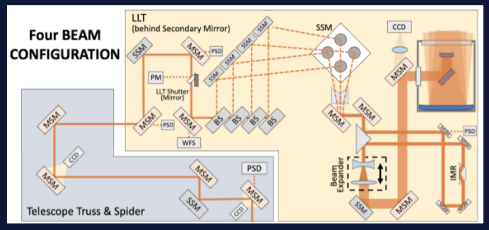


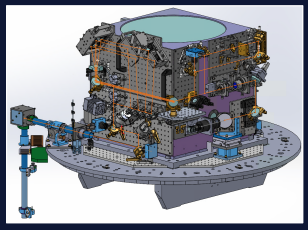


Acquired images of WFSs and reconstructed WF with a light source simulating Subaru + AO188

✓ Launching system of 4 laser guide stars

- TOPTICA 20W laser and laser relay optical system were installed on the Subaru telescope.
- On-sky tests are being conducted for open-use observations. LGS-AO mode with new laser has been available for open-use since S23A.
- Optical and mechanical design of 4 LGSs launching system is completed and its installation is planned in mid 2024.





(Left) First launch of the new 20W laser on March 3rd, 2022. (Middle) Schematic configuration for 4 LGS launching system. (Right) Opto-mechanical design of the LLT upgrade for splitting the single laser beam into 4.

✓ AO188 upgrade with 3228 element DM (see Ono et al. P011)

- ALPAO 3228 element DM is under testing and will be installed in AO188 2024.
- New NIR pyramid WFS, which can take full advantage of the new 3228 DM, has been installed in AO188 and on-sky observation have been conducted. This NIR WFS will be used as a low order WFS when LTAO-mode observations in the visible wavelength.

ALPAO 64 x 64 DM (3228 usable actuators)

✓ SHARPEST: Turbulence profiling with Shack-Hartmann WFSs (check Ogane's talk !)

- Initial results are published in Ogane et al. 2024.

SCHEDULE

SH WFS prototype test at Subaru:	2022
4 LGS launching system:	2023
AO188 DM upgrade:	2024
LTAO WFS installation on Subaru:	2024
First light of the LTAO:	**2024**
NIR imaging with LTAO (IRCS):	2024
Optical IFU with LTAO (3DII):	202X

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