ULTIMATE-Subaru Project Overview

Yosuke Minowa
(Subaru Telescope)
on behalf of

ULTIMATE-Subaru working group

PI: Michitoshi Yoshida (Director, Subaru)
Yusei Koyama, Ikuru Iwata, Yoshito Ono,
Takashi Hattori, Christophe Clergeon,
Ichi Tanaka, Naruhisa Takato (Subaru),
Yutaka Hayano, Shin Oya, Hideki Takami (NAOJ),
Masayuki Akiyama, Tadayuki Kodama,
Tatsuhiro Watanabe (Tohoku)
Kentaro Motohara (Univ. of Tokyo)
Francois Rigaut, Celine D'orgeville, Gaston
Gausachs, Nick Herrald, Visa Korkiakoski (ANU)
Nobuo Arimoto (Seoul National Univ.)

http://www.naoj.org/Projects/newdev/ngao/index.html

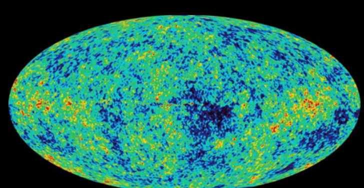
Subaru's Wide-Field Strategy in 2020s

Recommendation from Subaru Science Advisory Committee
(representative of the Subaru's community)

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)

Subaru will provide "legacy data" to answer the fundamental questions using HSC, PFS (in dark nights), and ULTIMATE (in bright nights)

Origin of the Universe



→

Evolution of the Universe

→

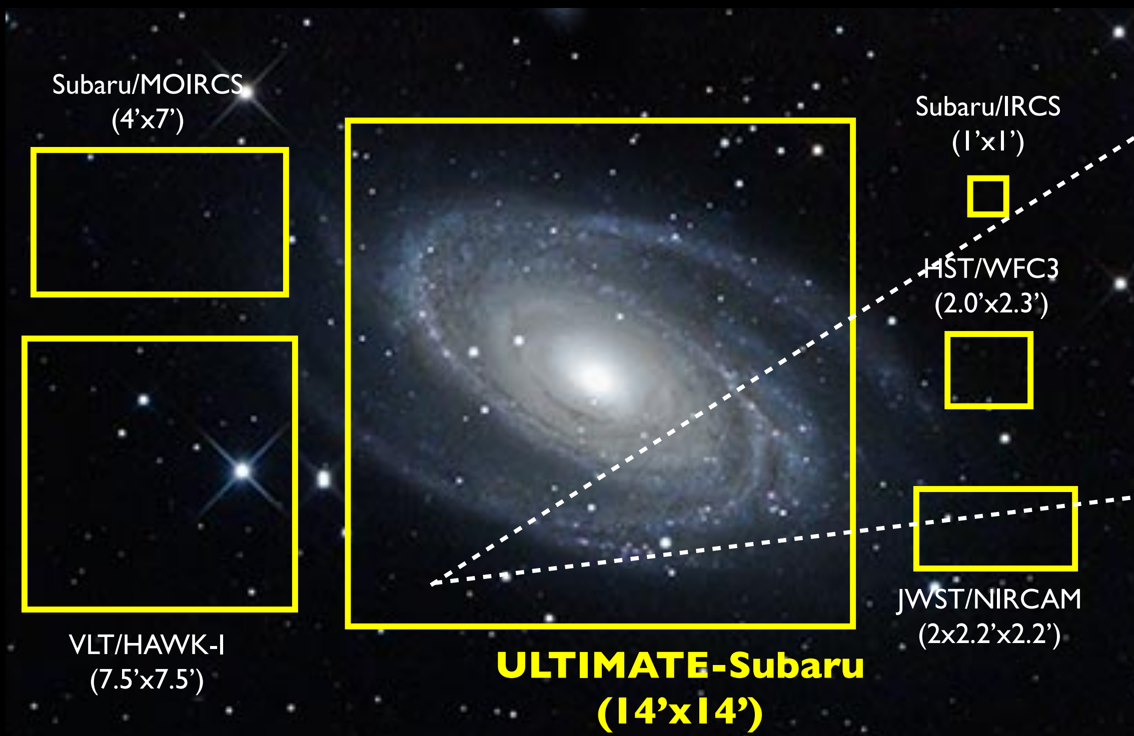
Origin of Life

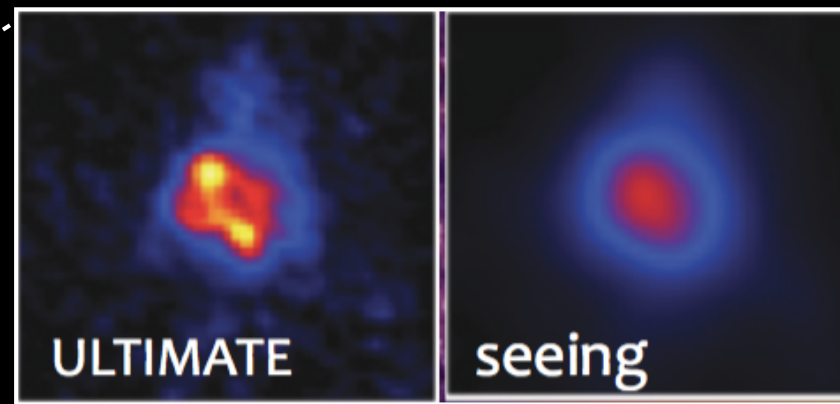
HSC/PFS

ULTIMATE

GLAO/LTAO | ExAO

High-resolution wide-field NIR survey capabilities to explore the high-redshift universe





Star-forming galaxies at z~2

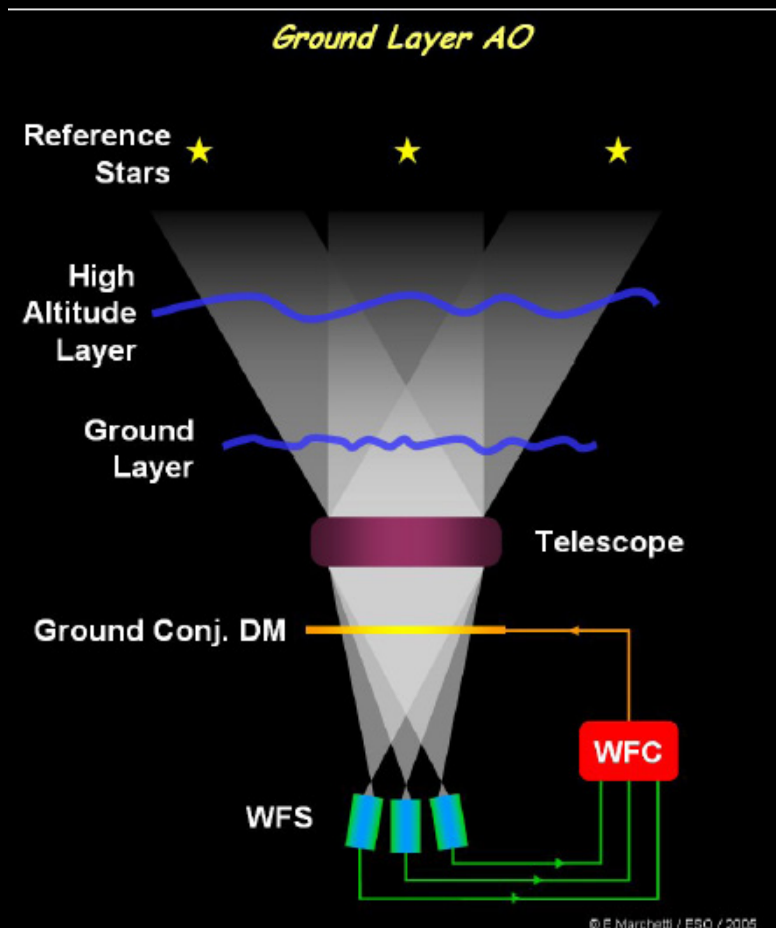
ULTIMATE-Subaru will deliver

- Subaru's original High-redshift targets to follow-up with TMT
- Spatially-resolved studies of the objects found by HSC/PFS
- SDSS like comprehensive imaging/spectroscopic survey for high-redshift universe (z>2).
- Synergy with the future surveys by wide-field satellites, such as Euclid, WFIRST, SPICA, ATHENA, etc.

Subaru's Next Facility Instrument Plan

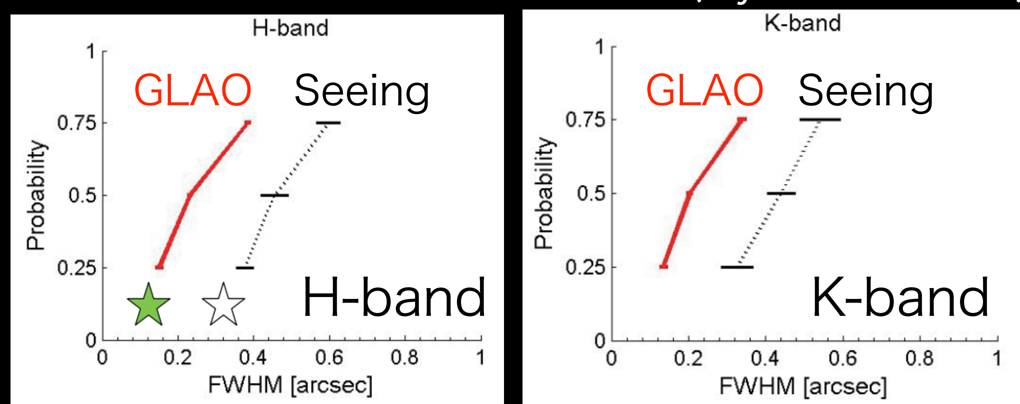
ULTIMATE-Subaru

Ground-Layer Adaptive Optics
x
Wide-Field near-infrared instrument



https://www.eso.org/sci/facilities/develop/ao/ao_modes/.html

GLAO performance simulation at Subaru
(Oya et al. 2014)



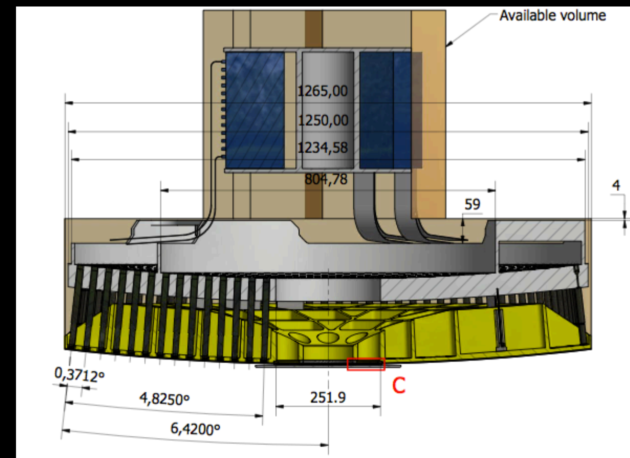
☆On-sky performance verification with RAVEN

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

Comprehensive performance simulations are ongoing with more conservative turbulence profile and more statistics (Visa's talk)

ULTIMATE telescope upgrade

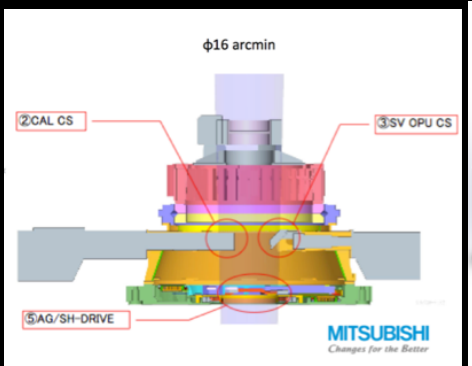
(1) Adaptive Secondary Mirror



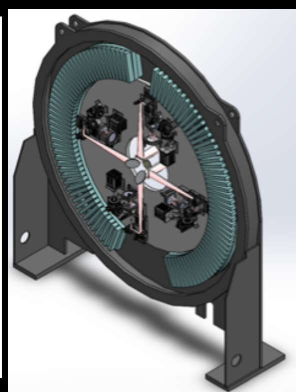
Preliminary Subaru ASM design by Microgate ADS

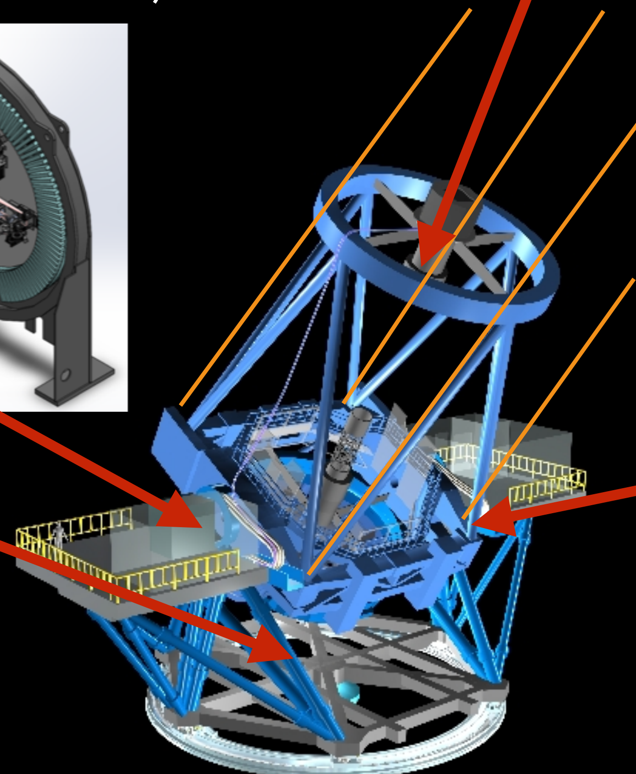
(3) Wavefront Sensors

Cs. Focus (FoV~20 arcmin)



Ns.IR Focus (FoV~10 arcmin)





(2) Laser Guide Star system

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

ULTIMATE-GLAO: Baseline Specification

Item	Specification
Guide stars	4 LGS, NGS(2∼4)
Location of guide stars	The edge of FoV > 15′ (LGS), Within the FoV (NGS)
Wavefront sensors	Each guide stars (Guide star oriented)
Wavefront sensor type	Shack-Hartmann (IR pyramid-WFS is optional)
Tip-tilt wavefront sensor type	2×2 Shack-Hartmann wavefront sensor or pyramid. (visible or NIR)
Sub apertures	> 100
Frame rate of wavefront sensor	> 500Hz
Deformable mirror	Adaptive secondary mirror
Actuators	∼1000
AO control type	GLAO (LTAO, ExAO modes)

- Use conventional SH-WFS as baselines for both LGS and NGS WFS
- Well developed Adaptive Secondary mirror is used

  → Low technical challenge for hardware development

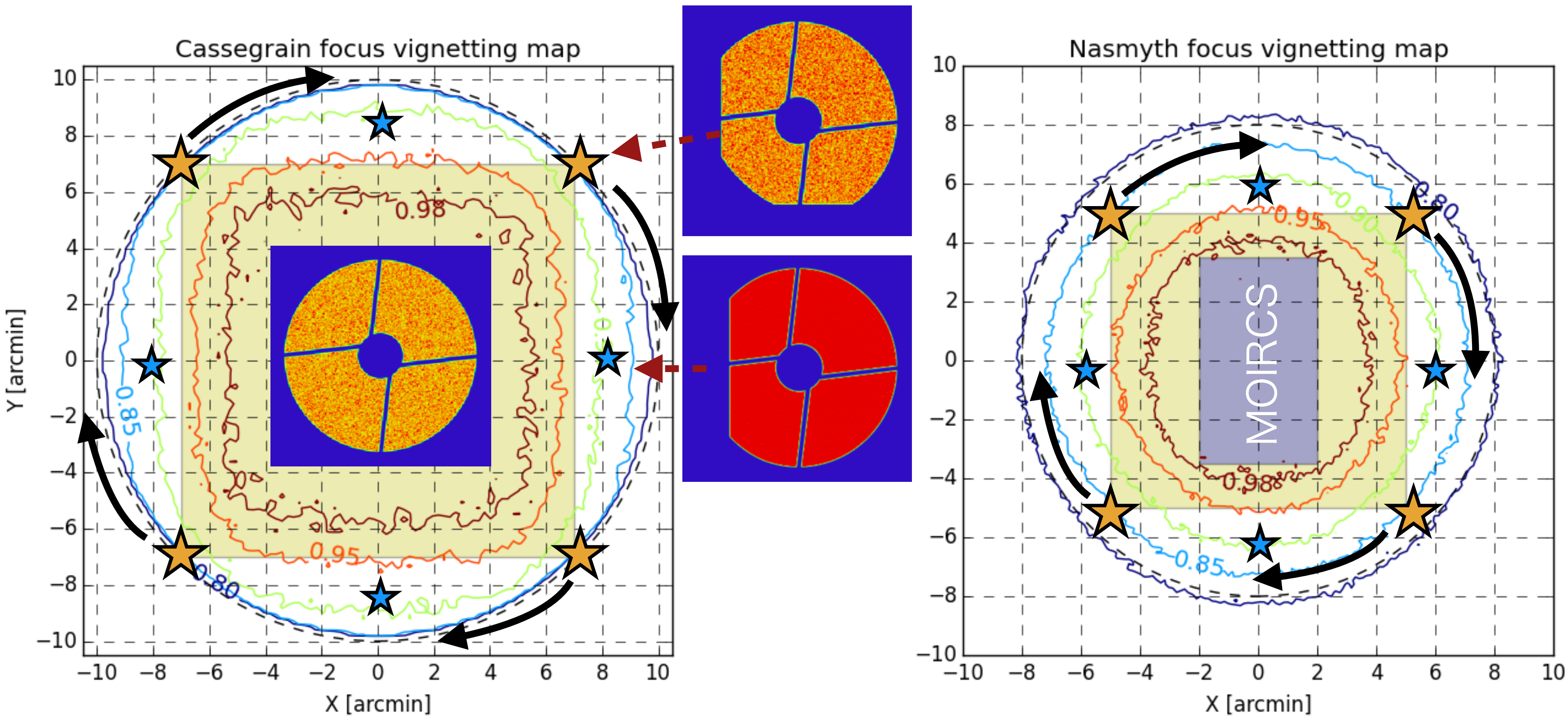
GLAO correction over the widest FoV ever achieved is a challenge.

Field coverage

Maximize the field of view to enhance the uniqueness of the ULTIMATE-Subaru

Cassegrain Focus

Nasmyth Focus



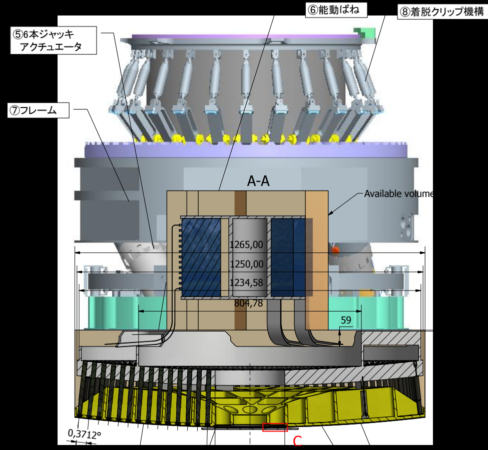
ϕ~20 arcmin

Science FoV: 14' x 14'

ϕ~14 arcmin

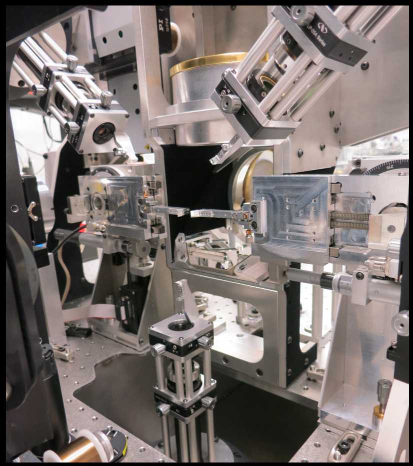
Science FoV: 10' x 10'

Key Technologies for GLAO



- (1) Adaptive Secondary Mirror
  - Develop ASM with ADOPTICA and Mitsubishi
  - Mitigate the technical risk by reusing the technology developed at VLT, MMT, and LBT
  - Frequent exchange of the ASM will be a challenge.

- (2) Sodium Laser Guide Star system
  - 2 Sodium LGS system from TOPTICA –> well developed technology
  - Early commissioning with the exisiting AO system (AO188)
- (3) Wide-field (Tomographic) Wavefront sensing
  - Make use of the previous experiences from the GLAO precursors at MaunaKea
    - RAVEN/Subaru (2014-2015): MOAO science demonstrators, GLAO performance at Subaru was demonstrated to be FWHM~0".2 at H-band. GLAO path-finder at Maunakea!!
    - Imaka/UH88 (2016-): GLAO performance verification at wide FoV (12′ x 12′) is ongoing.
  - On-sky test with the SH-WFS prototype for testing the tomographic wavefront reconstruction is being planned by Tohoku Univ (ULTIMATE-START)



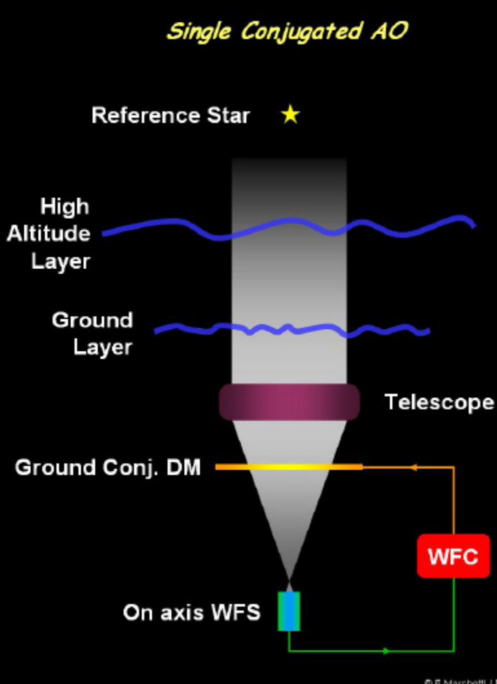
All technologies can be connected to operation and development at TMT.

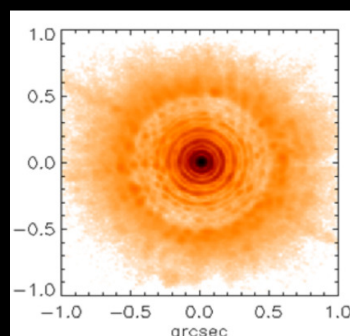
Other capabilities of ULTIMATE

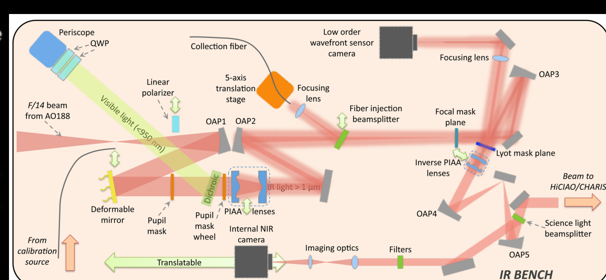
ASM will also provide the following AO modes,
which are not available with the TMT 1st. gen. instruments.

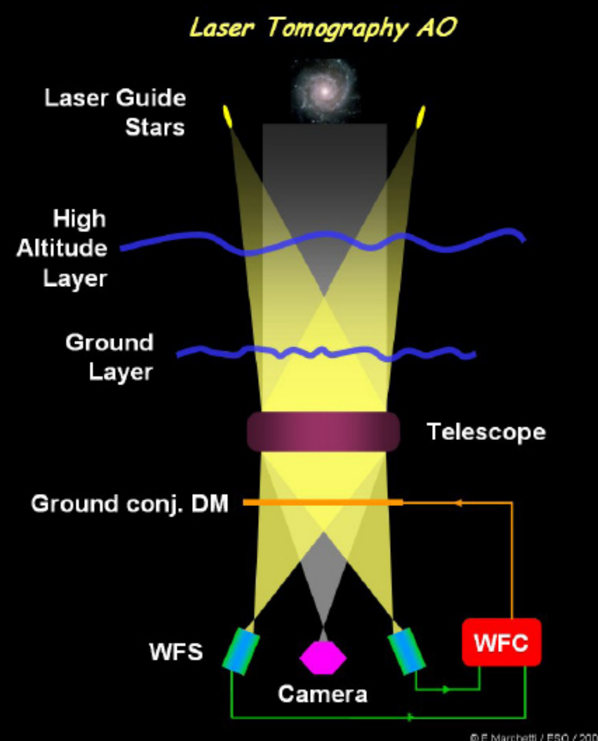
Extreme AO x High-contrast instrument

Laser-tomographic AO x Visible instrument









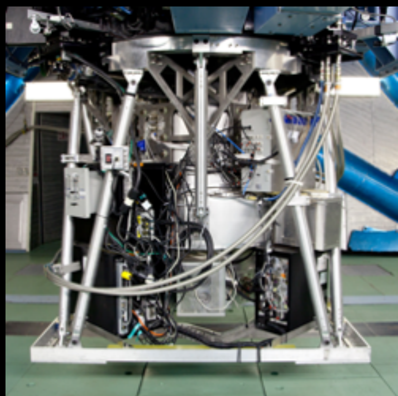
- ASM (~1000 actuators)+SCExAO or LTAO will provide superb Strehl ratio from visible to thermal infrared
- Subaru can be a pathfinder for TMT's 2nd gen. instruments

New Wide-field Instrument for ULTIMATE

2025

Phase 1

- Reuse MOIRCS at Ns. IR

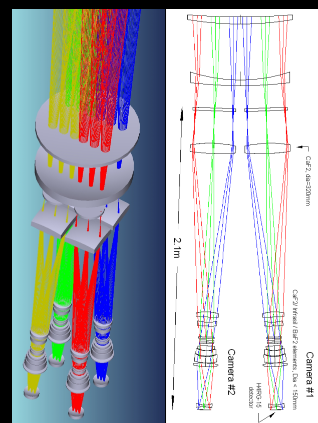


MOIRCS

GLAO first light instrument

Phase 2

- Wide-field imager (WFI) at Cs.



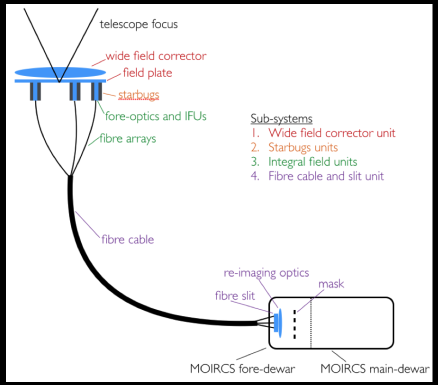
Imager concept by HIA (J. Pazder)

- 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)

- Unique instrument for large kinematic survey like MANGA/SAMI.
- Feed to the existing spectrograph (MOIRCS/PFS)

K-band Sensitivity improvement

- 0.8-1.0 mag (PSF)
- 0.5 mag (galaxies with Re~2kpc)

Survey power is 20 times higher than MOIRCS at Cs

Comparison with TMT/Space telescope in late 2020s

<table>
<tr><th rowspan="2"></th><th colspan="3">Imaging</th><th colspan="3">MOS</th><th>M-IFS</th></tr>
<tr><th>JH</th><th>K</th><th>MB, NB</th><th>J</th><th>H</th><th>K</th><th>JHK</th></tr>
<tr><td>Pointed observations</td><td colspan="7">JWST, TMT, …</td></tr>
<tr><td rowspan="2">Surveys</td><td rowspan="2">WFIRST</td><td colspan="2" rowspan="2">ULTIMATE-WFI</td><td colspan="2">WFIRST R~500</td><td rowspan="2">ULTIMATE-MOIRCS</td><td rowspan="2">ULTIMATE -MIFS</td></tr>
<tr><td>PFS R~3000</td><td>ULTIMATE-MOIRCS</td></tr>
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Slide courtesy of Y. Matsuoka

ULTIMATE-Subaru: Current activities

- International collaboration
  - Collaboration with ANU for based on the Subaru-Australia short-term agreement
    - ✳GLAO performance simulation and system optimization (Visa's talk)
    - ✳WFS and LGS opt/mechanical conceptual design
  - Looking into the possibility to extend the collaboration with ANU after the short-term agreement
  - Looking for more collaborators for GLAO and wide-field instruments

- Step-by-Step development for each ULTIMATE module
  - JSPS grant (Kiban-S: 2M USD for 5 years) has been allocated to kick-off the ULTIMATE-Subaru: ULTIMATE-Start (Akiyama-san's talk)
  - Upgrade the existing instruments
    - ✳GPU-based real-time system development for SCExAO, AO188, and ULTIMATE
    - ✳Develop high efficiency grism for MOIRCS

ULTIMATE-Subaru:

Past, On-going and future activities

(1) Adaptive Secondary

- Subaru is going to develop ASM with Adoptica and Mitsubishi.
- Phase1 Feasibility study by Adoptica has been started

(2) Laser

- 1st TOPTICA laser system will be delivered to Subaru on Mar, 2018 for AO188
- LLT and diagnostic system design and development

(3) Tomography WFS

- System optimization based on GLAO simulation (ANU, Tohoku Univ., Subaru)
- Conceptual design of WFS unit at Nasmyth and Cassegrain (Subaru, ANU)
- RTS development for AO188 and ULTIMATE
- Prototyping of SH-WFS at Tohoku Univ.

(4) Wide-Field Instruments

- Multi-IFU conceptual design by AAO (S. Ellis)
- Wide-Field imager conceptual optical design by NRC-HIA (J. Pazder)
- Prototyping of the Starbug positioner
- Conceptual design of the wide-field imager

(5) Science

- Contributions from domestic/international collaborators

ULTIMATE-Subaru Science Workshop @ Mitaka (2016/6/16-17)

Adaptive Secondary Mirror

Modify the existing IRM2 or CsOpt

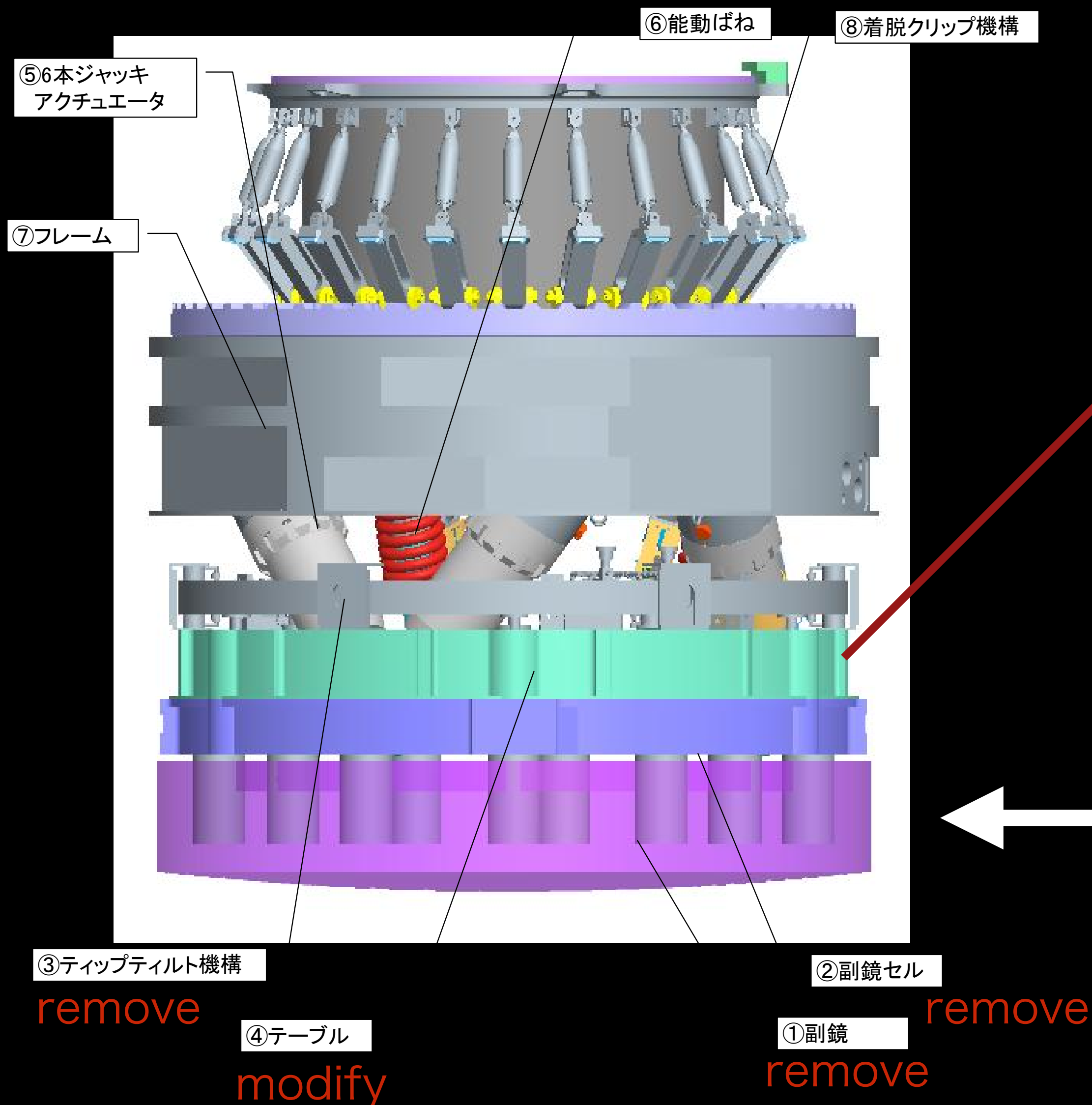
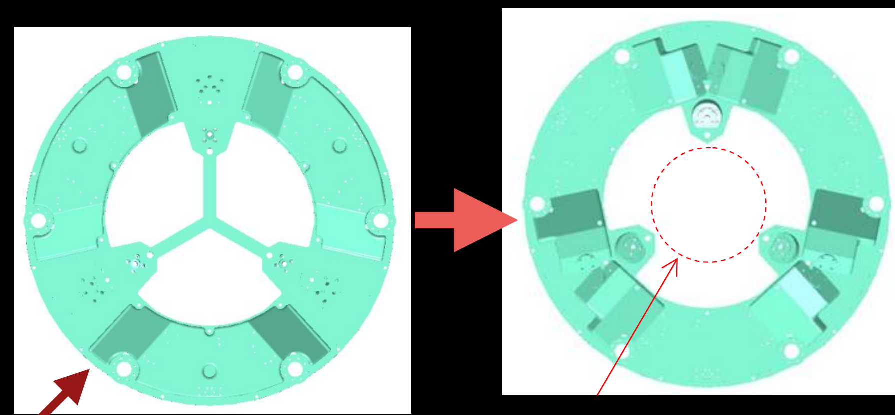
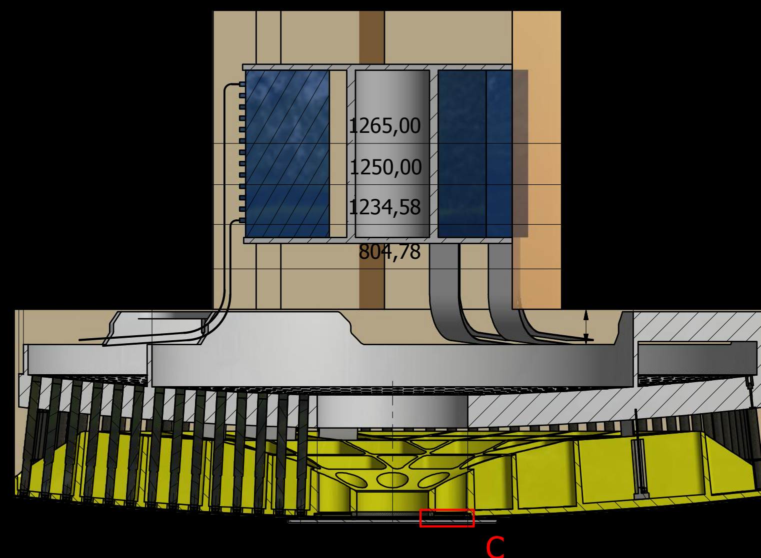


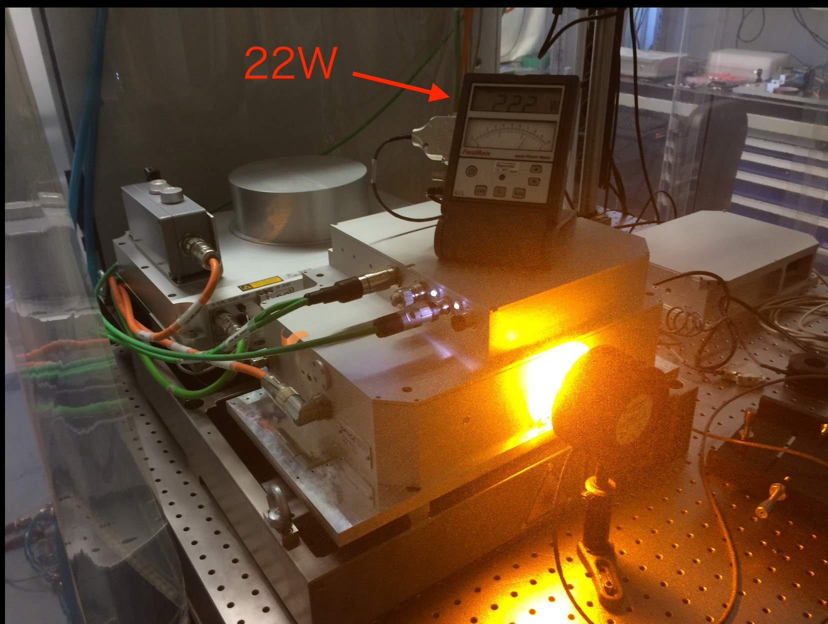
Table modification



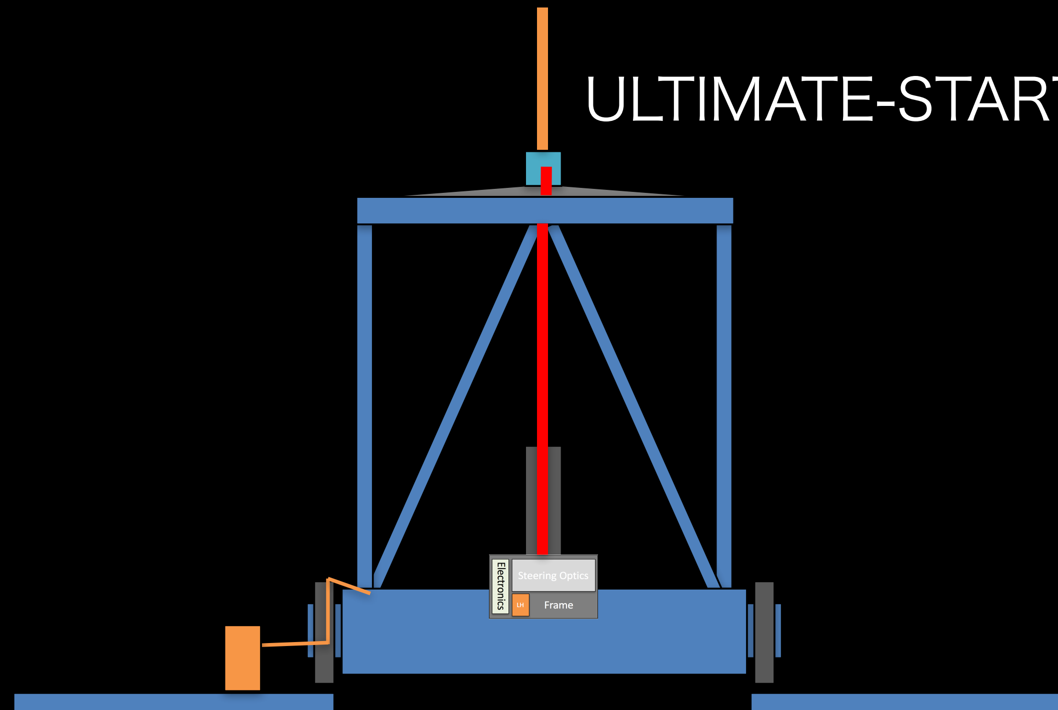


Preliminary Subaru ASM design by ADOPTICA

Laser Guide Star facility (LGSF)

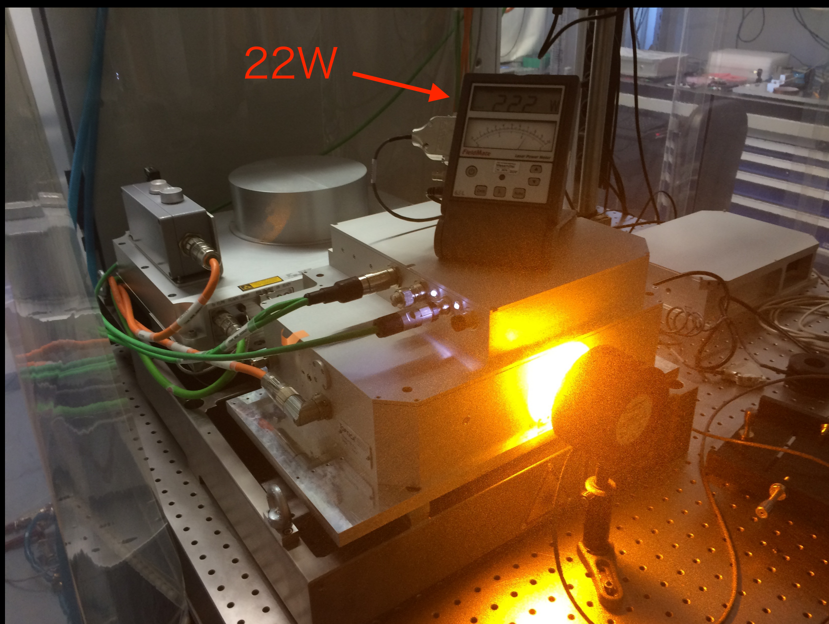


TOPTICA laser for Subaru



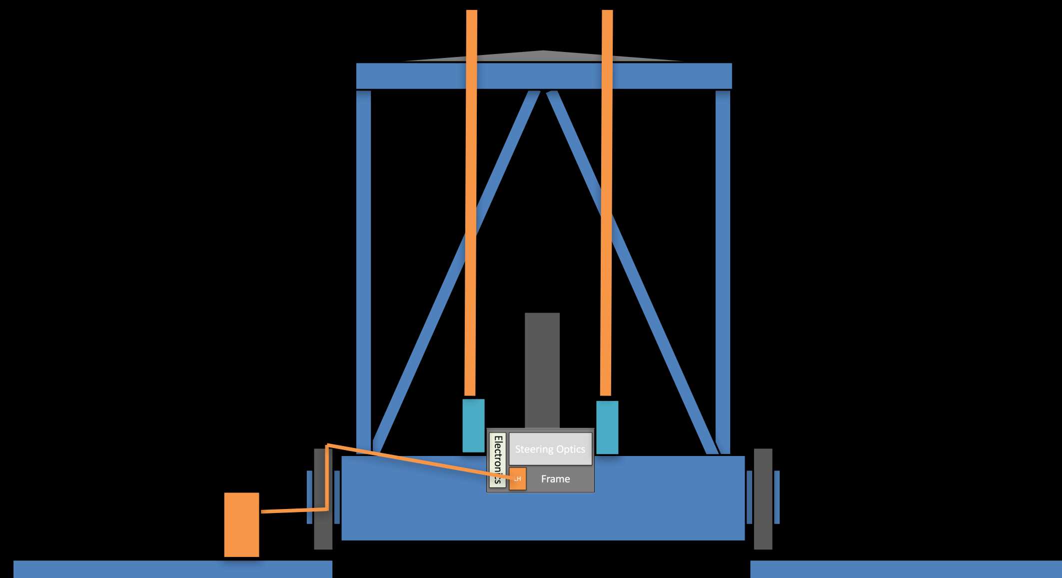
- Use two TOPTICA fiber lasers to generate 4 LGS
- Assembly of the 1st laser has been completed at TOPTICA factory
- The 1st laser will be used for AO188 (ULTIMATE-START) from FY2019
- Same optical mount will be used for ULTIMATE-Subaru in future.
- Alternative plan is to use a semi-conductor laser being developed by ANU for as a second laser.

Laser Guide Star facility (LGSF)



TOPTICA laser for Subaru

ULTIMATE-SUBARU



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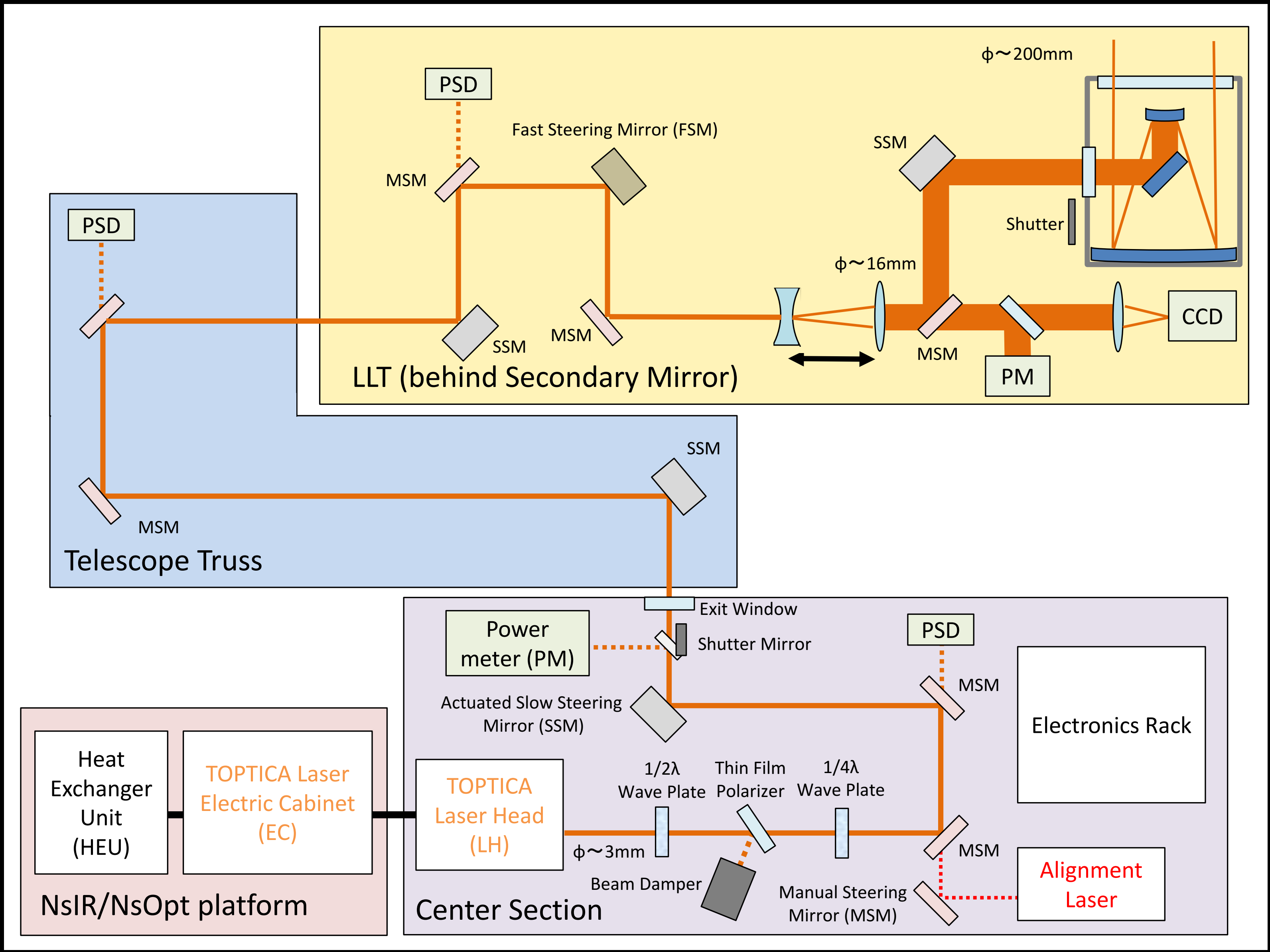
- The 1st laser will be used for AO188 (ULTIMATE-START) from FY2019
- Same optical mount will be used for ULTIMATE-Subaru in future.
- Alternative plan is to use a semi-conductor laser being developed by ANU for as a second laser.

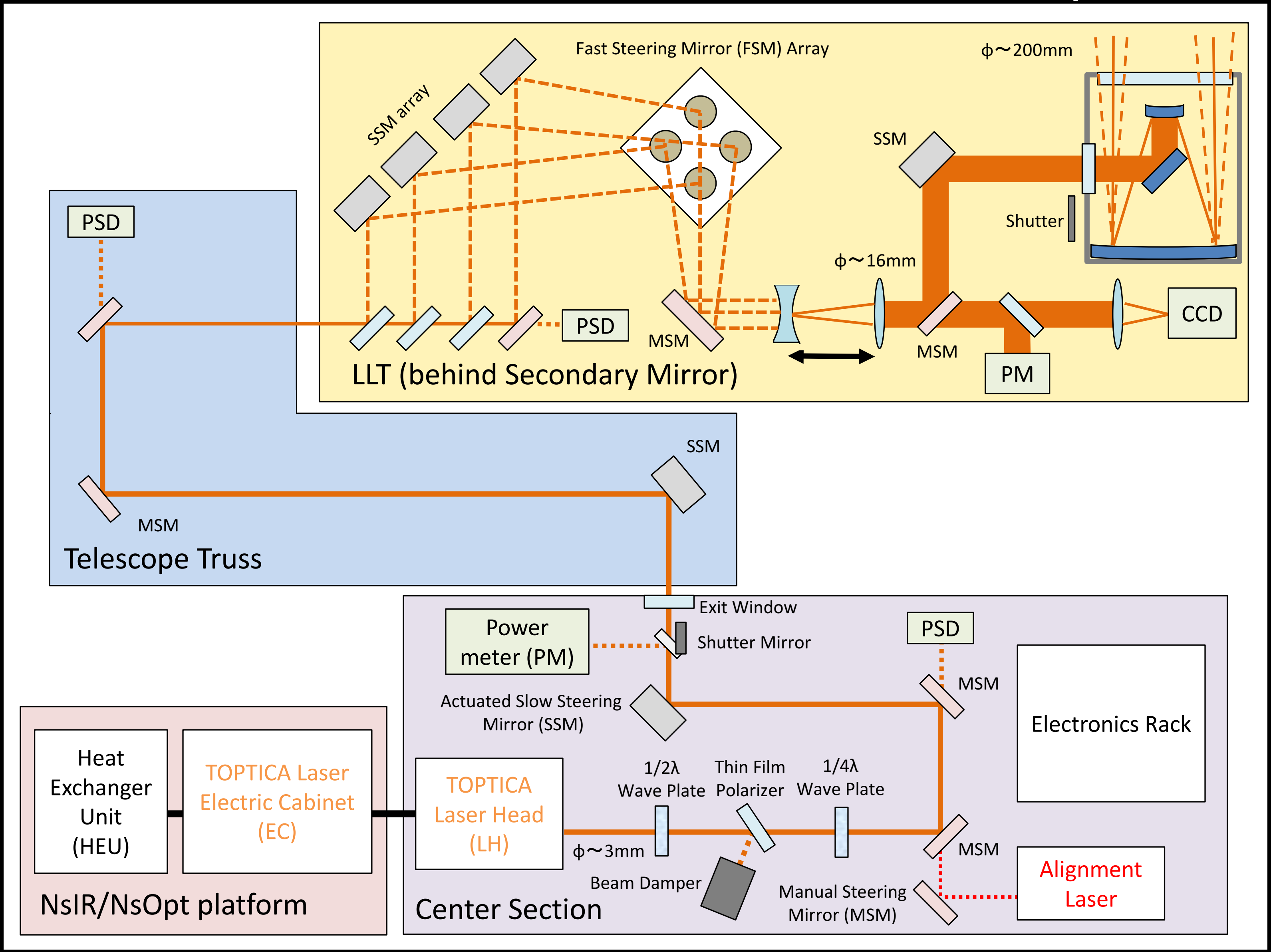
Laser Guide Star facility (LGSF)

Phase1: Single laser (center launch) for AO188



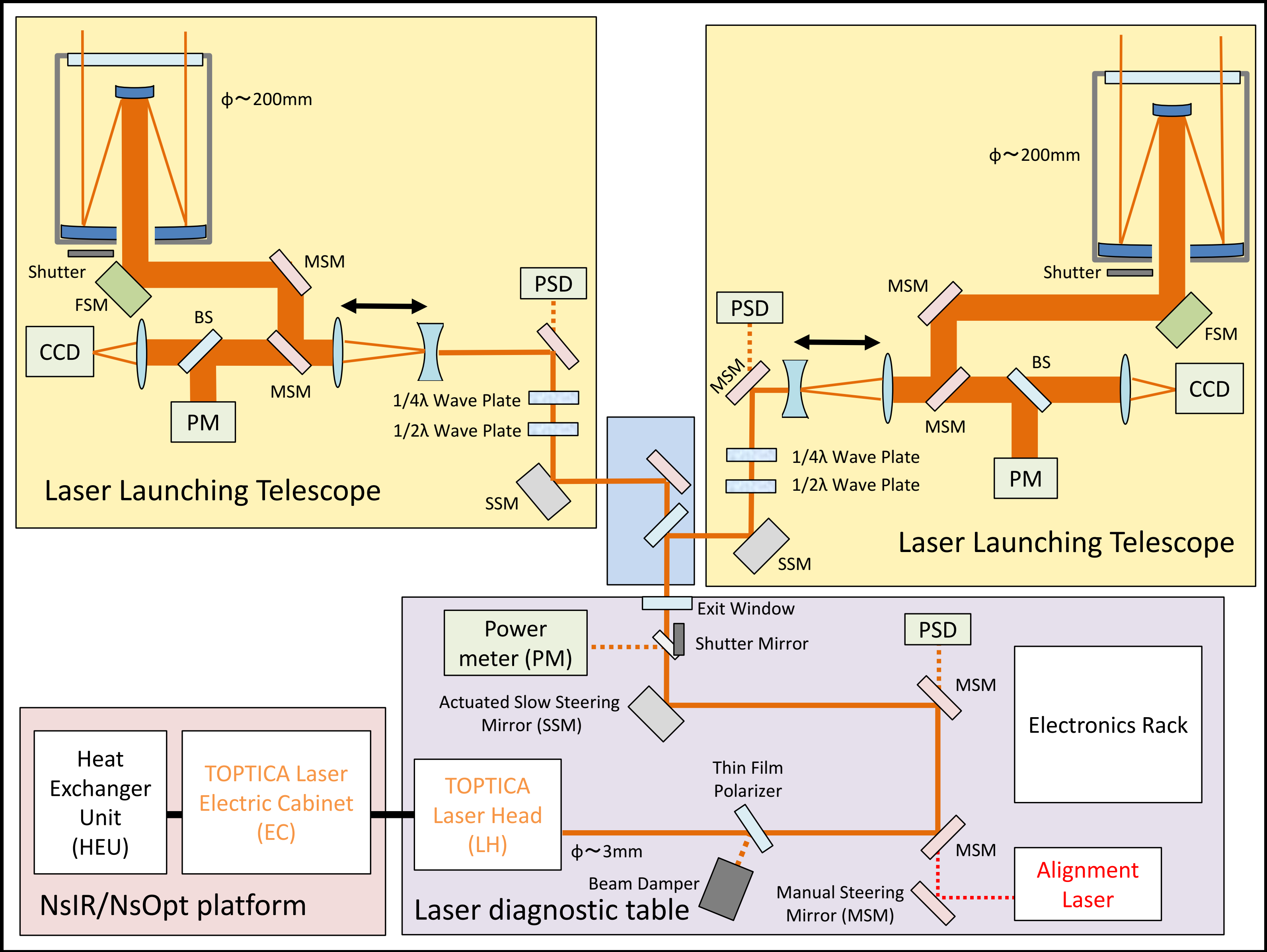
Laser Guide Star facility (LGSF)

Phase2: 4 laser (center launch) for LTAO experiment



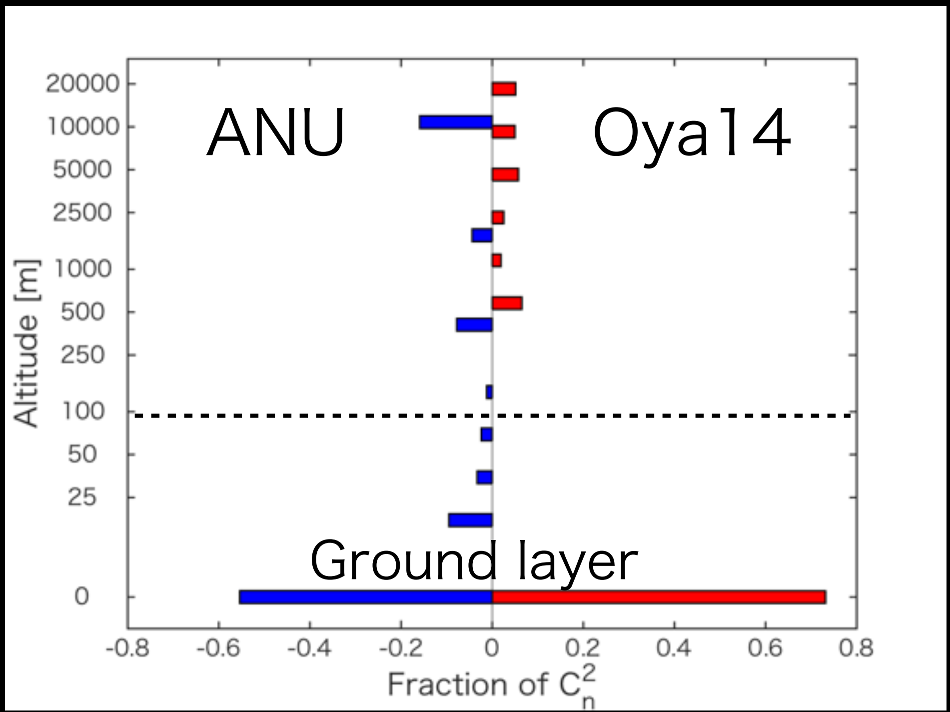
Laser Guide Star facility (LGSF)

Phase3: 4 laser (side launch) for ULTIMATE-Subaru



GLAO performance simulation

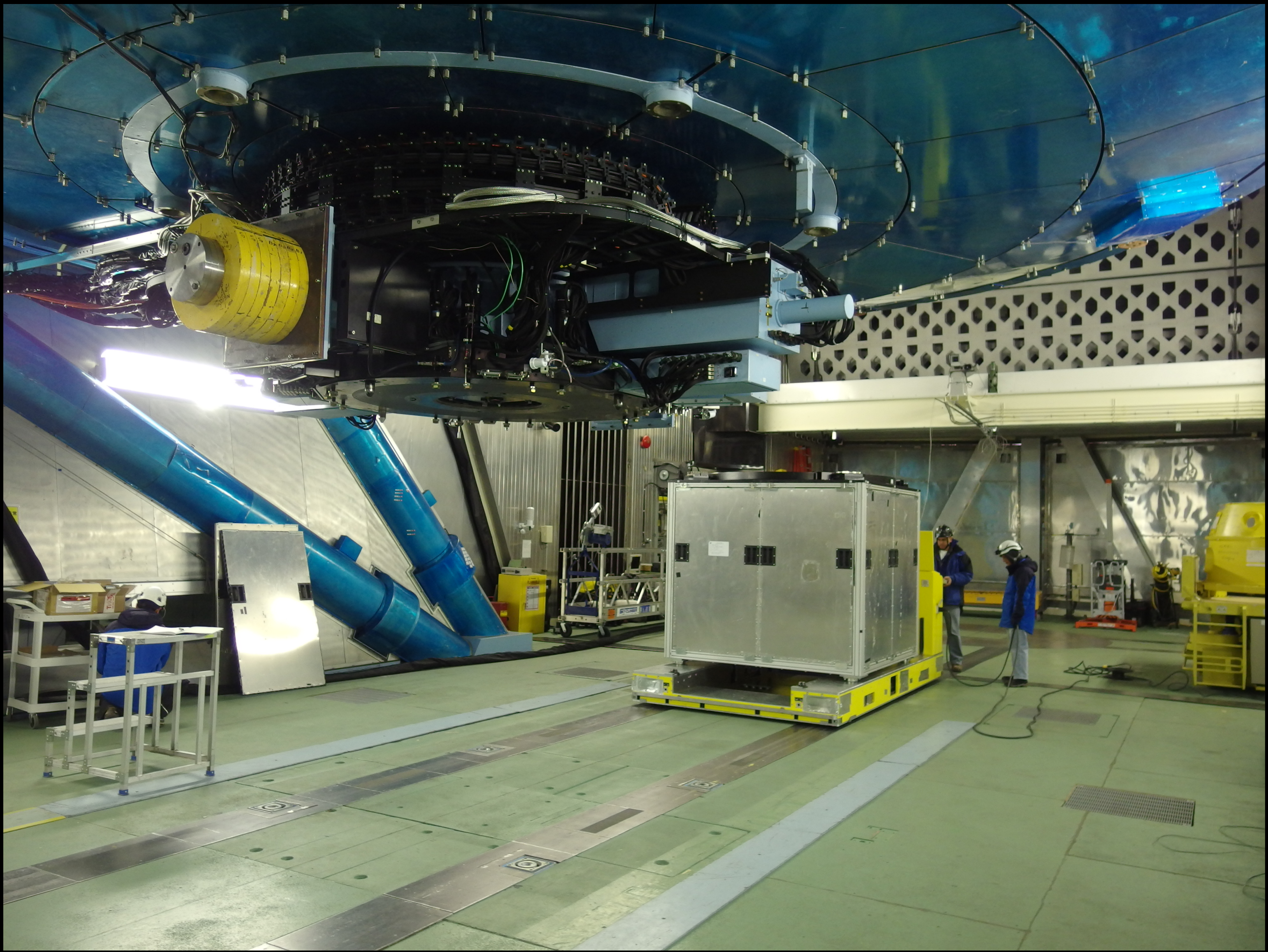
- Comprehensive GLAO simulation is being conducted by ANU to optimize the specification of the ULTIMATE AO system.
- Conservative turbulence profile with more layers below 100m based on the Maunakea seeing campaign data (Chun et al. ****) is used.
- Once the AO specification is optimized with the baseline turbulence profile, statistical data will be obtained by changing the turbulence profile based on the statistics obtained from the campaign data.



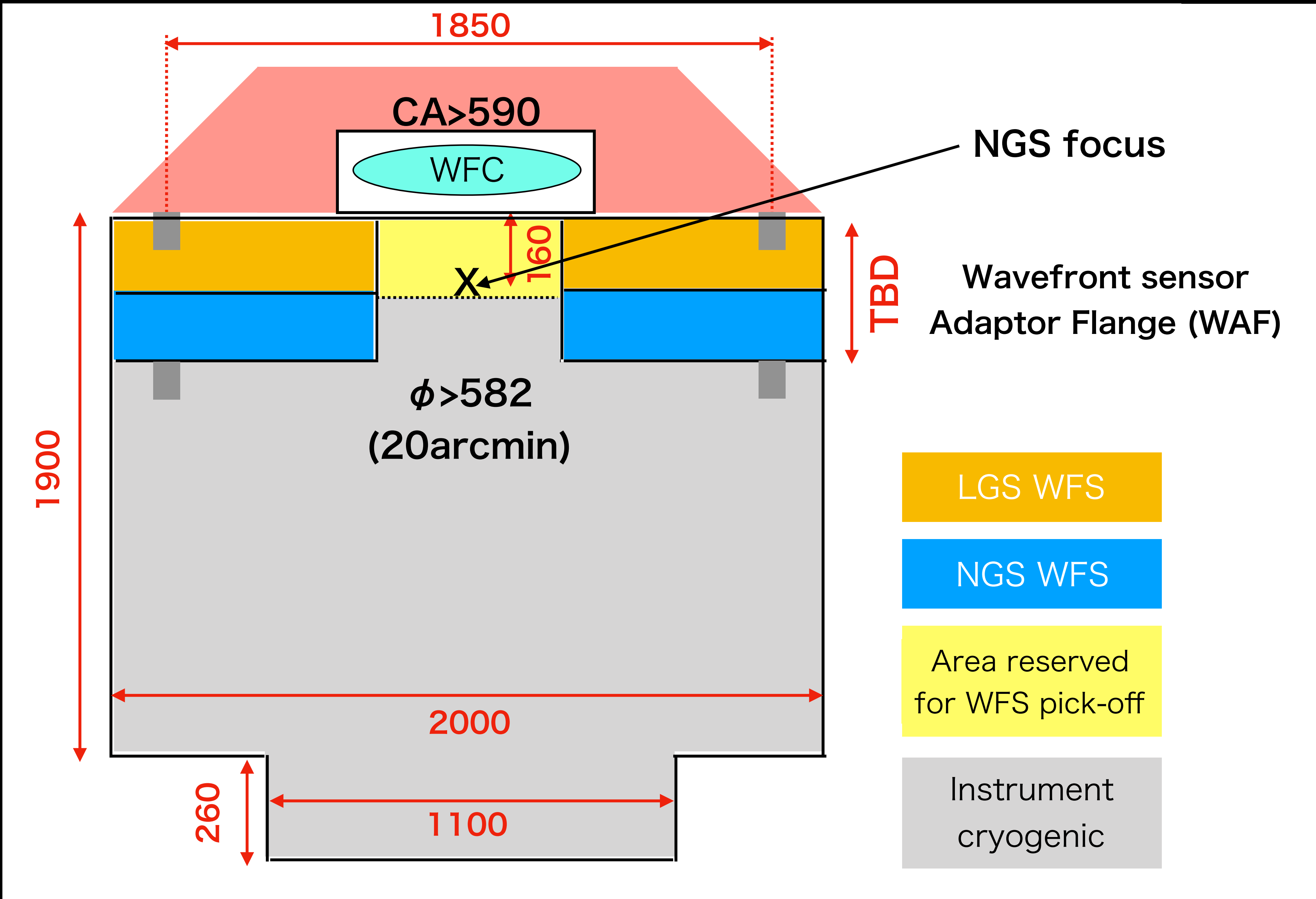
Turbulence profile assumed in the simulation

Visa Korkiakoski's talk for the latest results

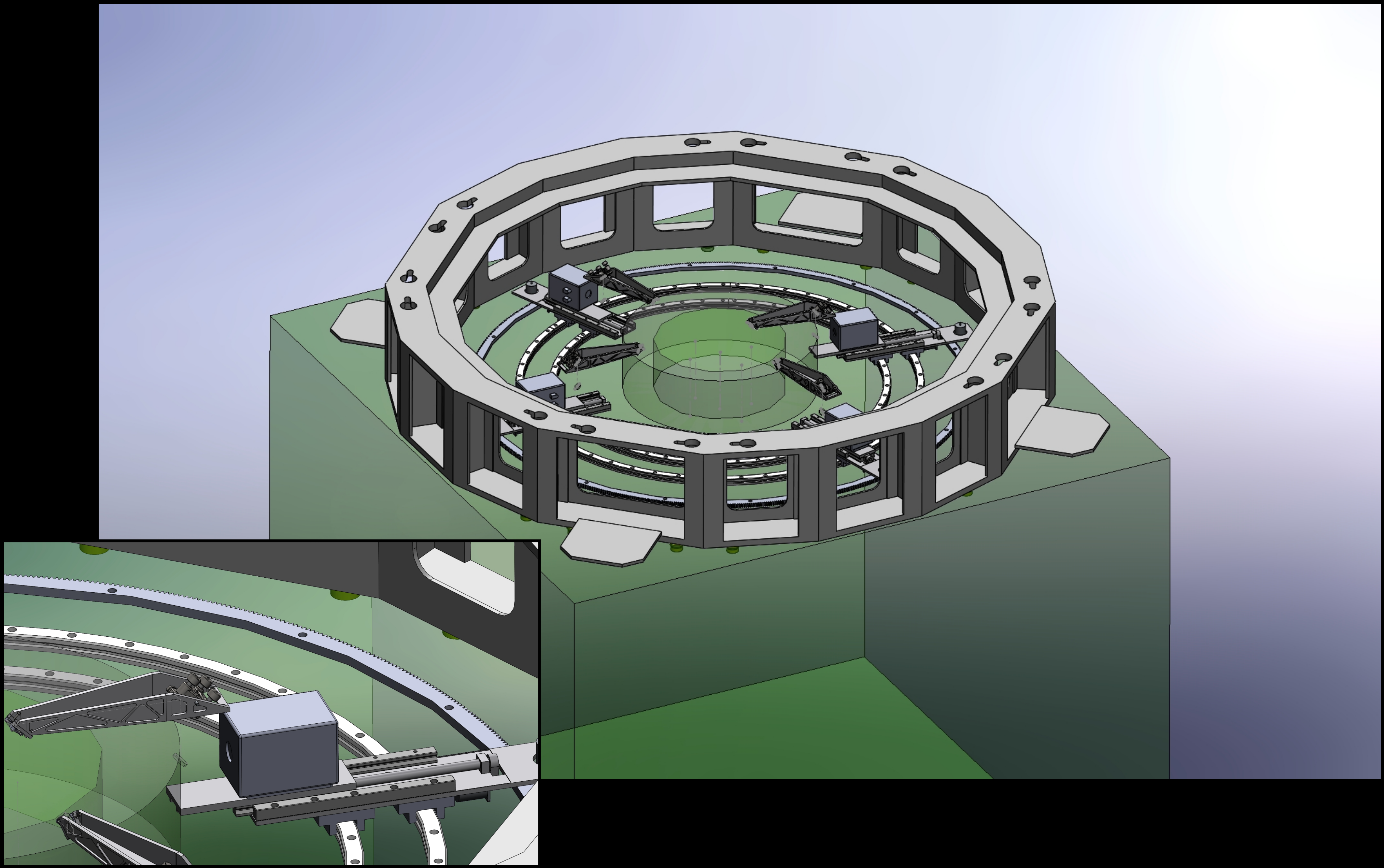
WFS and Instrument layout at Cs



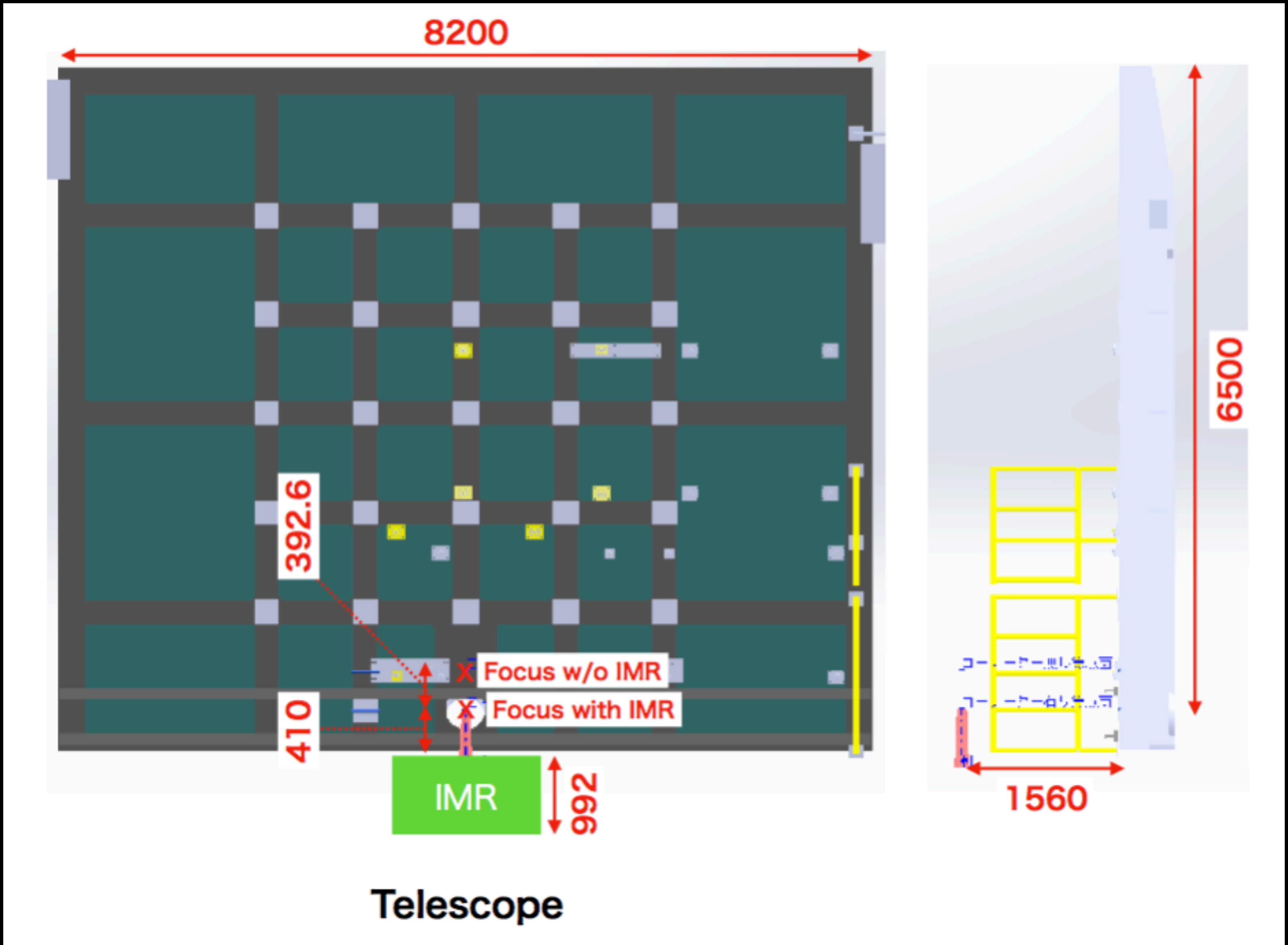
WFS and Instrument layout at Cs



Wavefront sensor Adapter Flange (WAF) conceptual design by ANU

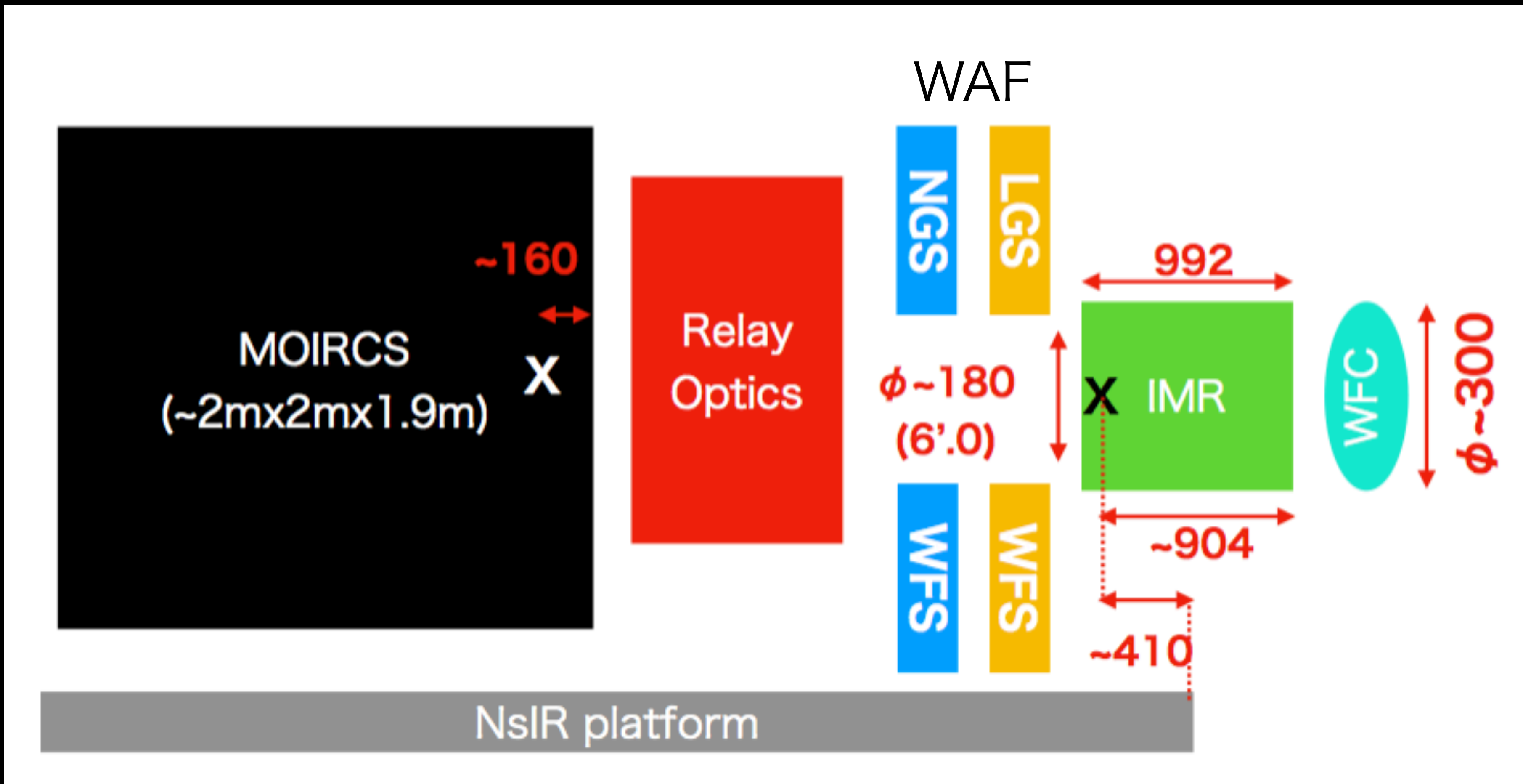


WFS and Instrument layout at NsIR



WFS and Instrument layout at NsIR

Plan A (side view)



Pros

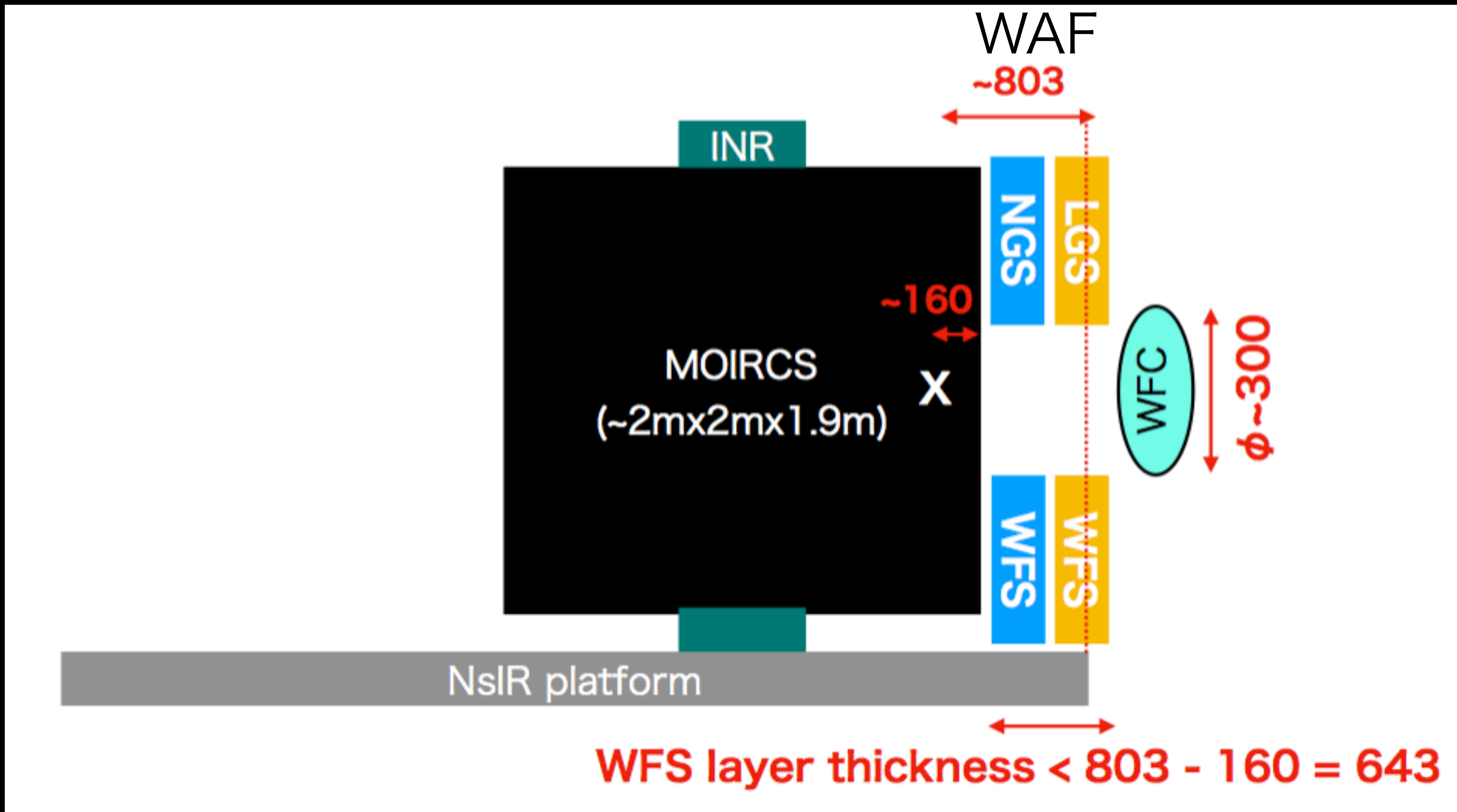
- Gravity-invariant design
- Enough space for the WAF
- The existing IMR can be reused

Cons

- FoV is limited to ϕ~6'
- Additional relay optics is required

WFS and Instrument layout at NsIR

Plan B (side view)



Pros

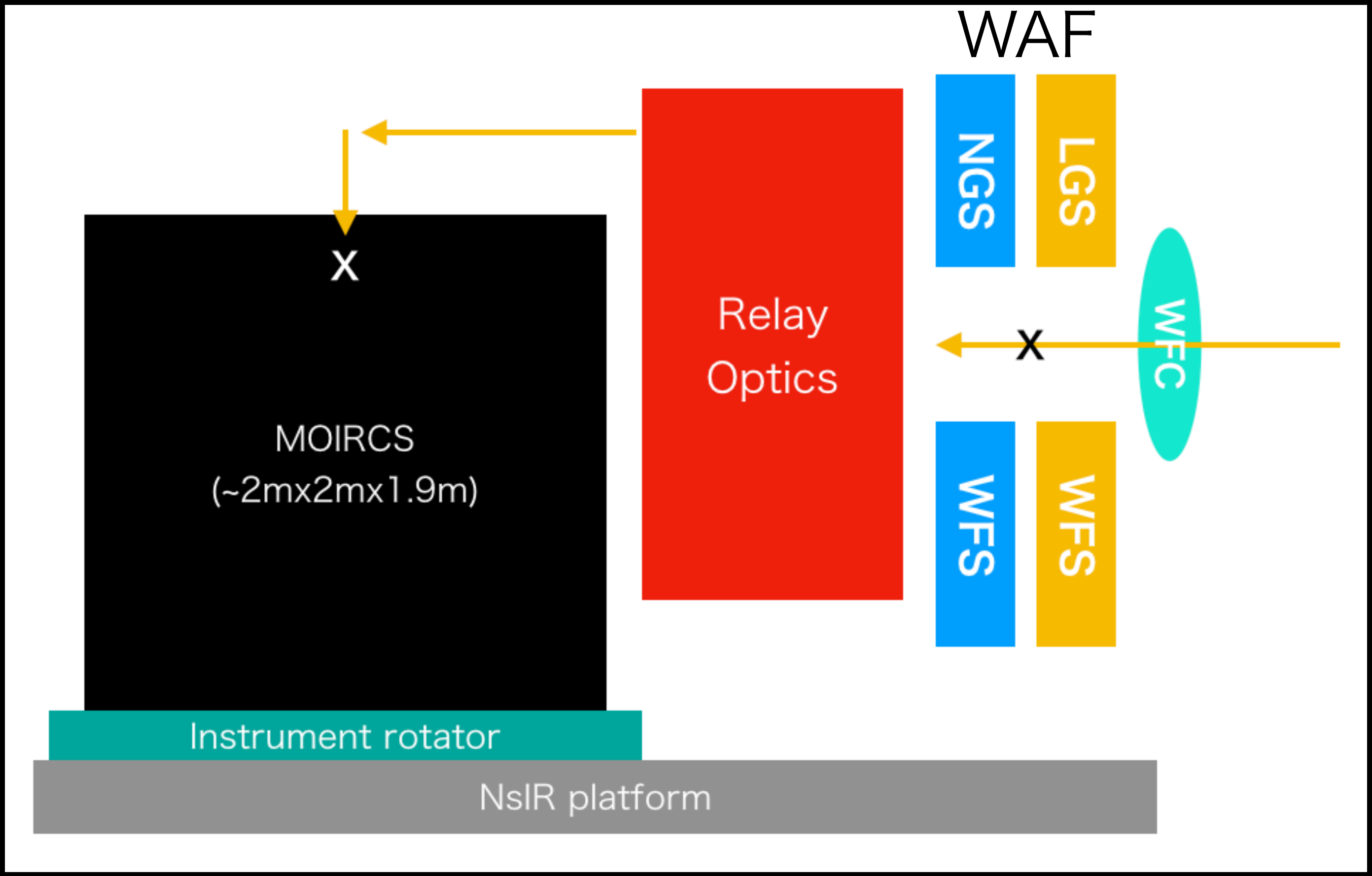
- Maximize the FoV (~14 arcmin)
- Minimize thermal emission

Cons

- Non gravity-invariant design
- Envelope available for the WAF is small

WFS and Instrument layout at NsIR

Plan C (side view)



Pros

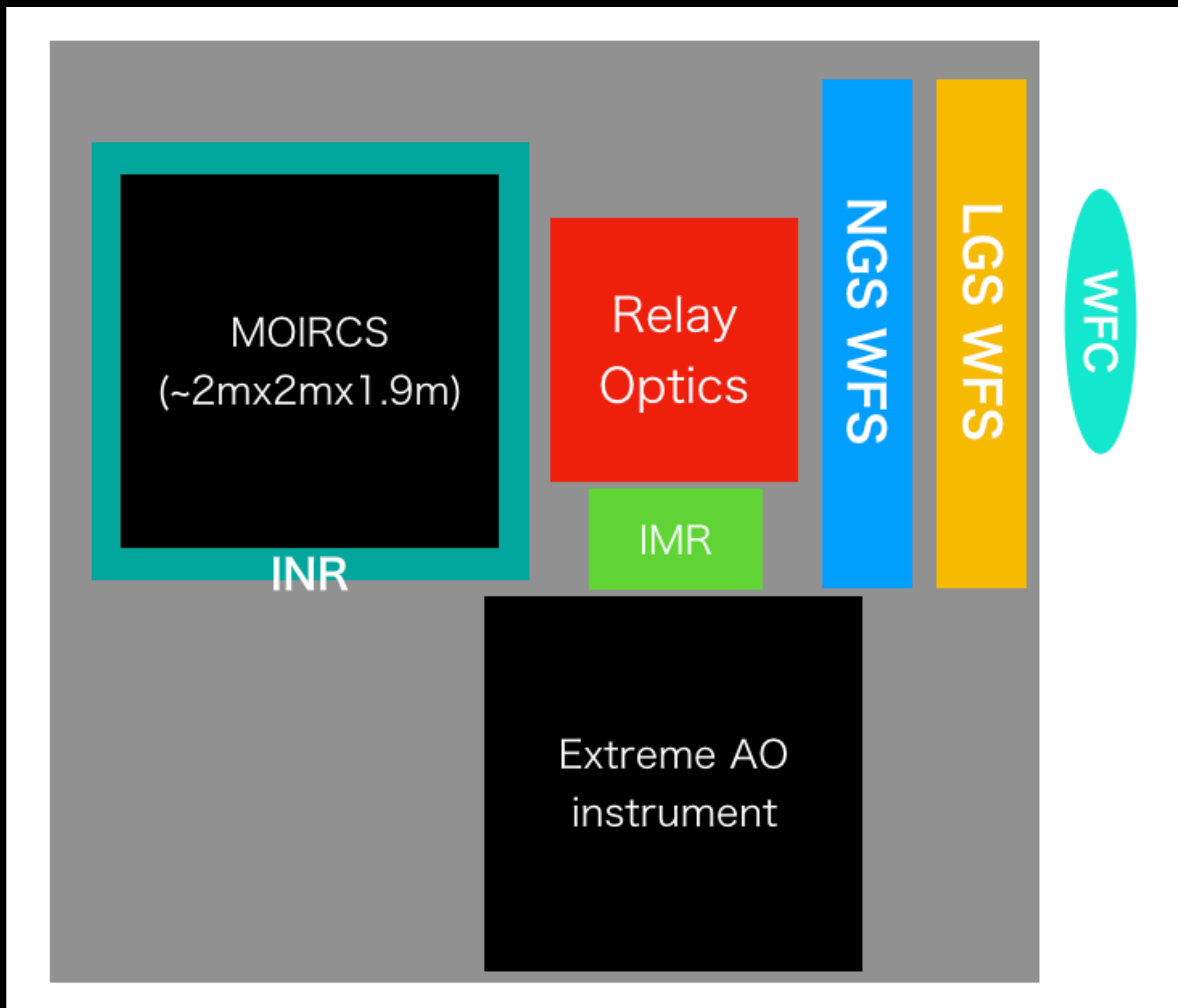
- Maximize the FoV (~14 arcmin)
- Gravity-invariant design
- Enough space for the WAF

Cons

- Relay optics is required

WFS and Instrument layout at NsIR

Plan C (top view)



Pros: NsIR platform can be shared with the extreme AO instrument

Team Organization

ULTIMATE-Subaru working group

PI: Subaru Director

M. Yoshida

Project Manager

Y. Minowa

Project Scientist

Y. Koyama

AO

Y. Minowa, Y. Ono, C. Clergeon, O. Guyon
M. Akiyama (Tohoku), Y. Hayano (ATC)

Instrument

T. Hattori, I. Iwata, I. Tanaka,
K. Motohara (Tokyo)

Science

Y. Koyama, T. Kodama, K. Motohara

International collaboration

GLAO system design
WFS and LGS development

WFI system design and development

M-IFS system design and development

Domestic and International scientists

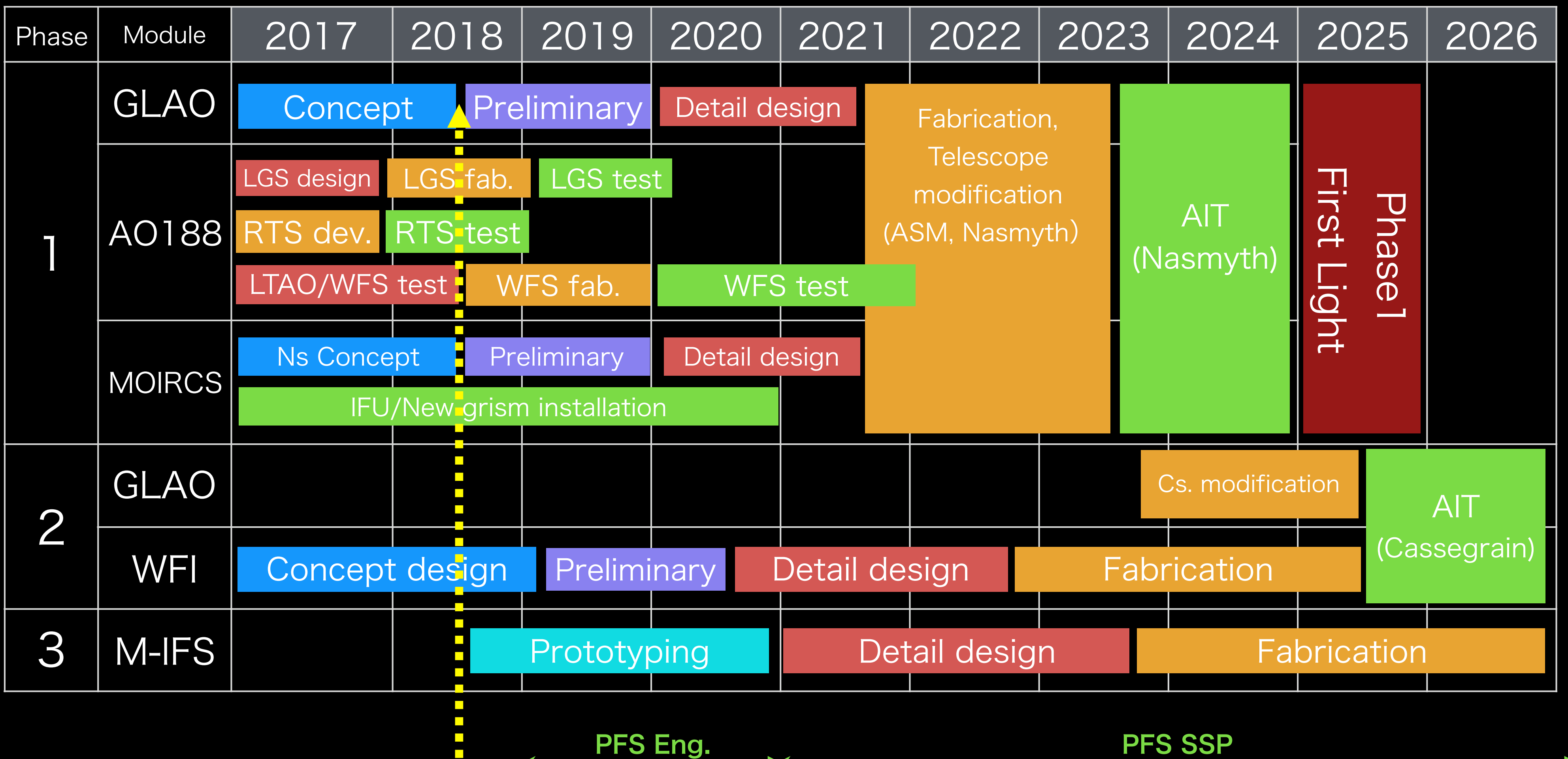
- Develop science case for ULTIMATE
- Summarize scientific requirement for determining the instrument and GLAO specifications.

Cost estimation, Budget Resources

Phase1

Items	Cost (USD)	Budget
(1) ASM&CAL system	$6M	NAOJ operation budget
(2) Laser system	$3M	JSPS Grant-in-aid / International
(3) WFS unit	$2M	JSPS Grant-in-aid / International
(4) Real time system	$0.1M	JSPS Grant-in-aid
(5) Telescope modification	$2M	NAOJ operation budget
(6) MOIRCS upgrade	$0.7M	NAOJ operation budget & JSPS Grant-in-aid
(7) Human resources	$2M	NAOJ operation budget & JSPS Grant-in-aid
(8) Contingency	$1.5M	NAOJ operation budget
Phase1 total	$18M (~ $10M from NAOJ operation budget)	
Phase2: WFI	$16-18M	JSPS Grant-in-aid / External
Phase3: M-IFS	$7M	JSPS Grant-in-aid / External
Total	~$43M	

ULTIMATE-Subaru: Schedule



GLAO CoDR planned in early July, 2018

Summary

- ULTIMATE-Subaru is a Subaru's next generation facility instrument plan after PFS. Science and development team is led by the observatory.
- ULTIMATE-Subaru will develop a ground-layer AO system and wide-field near-infrared imager, which provide ~14x14 arcmin^2 FoV with ~0".2 spatial resolution in K-band.
- Instrument development will be done in phased approach starting from the upgrade of the existing AO system. Science output at each phase is expected.
- AO188 upgrade project to kick-off the ULTIMATE-Subaru (ULTIMATE-START) is funded. LGS and WFS design and fabrication are ongoing.
- Conceptual design of the GLAO is ongoing in collaboration with Australia. CoDR will be at mid-2018
- Expecting involvement from international collaborators for GLAO, wide-field imager (WFI), and multi-IFU spectrograph (M-IFS).
- We will first develop GLAO as an upgrade of telescope capabilities and develop dedicated science instruments (WFI and M-IFS) later, while continuing early science with the existing instrument (MOIRCS). Expected first light of GLAO+MOIRCS is around 2025.