Science with Ground Layer
Adaptive Optics at Subaru and TMT

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Outline

• Uniqueness of GLAO at TMT
  - Expected performance improvement
  - Gain from GLAO correction in visible and NIR
  - Examples of “extragalactic” science cases that would benefit from GLAO

• Subaru’s GLAO project: ULTIMATE-Subaru
  - Instrument overview
  - Technical overwrap with TMT GLAO
  - Science cases
  - Schedule
Uniqueness of GLAO

- **Seeing enhancement**
  - Improve the sensitivity at all wavelength

- **Improved spatial resolution**
  - Resolve internal structure of extended sources in NIR wavelength

- **Wide-field coverage**
  - Uniform seeing improvement
  - Wide-field survey capability

ESO-AO Modes
https://www.eso.org/sci/facilities/develop/ao/ao_modes.html
GLAO expected performance

TMT GLAO performance with AM2 by Lianqi Wang

GLAO can reduce the FWHM down to ~0".2 under moderate seeing condition
GLAO correction under bad seeing is similar to the good seeing
GLAO sensitivity gain in NIR

Point source

Extended source (galaxies with Re~0.2)

Sensitivity gain: x2.0-2.5

Sensitivity calculation for Subaru GLAO (Subaru GLAO study report 2016)
Improved Spatial Resolution in NIR

Size evolution of galaxies (Shibuya et al. 2015)

Seeing (0''5)
GLAO (~0''2)
8m AO (~0''07)
30m AO (~0''01)

Cosmic noon

Redshift

Proper scale [kpc]

0.01 0.10 1.00 10.00
0 1 2 3 4 5 6 7

z=1-3 star-forming galaxies
1~2kpc

(Subaru GLAO study report)

z=1-3 compact galaxies
< 1kpc

(van Dokkum et al. 2015)
Spatially-resolved NIR spectroscopy of galaxies at cosmic noon

- Spatial resolution of GLAO in NIR (FWHM~0”.2) can resolve the galaxies at cosmic noon (z~2) into disk and bulge (core) regions.

- When, where, and how the star-formation quenched and galaxies grew in size?

- Spatially-resolved spectroscopic survey of z~2 galaxies will provide stellar age and dynamics by tracing post-starburst features (Balmar absorption lines) in galaxies as a function of radius from the center.

- TMT/IRMOS or IRMS multi-object (IFU) spectroscopy with GLAO spatial resolution

van de Sande et al. 2013
GLAO gain in visible

- Seeing improvement in visible (10-20%) is not as large as that in NIR (especially in K-band, ~50%).
- GLAO can be used as a seeing enhancer for WFOS, HROS, or any visible instruments.
- Science cases that requires wide-field of view would most benefit from GLAO.

Additional sensitivity leverage to the IGM tomography at $z>2$

- TMT/WFOS will use many sight lines toward faint galaxies in 3’x8’ FoV (~10 Mpc) at $z$~2 and beyond for IGM and CGM tomography.
- GLAO will provide additional leverage to increase the number of sight lines and to decrease the survey time.
Simplify the instruments by AM2

- TMT GLAO will use an adaptive M2 (AM2).

- AM2 can feed the AO corrected light to all instruments at TMT without any complicated relay optics
  - GLAO correction for all instruments at TMT
  - Woofer for the other AO modes (ExAO, MOAO)
  - Provide diffraction limited performance in MIR with minimum increase of thermal background.

- Demerit:
  - Cost effectiveness
    - New instrument to take full advantage of GLAO (e.g. wide-field imager or spectrograph in NIR).
  - AM2 can be a single point of failure for TMT

http://www.adoptica.com/
Subaru’s GLAO project

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Subaru’s Wide-Field Strategy in 2020s

1. Very wide-field optical imager
2. Wide-field multi-object spectrograph
3. Wide-field near-infrared imager and MOS spectrograph including AO assisted IFU

- HSC (2013)
- PFS (2019)
- ULTIMATE-Subaru (2025)

- Uniform seeing improvement over ~20 arcmin FoV
- FWHM < 0.2 at K-band, which is equivalent to HST/WFIRST
- Provide Subaru’s original High-redshift targets to follow-up with TMT
- Good synergy with satellite-based survey (WFIRST, Euclid) at $\lambda < 2.0\,\mu m$
ULTIMATE-Subaru: GLAO system overview

(3) Wavefront Sensors
- Cs. Focus (FoV~20 arcmin)
- Ns.IR Focus (FoV~6 arcmin)

(1) Adaptive Secondary Mirror
Preliminary Subaru ASM design by Microgate ADS

(2) Laser Guide Star system
TOPTICA fiber laser(589nm) x 2
Generate 4 laser guide stars

Cassegrain Focus
LGS
TTGS
14' x 14'
Key Technologies for GLAO

• (1) Adaptive secondary mirror
  - Develop AM2 with ADOPTICA and Mitsubishi
  - Feasibility study for having the AM2 at Subaru
  - Handling of the AM2 during the instrument exchange is a challenge
  - Procedure to calibrate the AM2 before installing into the telescope

• (2) Sodium laser guide star system
  - Sodium LGS system from TOPTICA —> well developed technology
  - Early commissioning with the existing AO system (AO188)
  - 4 LGSF for the LTAO experiment at Subaru is being developed.

• (3) Wide-field (tomographic) wavefront sensing
  - Make use of the previous experiences
    - RAVEN/Subaru (2014-2015): MOAO science demonstrators, GLAO performance at Subaru was demonstrated to be FWHM~0’’2 at H-band.
    - On-sky test with the WFS prototype for testing the wide-field wavefront reconstruction is ongoing by Tohoku Univ. for ULTIMATE and TMT-AGE.
  - LTAO experiment with 4 LGSs is started as an upgrade of AO188.

All technologies can be connected to development and operation of GLAO at TMT.
Wide-field Instrument for ULTIMATE

Phase 1
- Reuse MOIRCS at Ns. IR

Phase 2
- Wide-field imager (WFI) at Cs.

Phase 3
- Fiber-bundle multi-IFU at Cs

Overwrap with GLAO at TMT
- Deployable fiber IFU at WFOS
- Science cases with 15’x15’ FoV

MOIRCS
GLAO first light instrument

Imager concept by HIA (J. Pazder)
- Workhorse instrument for large SSP imaging survey
- Wide-variety of narrow/medium band filters

Multi-IFU concept by AAO (S. Ellis)
- 10-40 deployable IFU with fibers
- Feed to the existing spectrograph (MOIRCS/PFS)
- Kinematic survey at z~1 like MANGA/SAMI.
Key science: Complete census of galaxy evolution

“Birth, Life, Death” of galaxies in the cradle of large-scale structure

1. First galaxies (birth)
   - Unprecedently deep NB imaging to detect galaxies at “cosmic dawn” (z>>7).
   - Extension of HSC optica NB survey

2. Stellar build-up (life)
   - Origin of Hubble sequence: bulge, disk, and black hole growth
   - Deep & sharp & panoramic NB imaging and 3-D spectroscopy of galaxies at “cosmic noon” (z=0.5-3.5)

3. Quenching (death)
   - Tracking down the “passive” galaxies to z~5 with deep BB/MB imaging (in K-band).
   - Environment of dead galaxies: do first galaxies die in isolation or in clusters?
   - Great synergy with WFIRST.

Galaxies at z=4

ULTIMATE

ULTIMATE
Kinematics Survey of galaxy evolution

High-redshift (z>1) extension of SDSS imaging/spectroscopy/IFU surveys at Subaru

HSC (Imaging) → PFS (Spectroscopy) → ULTIMATE Phase3 (IFU)

- SAMI observations of an edge-on galaxy at z~0 (Ho et al. 2016).

Measure properties of galaxy evolution across disk (SFR, kinematics, outflow, metallicity gradient, etc.) via emission to understand:

- quenching mechanism
- feedback process
- galaxy transformation (e.g. mergers)

(Ellis et al. 2015)
ULTIMATE-Subaru: Schedule

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GLAO CoDR

ULTIMATE-Subaru will demonstrate GLAO operation at Maunakea in advance.
Summary

- GLAO can uniformly improve the seeing over “wide” field of view.

- GLAO (or AM2) corrected light can be fed to the all instruments from visible to mid-infrared.

- GLAO in NIR will be able to conduct spatially-resolved studies of extended source with medium spatial resolution (FWHM~0”.2)

- GLAO in visible will be able to use as a seeing enhancer

- ULTIMATE-Subaru is a GLAO project at the Subaru telescope, which provides ~14’x14’ science FoV with FWHM~0”.2 resolution in K.

- There are many technical/science overwrap with TMT GLAO.

- ULTIMATE-Subaru would be a pathfinder for GLAO at TMT.