Science with Ground Layer Adaptive Optics at Subaru and TMT

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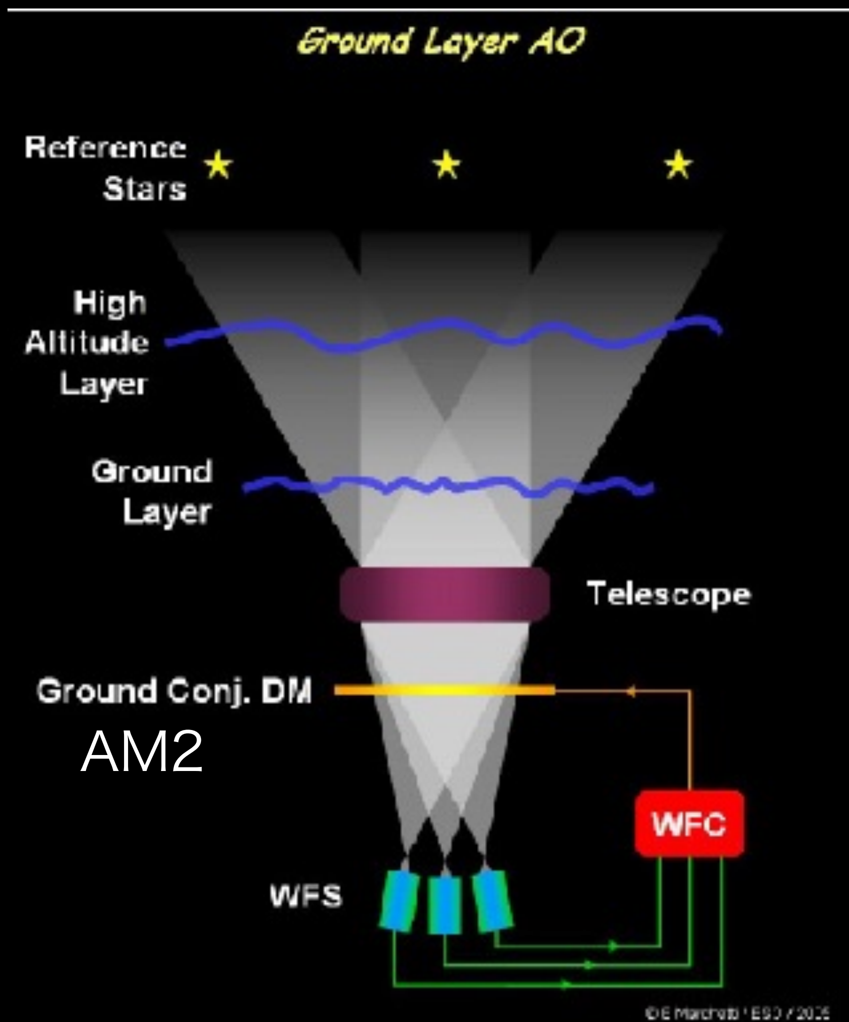
Outline

- 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



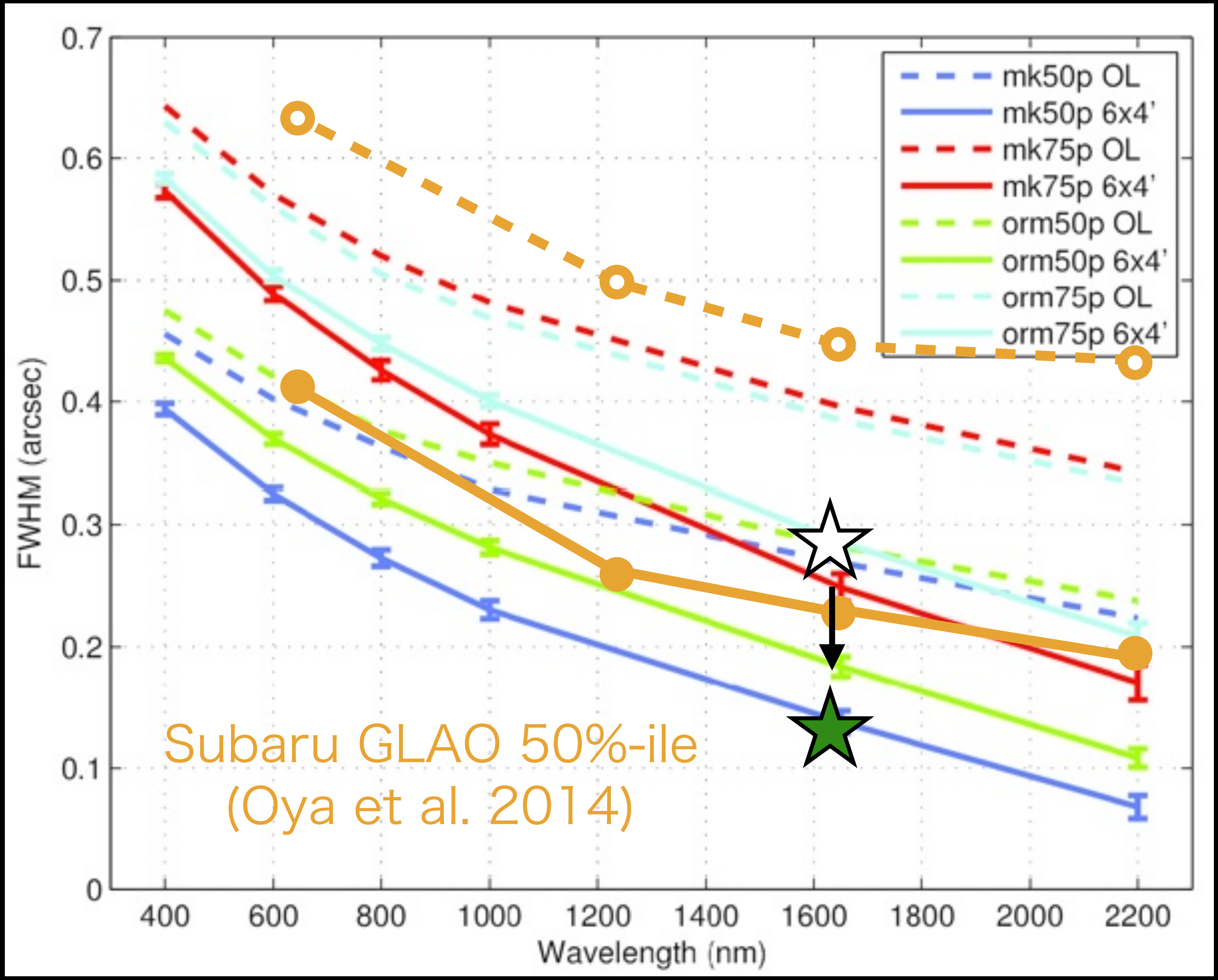
AM2

- 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



★ Seeing ★ GLAO

RAVEN at Subaru on-sky demonstration in GLAO mode (Ono et al. 2016)

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

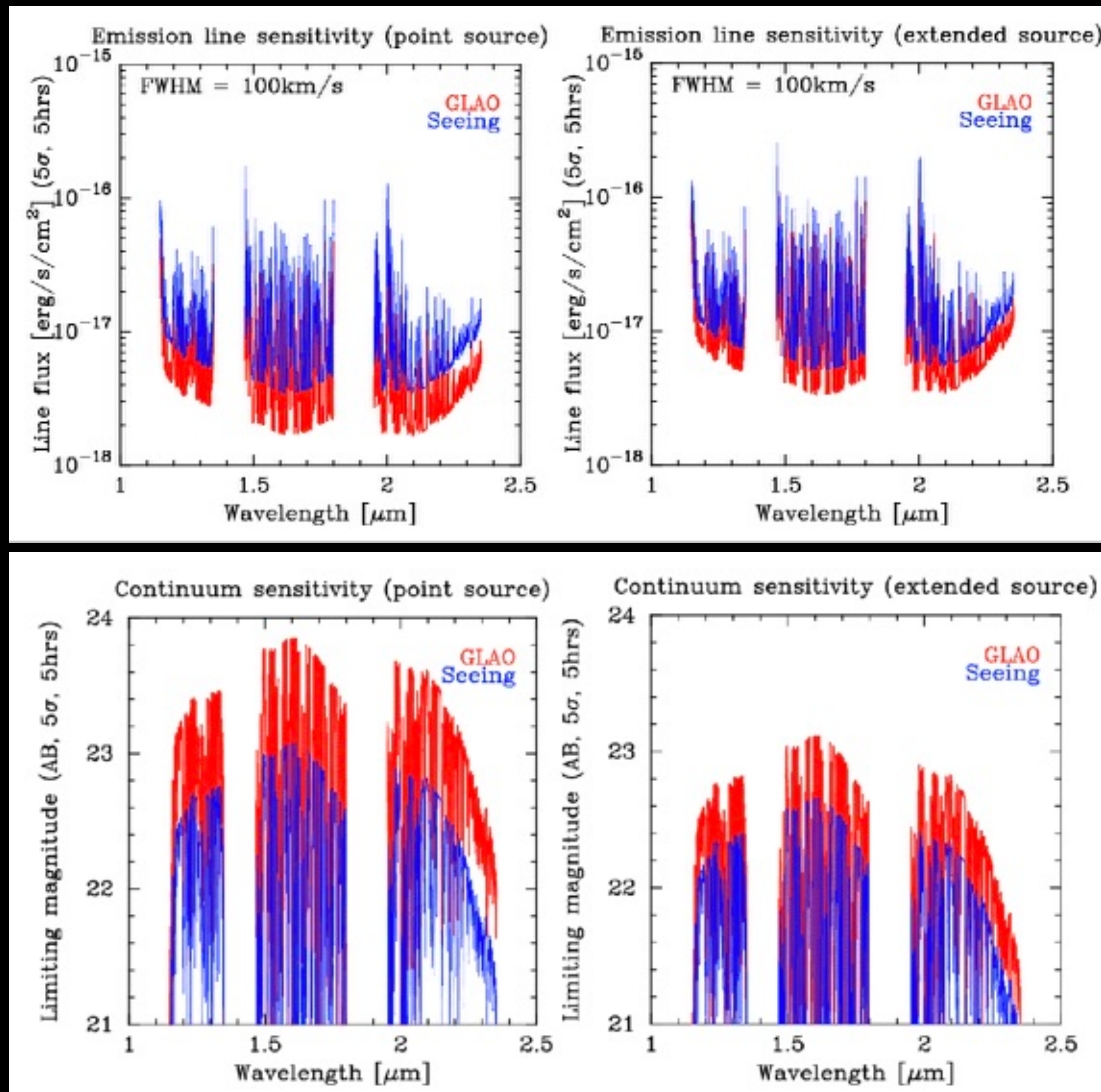
GLAO sensitivity gain in NIR

Point source

Extended source
(galaxies with Re~0".2)

Emission line

Continuum

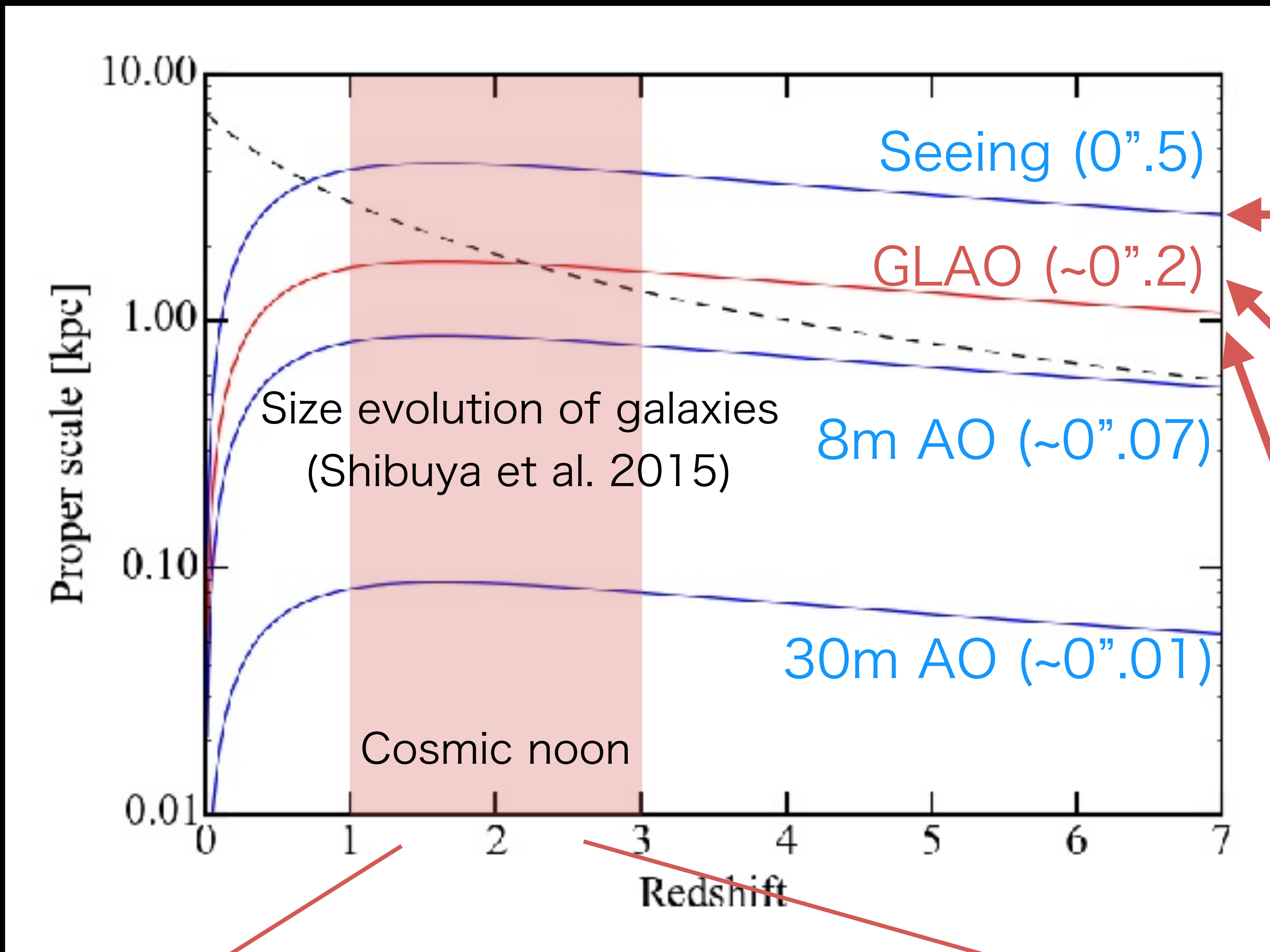


Sensitivity gain:
x2.0-2.5

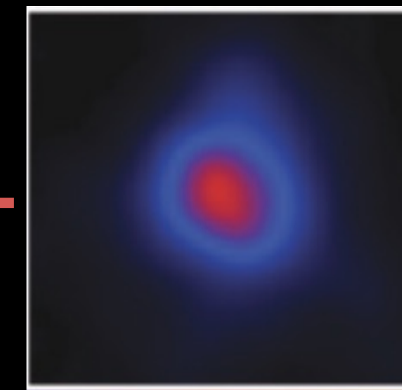
Sensitivity gain:
0.5-0.7mag

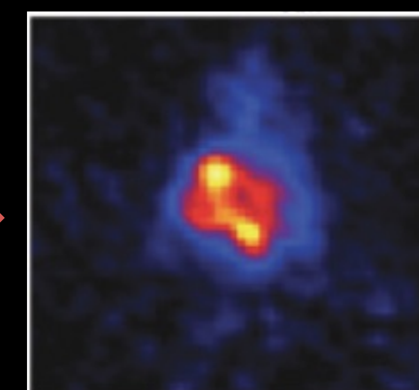
Sensitivity calculation for Subaru GLAO (Subaru GLAO study report 2016)

Improved Spatial Resolution in NIR



z=1-3 star-forming galaxies





1~2kpc

(Subaru GLAO study report)

z=1-3 compact galaxies

< 1kpc

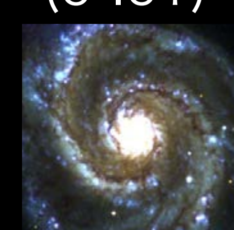
(van Dokkum et al. 2015)

Seeing
(0".5)

GLAO
(HST/WFIRST)
(0".2)

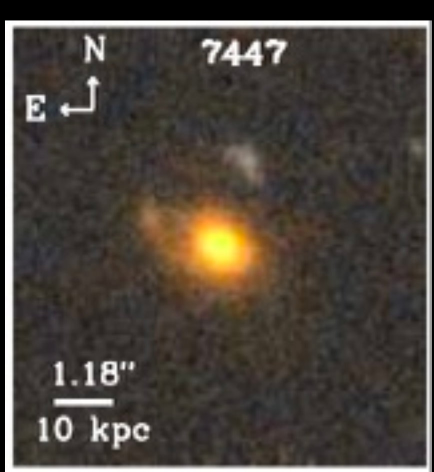
8m
diffraction limit
(0".07)

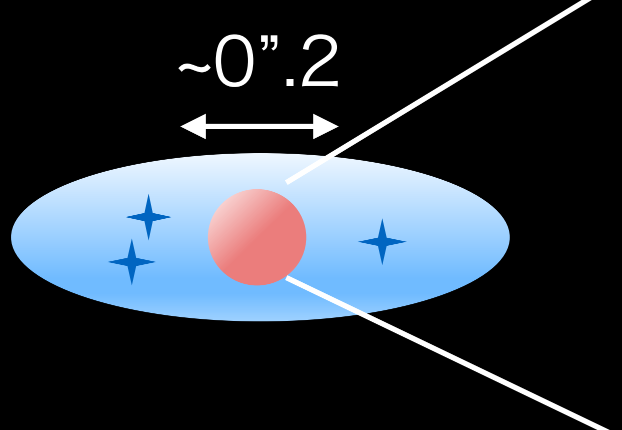
30m
diffraction limit
(0".01)

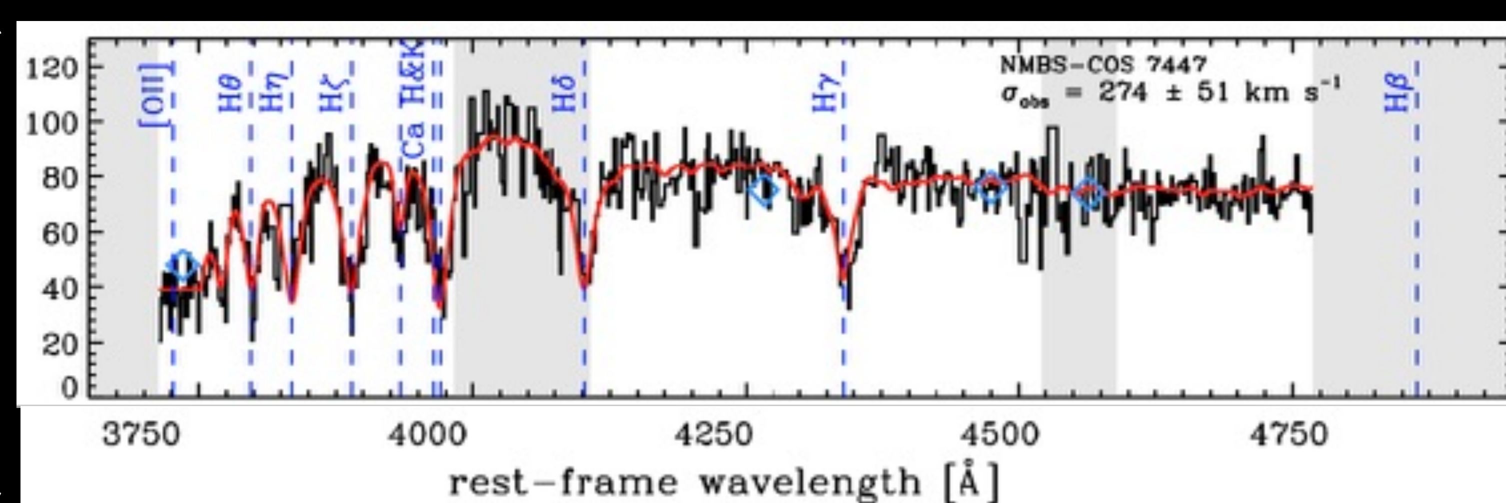


Spatially-resolved NIR spectroscopy of galaxies at cosmic noon

- 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





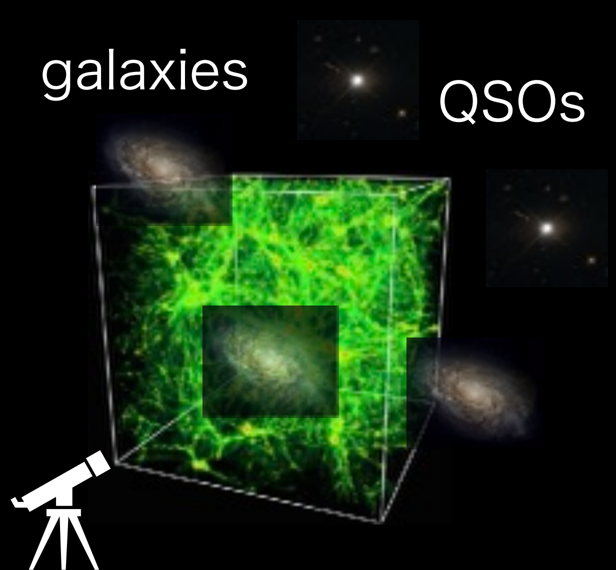


van de Sande et al. 2013

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.

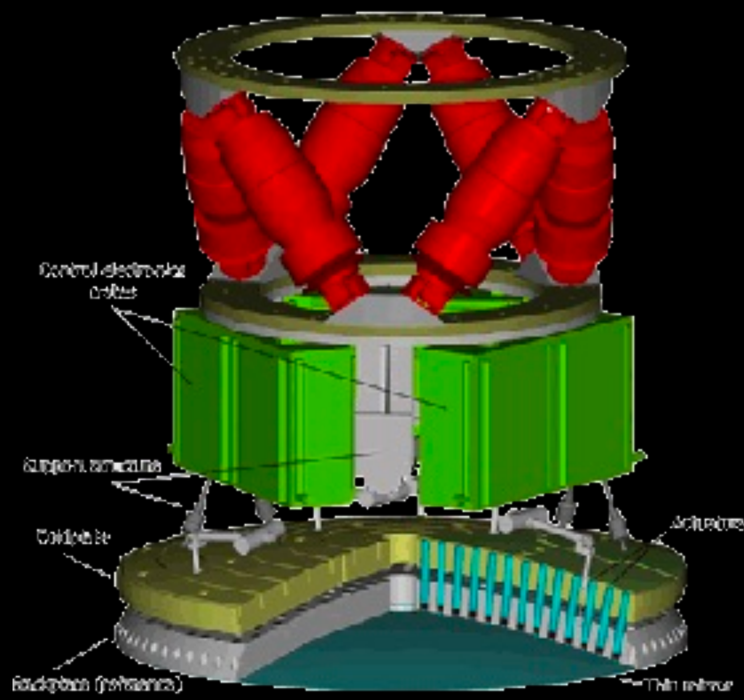
Additional sensitivity leverage to the IGM tomography at z>2



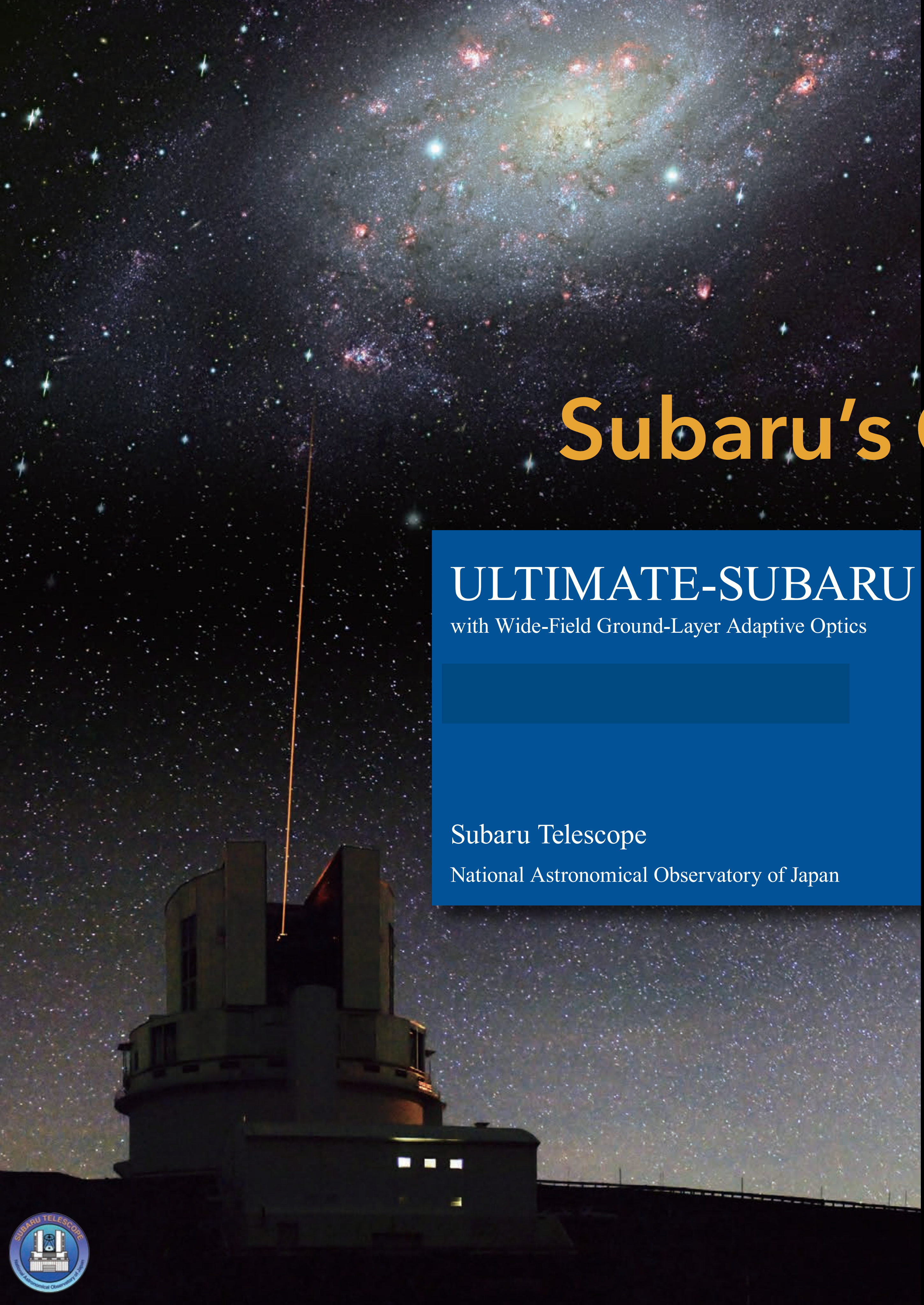
- TMT/WFOS will use many sight lines toward faint galaxies in 3'x8' FoV (~10 Mpc) at z~2 and beyond for IGM and CGM tomography.
- GLAO will provide additional leverage to increase the number of sight lines and to decrease the survey time.

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

ULTIMATE-SUBARU

with Wide-Field Ground-Layer Adaptive Optics

Subaru Telescope

National Astronomical Observatory of Japan

Michitoshi Yoshida (PI, Director, Subaru),
Yosuke Minowa (PM, Subaru),
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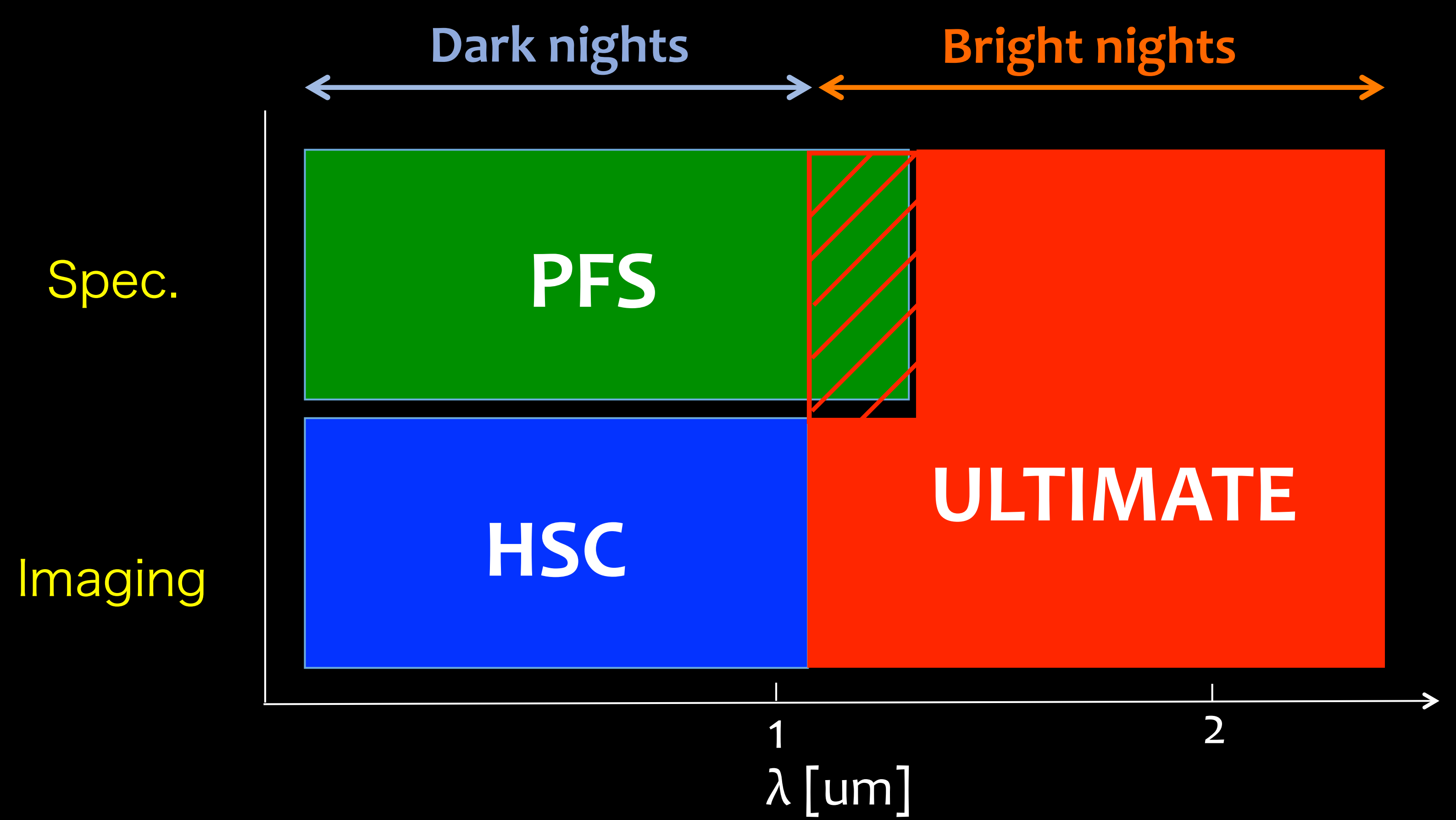
Ichi Tanaka, Naruhisa Takato (Subaru),
Yutaka Hayano, Shin Oya, Hideki Takami (NAOJ),
Tadayuki Kodama, Masayuki Akiyama,
Tatsuhiro Watanabe (Tohoku)
Kentaro Motohara (Univ. of Tokyo)
Francois Rigaut, Celine D'orgeville (ANU)
Nobuo Arimoto (Seoul National Univ.)

Subaru's Wide-Field Strategy in 2020s

1. Very wide-field optical imager — HSC (2013)
2. Wide-field multi-objet spectrograph — PFS (2019)
3. Wide-field near-infrared imager and MOS spectrograph including AO assisted IFU — ULTIMATE-Subaru (2025)



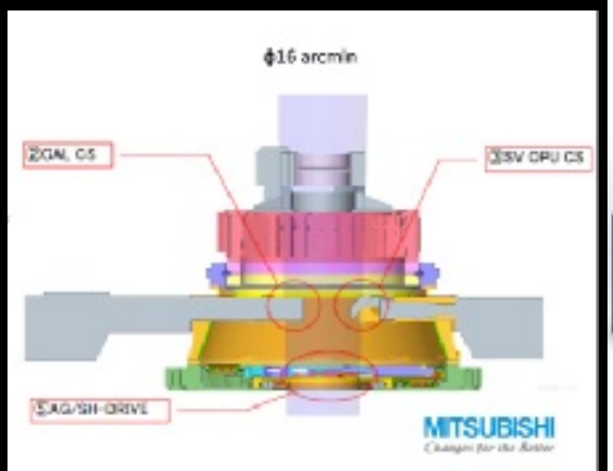
- Uniform seeing improvement over ~20 arcmin FoV
- FWHM < 0".2 at K-band, which is equivalent to HST/WFIRST

- Provide Subaru's original High-redshift targets to follow-up with TMT
- Good synergy with satellite-based survey (WFIRST, Euclid) at $\lambda < 2.0\mu m$

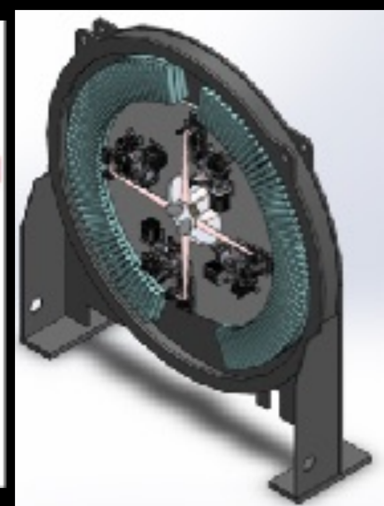
ULTIMATE-Subaru: GLAO system overview

(3) Wavefront Sensors

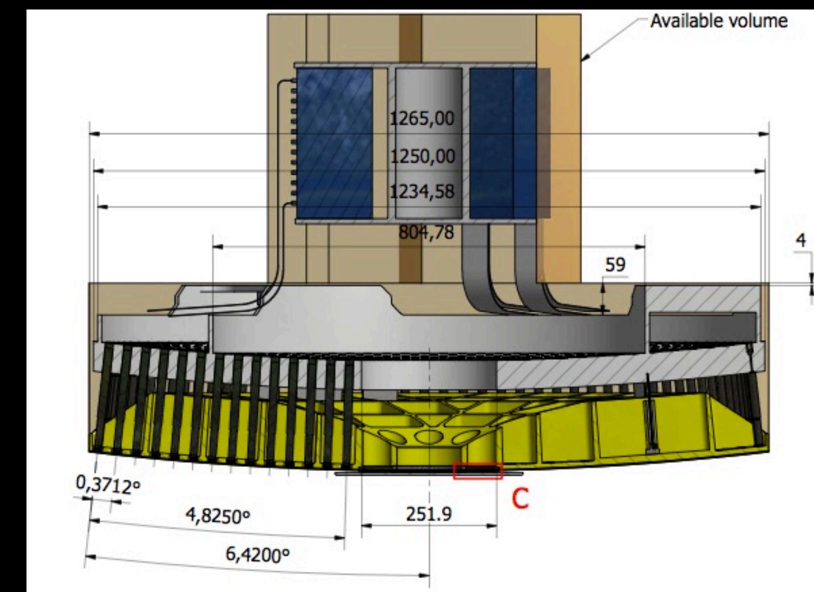
Cs. Focus
(FoV~20 arcmin)



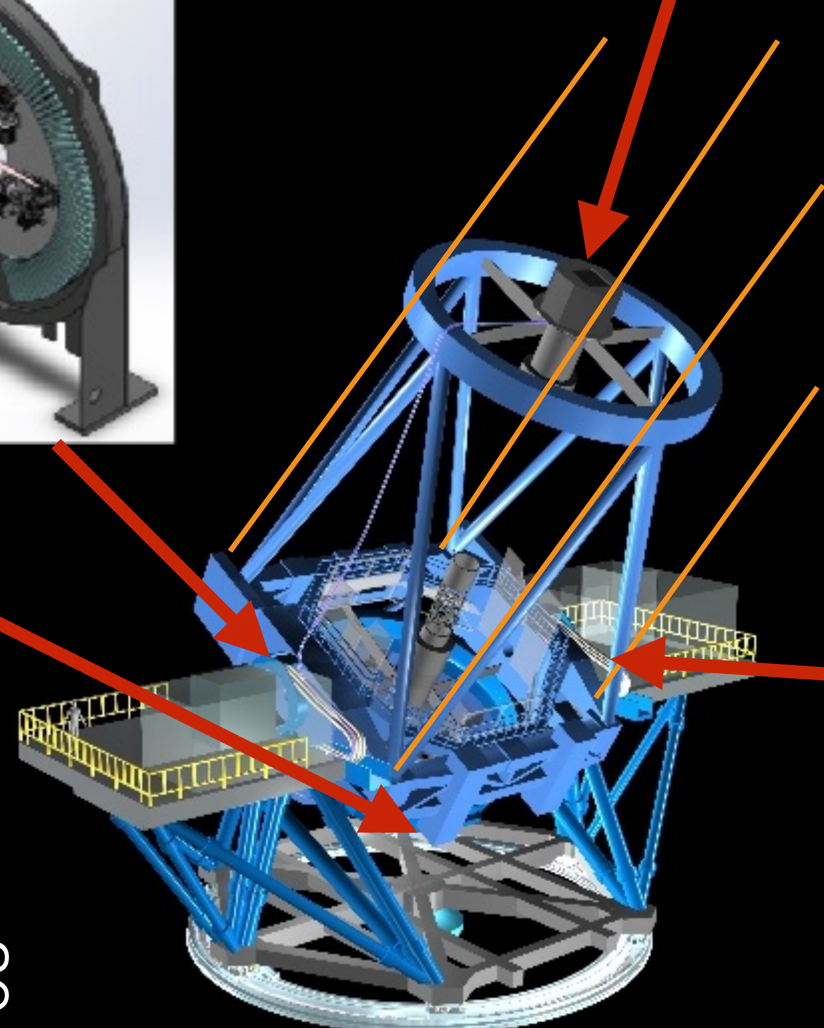
Ns.IR Focus
(FoV~6 arcmin)



(1) Adaptive Secondary Mirror



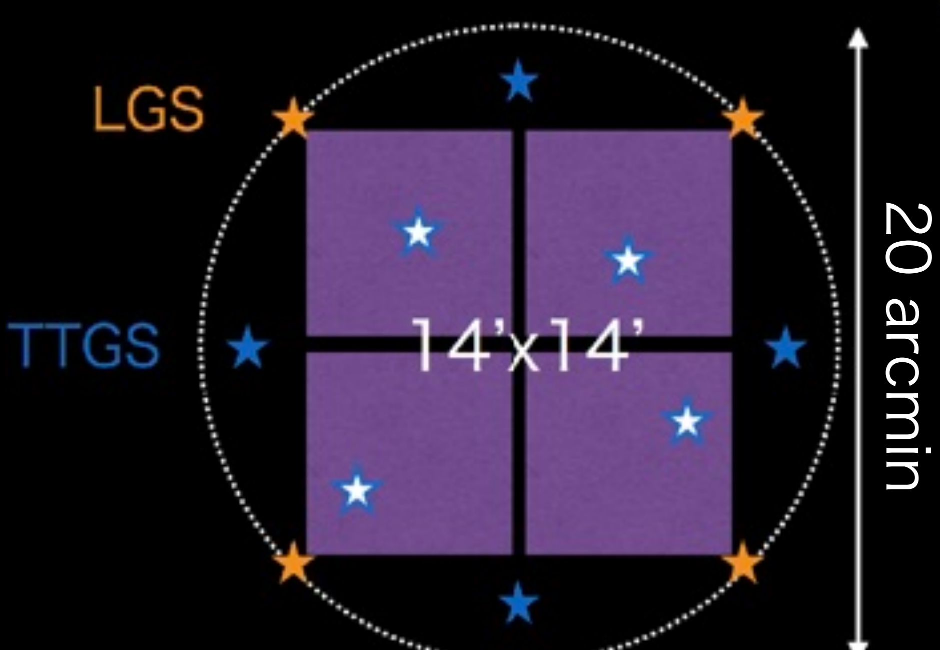
Preliminary Subaru ASM
design by Microgate ADS



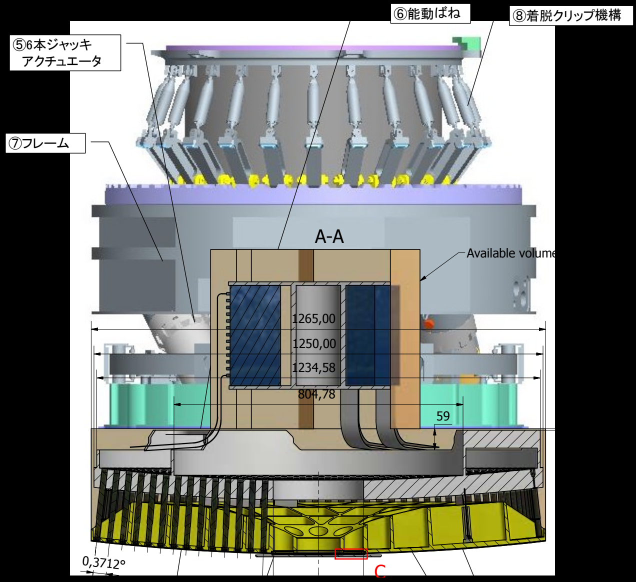
(2) Laser Guide
Star system

TOPTICA fiber laser(589nm) x 2
Generate 4 laser guide stars

Cassegrain Focus



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

2025

Phase 1

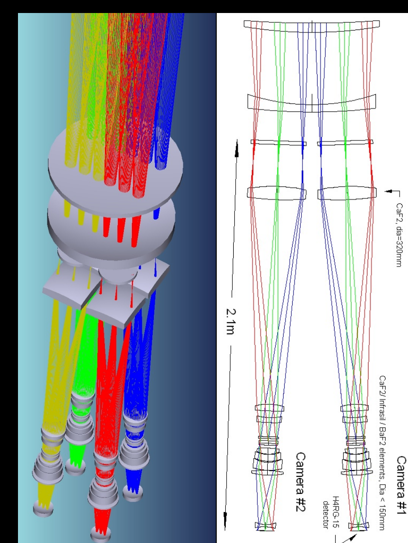
- Reuse MOIRCS at Ns. IR

MOIRCS

GLAO first light instrument

Phase 2

- Wide-field imager (WFI) at Cs.



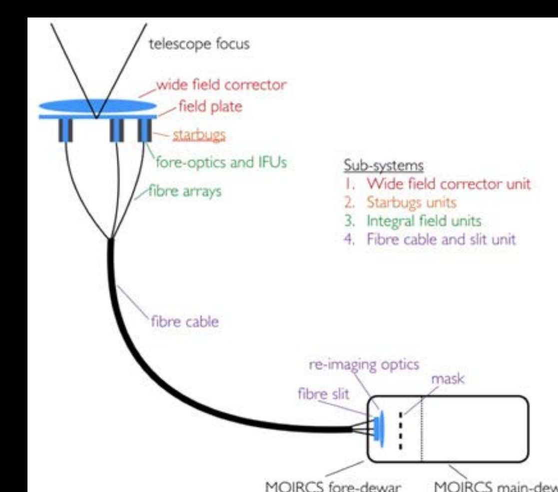
Imager concept by HIA (J. Pazder)

- Workhorse instrument for large SSP imaging survey
- Wide-variety of narrow/medium band filters

2030

Phase 3

- Fiber-bundle multi-IFU at Cs



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.

Overwrap with GLAO at TMT

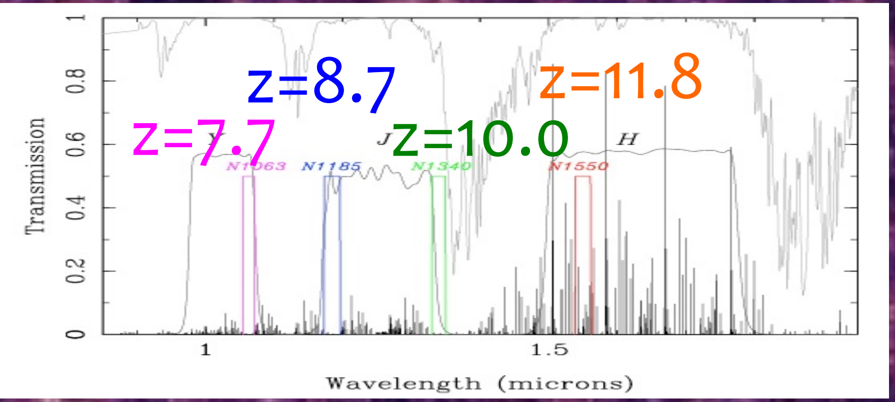
- Deployable fiber IFU at WFOS
- Science cases with 15’x15’ FoV

Key science : Complete census of galaxy evolution

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

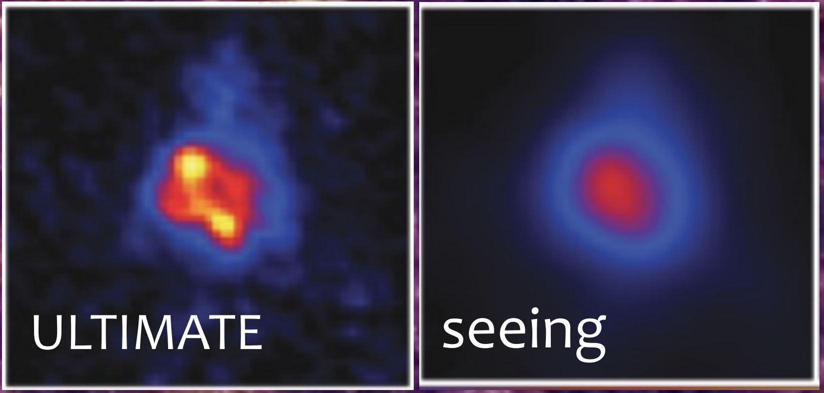
1. First galaxies (birth)

- Unprecedentedly deep NB imaging to detect galaxies at "cosmic dawn" (z>>7).
- Extension of HSC optica NB survey



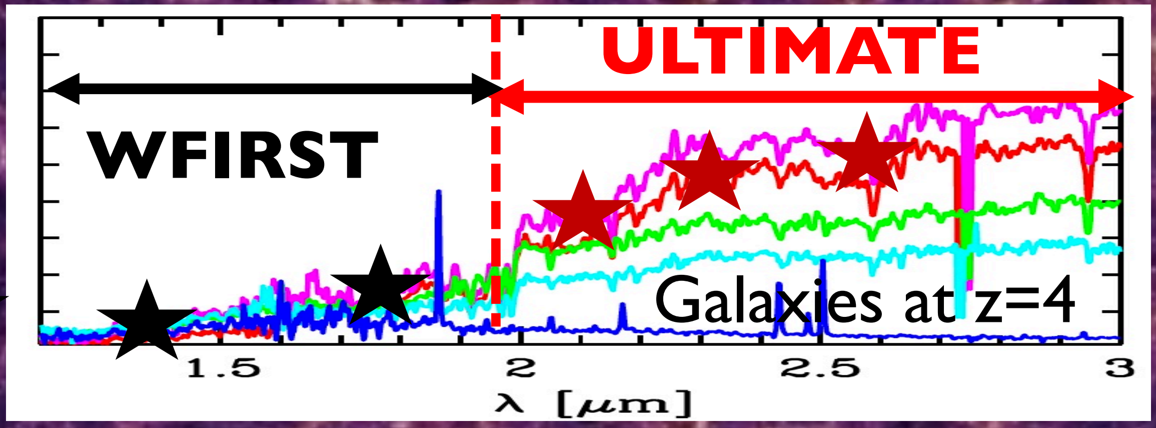
2. Stellar build-up (life)

- 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)

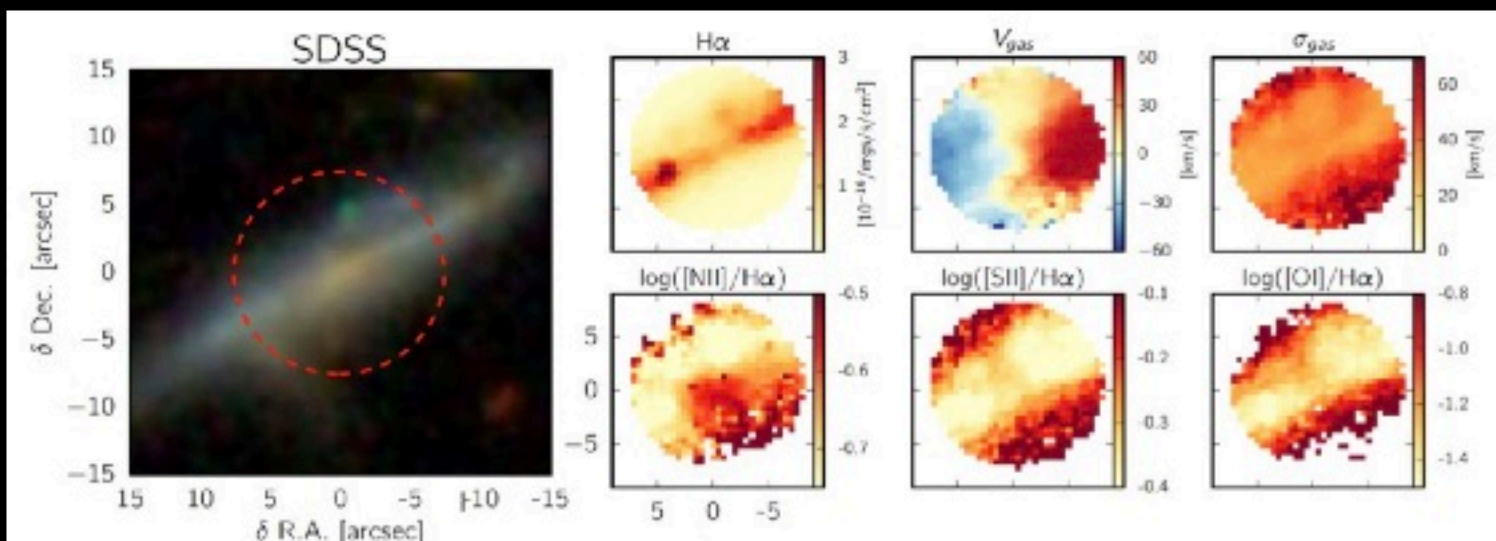
- Tracking down the "passive" galaxies to z~5 with deep BB/MB imaging (in K-band).
- Environment of dead galaxies: do first galaxies die in isolation or in clusters?
- Great synergy with WFIRST.



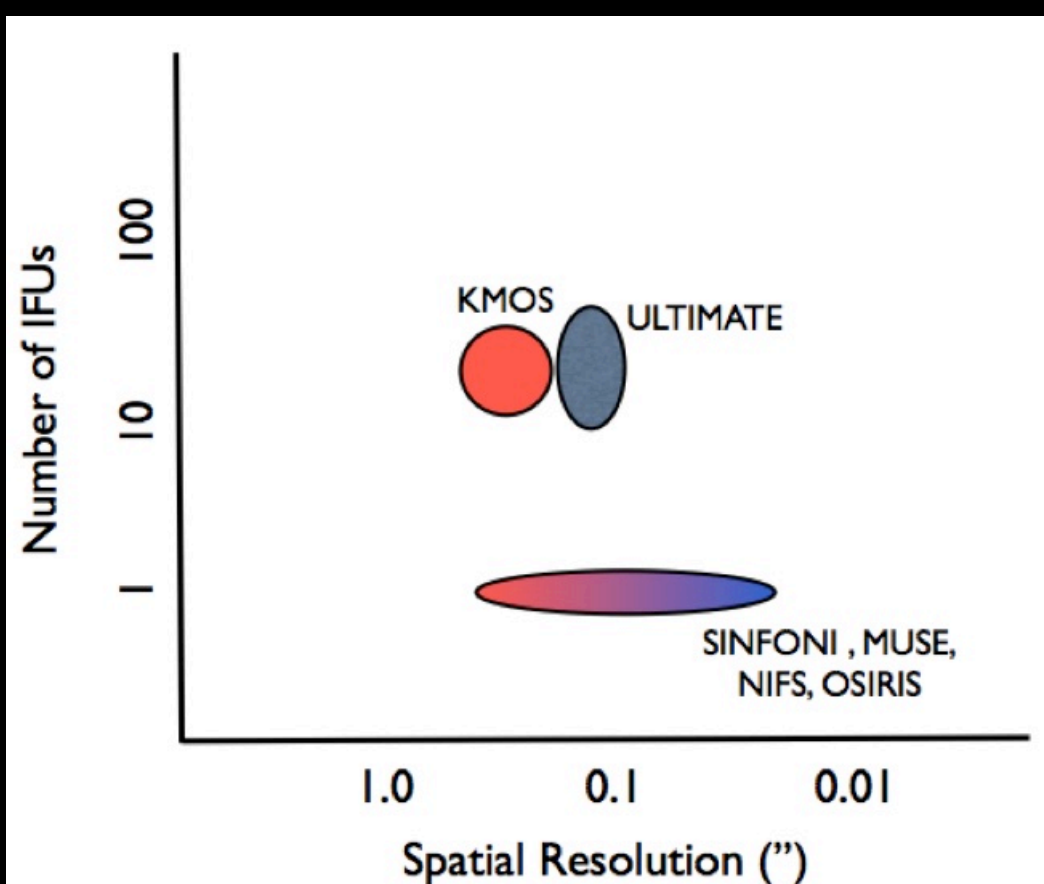
Kinematics Survey of galaxy evolution

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).

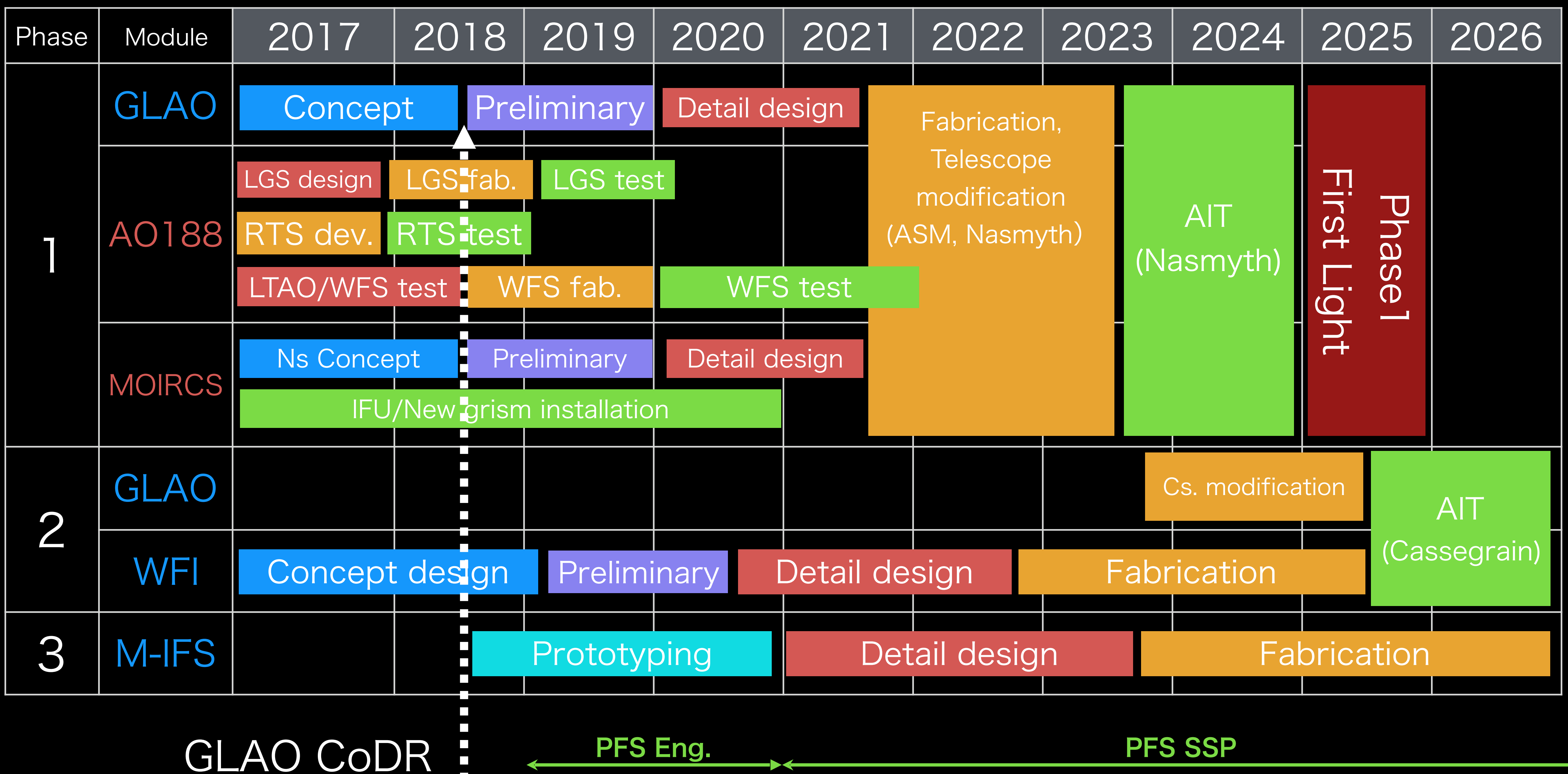


Measure properties of galaxy evolution across disk (SFR, kinematics, outflow, metallicity gradient, etc.) via emission to understand:

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

(Ellis et al. 2015)

ULTIMATE-Subaru: Schedule



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.