

ULTIMATE-START: On-sky Engineering Status of Subaru Laser Tomography Adaptive Optics Experiment

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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 the NIR bands, but also in the visible bands above 600nm. The LTAO system is operated by four 32x32 Shack-Hartmann wavefront sensors (SH-WFSs) and four LGSs. The LTAO WFS unit also has a truth-WFS, which acquires NGS wavefront to evaluate the tomographic AO performance. The LTAO WFS unit is installed behind AO3K, which is the upgraded facility AO system, AO188, with the new 3228 element DM. We will use the low-order WFS of the AO3K for Tip-Tilt measurements with a NGS. Four laser guide star launching system is installed to the existing laser launching telescope and 4 LGSs are formed on-sky successfully Mar. 2025. The tomography WFS unit is installed on NsIR platform of the Subaru telescope Aug. 2025. Optical alignment works are completed, and AO loop with the 32x32 truth-WFS and the 3K element DM is closed. The first engineering observation is completed Dec. 2025. In the next engineering run in Jun. 2026, we will try to close the tomographic AO loop and evaluate the performance of the system.

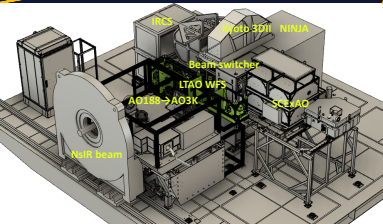
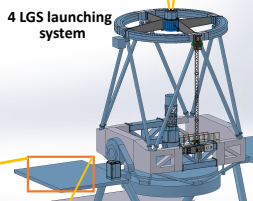
OVERVIEW

ULTIMATE-START is an upgrade project of current AO188 LGS system to implement LTAO mode by installing the LTAO WFS unit behind AO3K. 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 = AO3K
- The corrected output beam will be fed into the Beam switcher system, which will feed 4 instruments with switching.

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

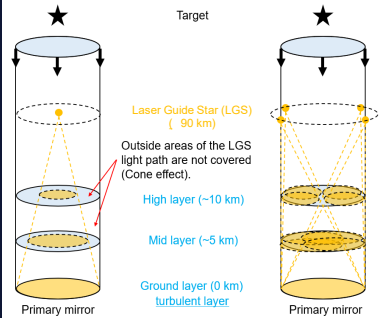
4 LGS launching system



Laser Tomography Adaptive Optics (LTAO)

Current LGS-AO system (AO3K)

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.

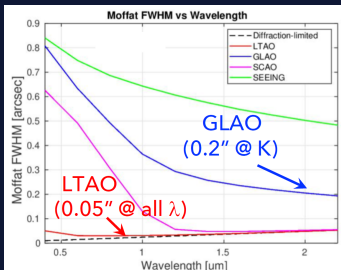
Integrating along the target light path to estimate the optimal correction for the target

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

STARTED ON-SKY ENGINEERING OBSERVATIONS FROM DEC. 2025 !



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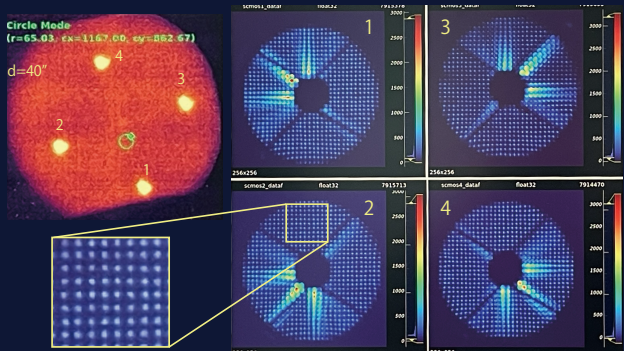
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4 Laser Guide Stars acquired with 4 SH-WFSs !

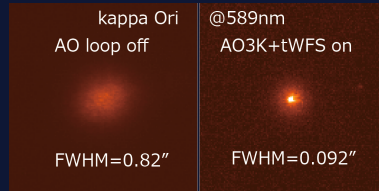
- 4 LGSs are launched by splitting one TOPTICA 20W laser with 4 diffractive optical elements (DOEs) with the asterism diameters of 10, 20, 30, and 40 arcsec.
- 4 LGSs are formed successfully on-sky in Mar. 2025 engineering run. 4 SH-WFSs of the LTAO WFS unit successfully acquired the 4 LGSs in Dec. 2025 engineering run as shown in the left.
- We found mis-alignment of the 4 SH-WFSs affects closing the LGS jitter loop of them. We re-adjusted the alignment of the 4 SH-WFSs in on-site engineering work in Feb. 2025.
- We also found Rayleigh scattering components of the higher order (3rd, 5th) diffraction component affect SH-WFS measurements. We fabricated masks to shade the higher-order component. The masks will be installed in the next week.



The 4 LGSs on-sky observed with the LGS acquisition camera (top-left). 4 SH-WFS images with the 4 LGSs. Rayleigh scattering component of the other 3 LGSs appears as bright contamination in each SH-WFS. Additionally, higher-order diffraction contaminating the SH-WFS images.

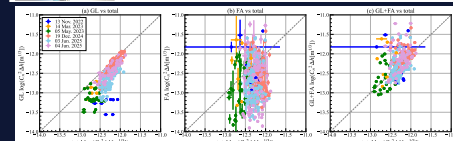
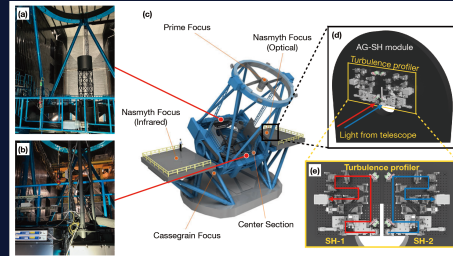
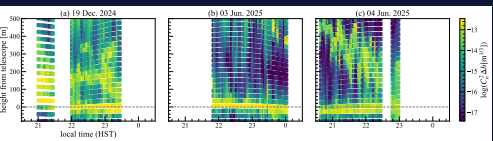
AO-loop is closed on-sky with a bright star between the truth-WFS (NGS WFS) and 3K elements DM !

- As the first step of the AO-closed loop testing, we closed loop with a bright NGS, kappa Ori with 3 mag, between the truth-WFS and 3K elements DM.
- The right panel shows the images with AO loop off (left) and on (right) taken with the LGS acquisition camera, which covers wavelength range around 589nm. The closed loop image indicates that the AO loop is effective even in the visible band with the 3K elements correction. We have not optimized the correction loop, and the result is promising. We try to realize the same performance with the 4 LGSs in the next step.



SHARPEST: Turbulence profiling observations continue !

- SHARPEST (right panel shows the related instruments) is an associated research to characterize Free-Atmospheric turbulence (0.5-20 km) to optimize LTAO (ULTIMATE-START), and Ground-Layer turbulence (0-0.5 km) including dome seeing to validate GLAO (ULTIMATE-Subaru). 7 half-nights of SH-MASS/SLODAR ((d)(e)) turbulence observations (2022-2025) combined with simultaneous local turbulence sensor (AIRFLOW) measurements ((a)(b)) have been conducted.
- GL turbulence is dominant, accounting for >50% of the total amount most of the time. The stable FA seeing matches long-term stats (0.39''), strongly supporting the feasibility of GLAO.



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SCHEDULE

AO188 DM upgrade → AO3K: 2024
4 LGS launching test: 2025 Mar.
LTAO WFS installation on Subaru: 2025 Aug.
First light of the LTAO: 2025 Dec. !!
NIR imaging with LTAO (IRCS): 2026
Optical IFU with LTAO (3DII): 2027