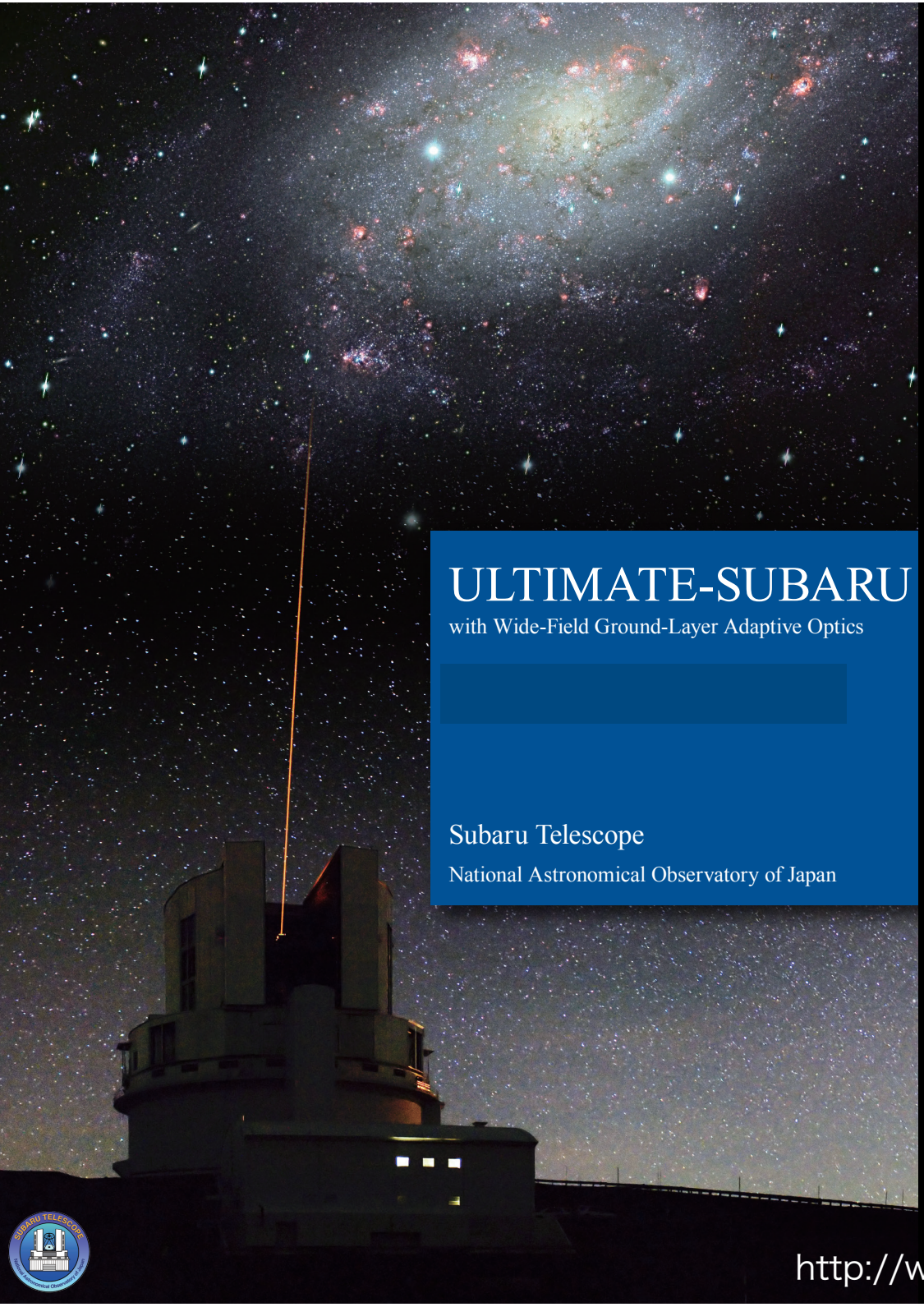


ULTIMATE-Subaru Project Overview

Yosuke Minowa
(Subaru Telescope)

on behalf of

ULTIMATE-Subaru working group

Yusei Koyama, Ikuru Iwata, Takashi Hattori,
Christophe Clergeon, Ichi Tanaka, Naruhisa
Takato, Nobuo Arimoto (Subaru),
Tadayuki Kodama, Yutaka Hayano, Shin Oya,
Hideki Takami (NAOJ),
Masayuki Akiyama, Tatsuhiro Watanabe (Tohoku)
Kentaro Motohara (Univ. of Tokyo)

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

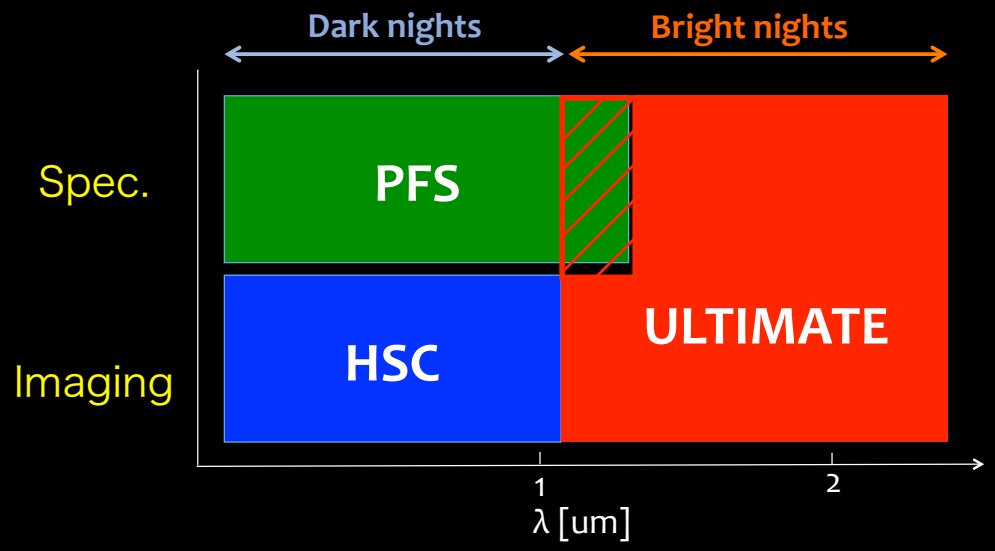
Subaru's Wide-Field Strategy toward 2020s

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

1. Very wide-field optical imager SupCam —> HSC (2013)

2. Wide-field multi-objet spectrograph FOCAS, FMOS —> PFS (2019)

3. Wide-field near-infrared imager and multi-object spectrograph
IRCS, MOIRCS —> ULTIMATE-Subaru (2023)

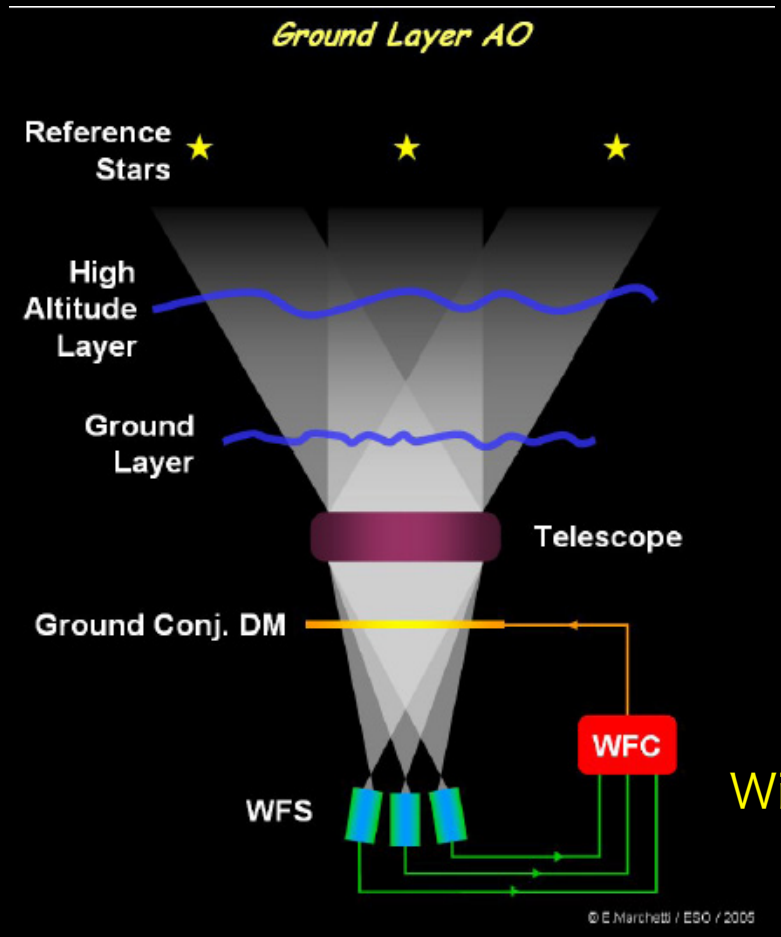


Extend Subaru's survey capability to near-infrared

Subaru's Next Facility Instrument Plan

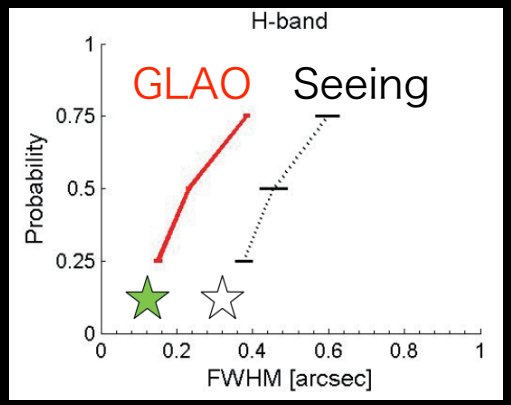
ULTIMATE-Subaru

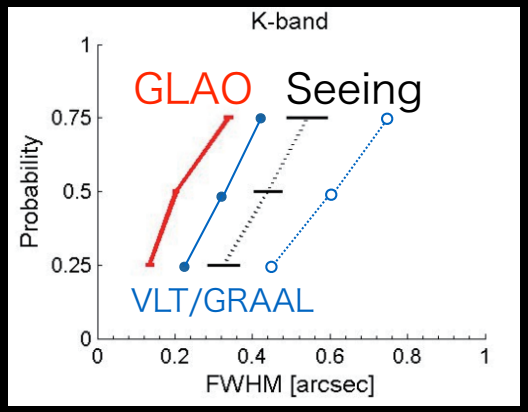
Ground-Layer Adaptive Optics
x
Wide-Field near-infrared instrument



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

GLAO performance simulation at Subaru





☆On-sky performance verification with RAVEN

(Oya et al. 2014)

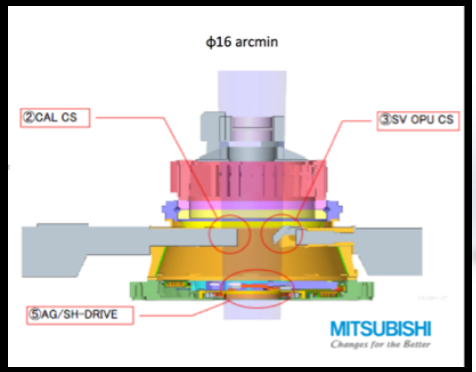
- Uniform seeing improvement over ~20 arcmin FoV
- FWHM < 0".2 at K-band

Wider FoV and better image quality than VLT GLAO

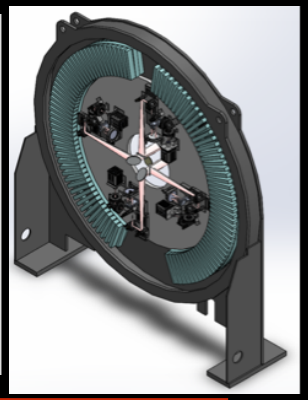
(Seeing 0".6 —> GLAO 0".32 at K, FoV~7'.5)

(3) Wavefront Sensors

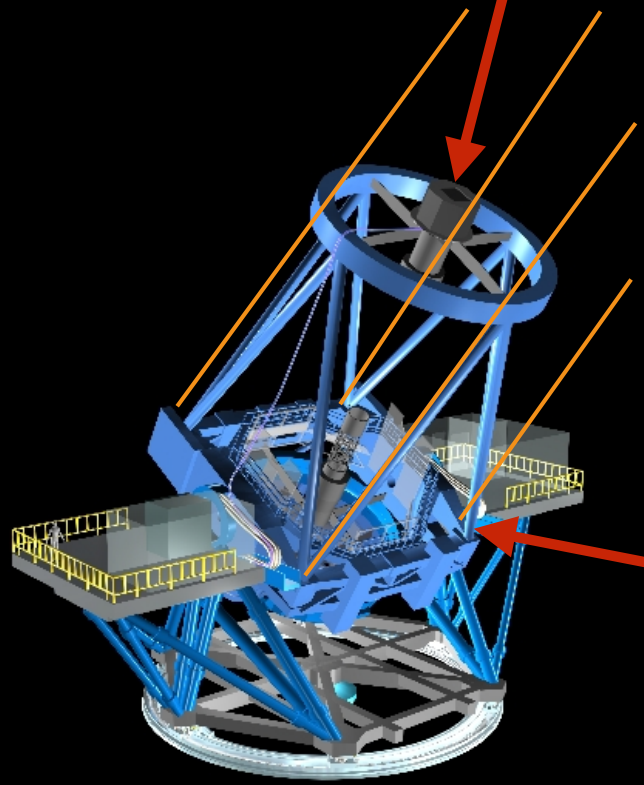
Cs. Focus (FoV~20 arcmin)

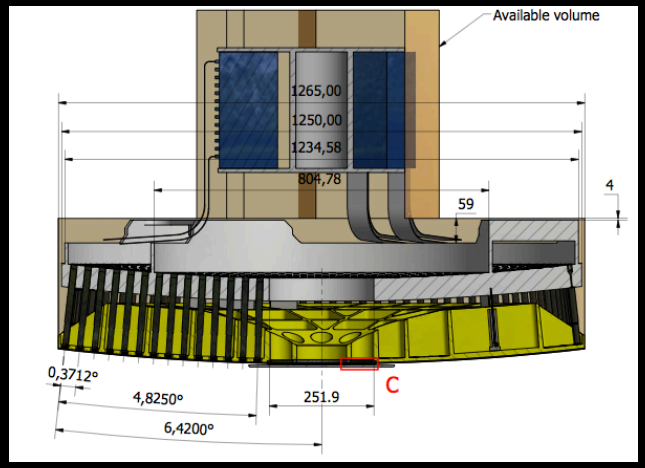


Ns.IR Focus (FoV~6 arcmin)



(1) Adaptive Secondary Mirror





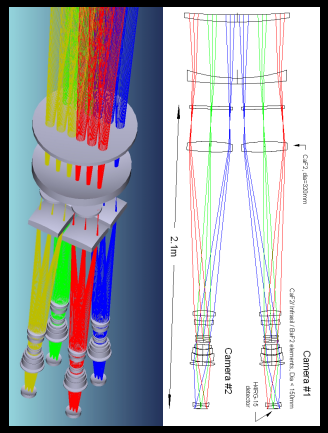
Preliminary Subaru ASM design by Microgate ADS

(2) Laser Guide Star system

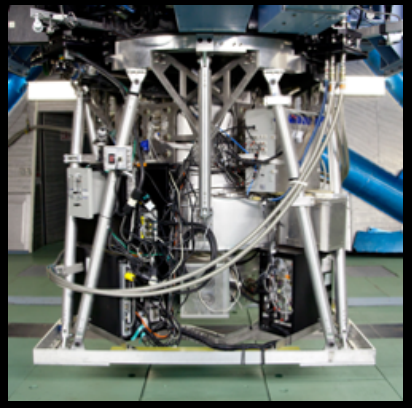
TOPICA fiber laser(589nm) x 2
Generate 4 laser guide stars

(4) Wide-field NIR instruments

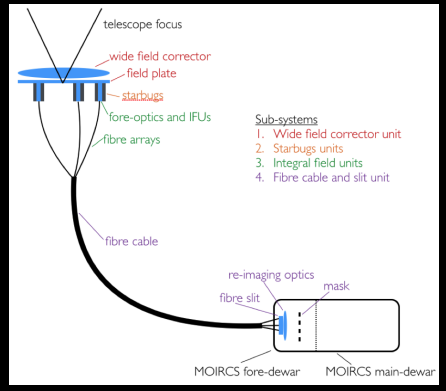
- Wide-field imager (WFI) at Cs.
- Reuse MOIRCS at Ns. IR
- Fiber-bundle multi-IFU at Cs. proposed by AAO, Australia



Imager concept

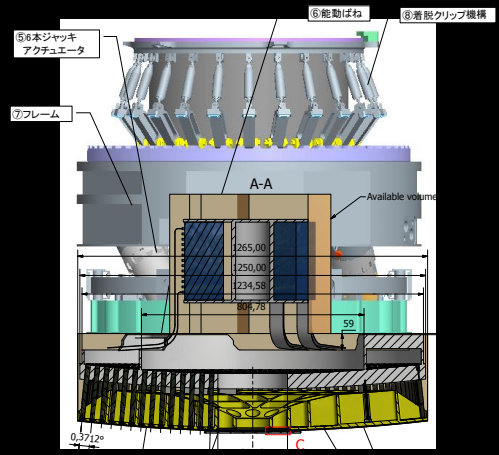


MOIRCS



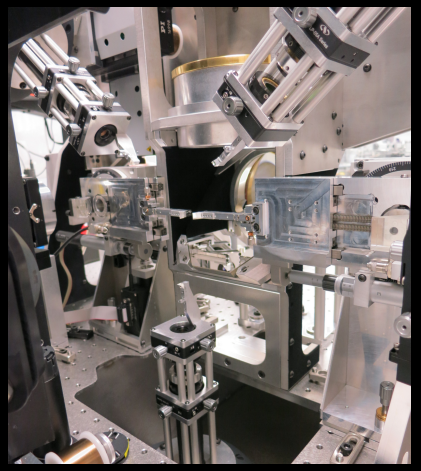
Multi-IFU concept

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)
  - Keck, Gemini, Subaru are collaborating for commissioning and maintaining the TOPTICA laser
  - ANU and Subaru will collaborate on the development of the laser relay optics.

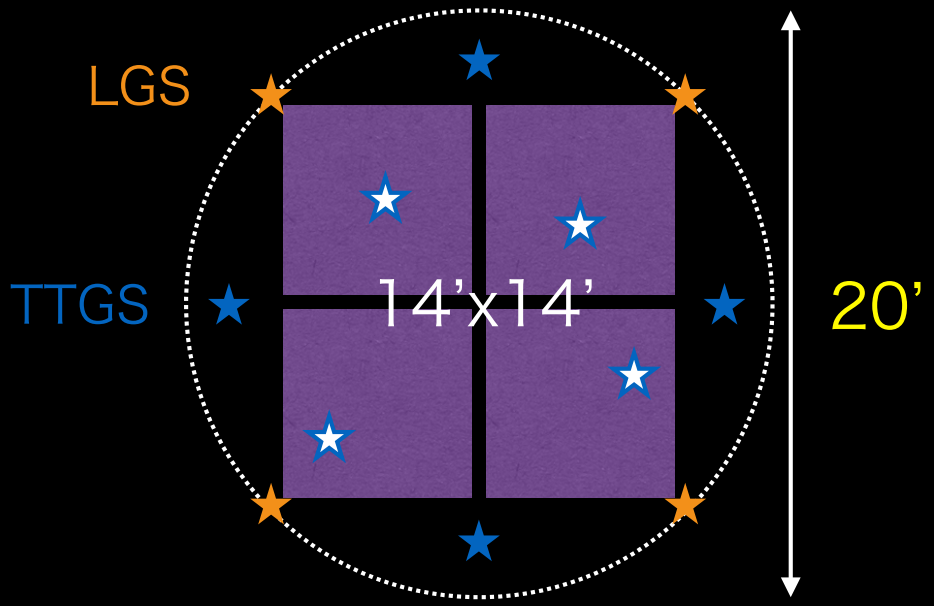


- (3) Wide-field (Tomographic) Wavefront sensing
  - Make use of the previous experiences from the GLAO precursors at MaunaKea
    - RAVEN/Subaru (2014-2015): MOAO science demonstrators, GLAO performance at Subaru was demonstrated to be FWHM~0″.2 at H-band. GLAO path-finder at Maunakea!!
    - Imaka/UH88 (2016-): GLAO performance at wide FoV (12′ x 12′) .
    - Comprehensive simulation works are ongoing to confirm the wavefront sensing technique and expected performance in collaboration with ANU and Tohoku Univ.
  - On-sky test with the WFS prototype for testing the wide-field wavefront reconstruction is being planned by Tohoku Univ.

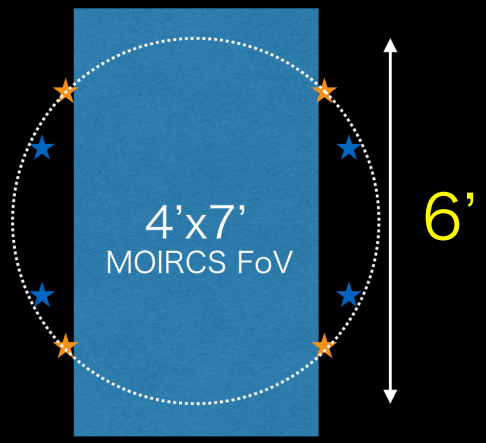
ULTIMATE-GLAO: Baseline Specification

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)

Cassegrain Focus

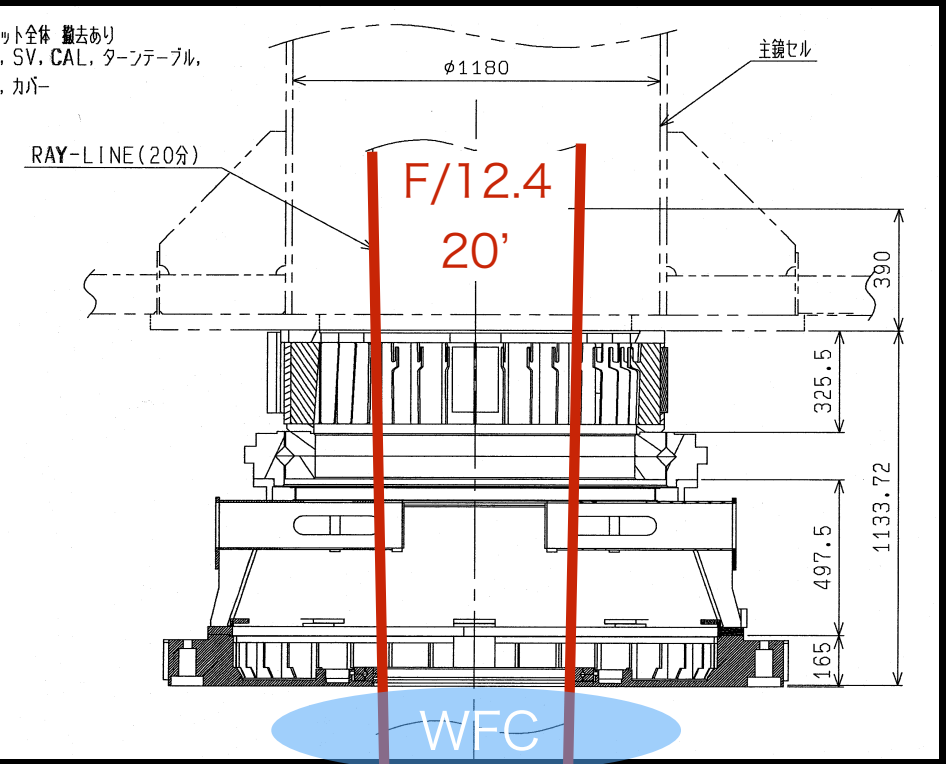


Nasmyth Focus



WFS and Instrument configuration

Cassegrain Focus

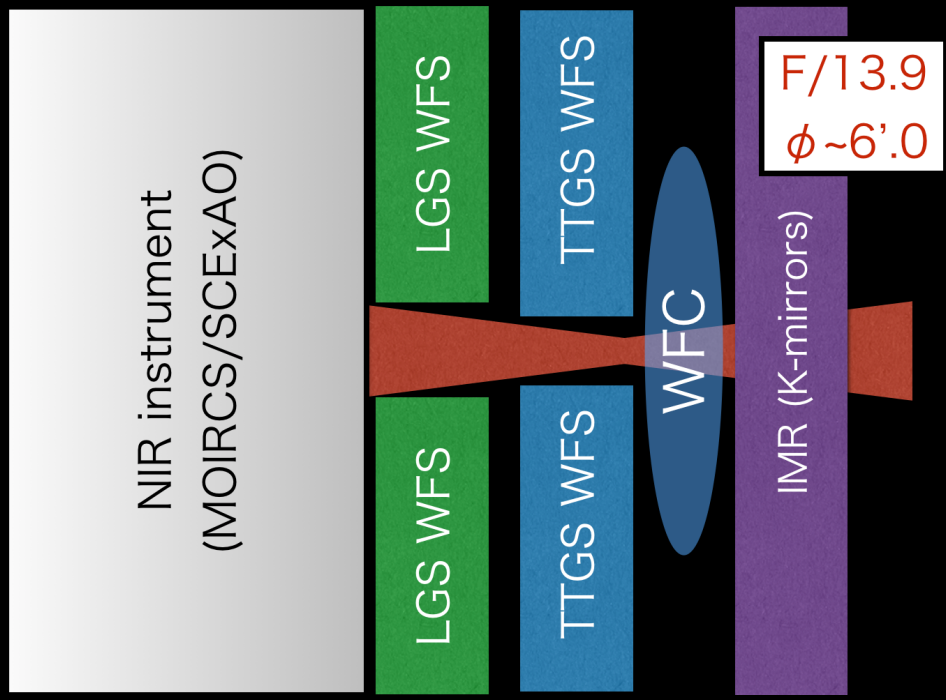


TTGS | WFS | Cs. focus

LGS | WFS

Imager
or
Fiber positioner for IFS

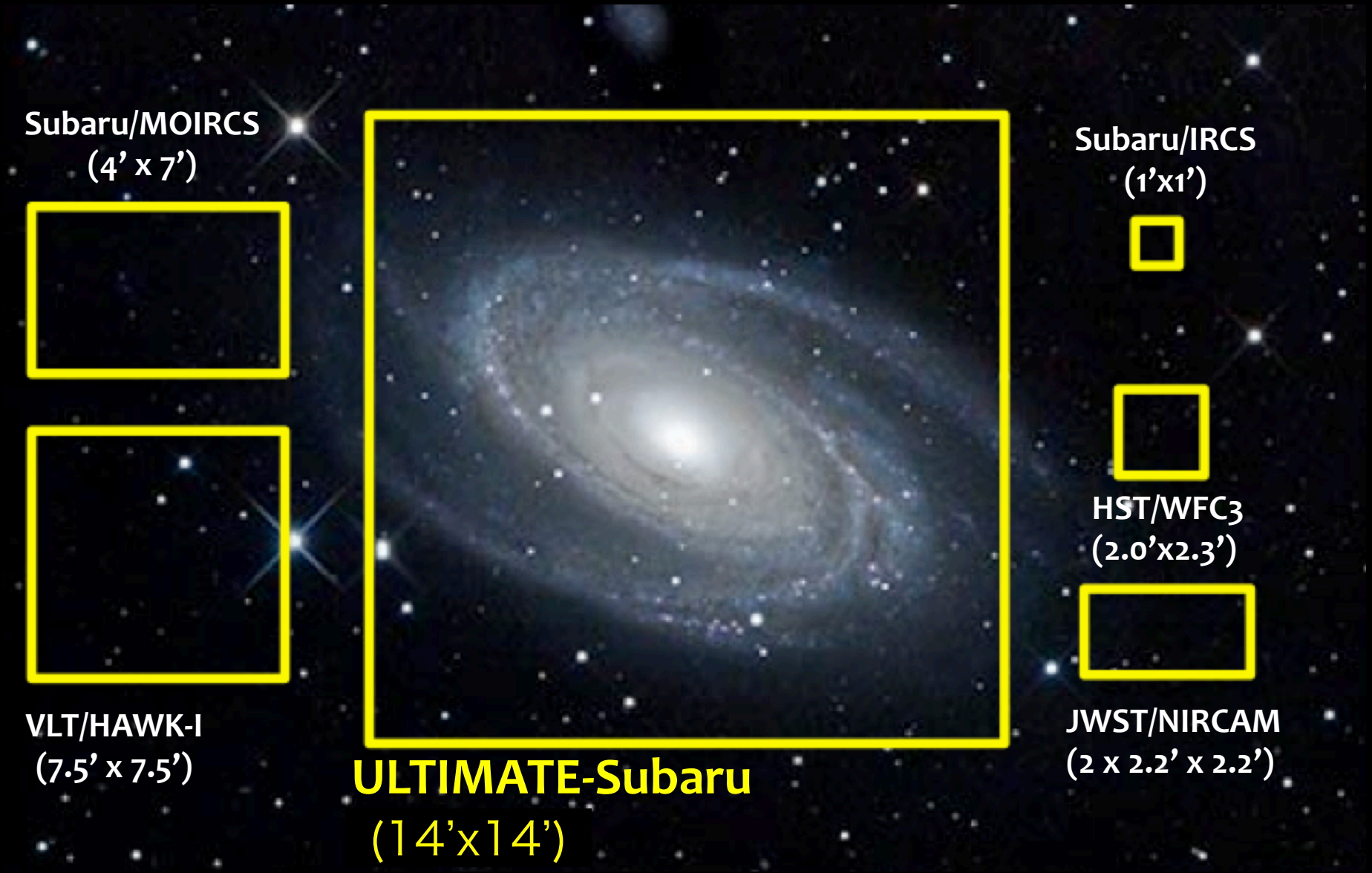
Nasmyth Focus



Nasmyth Platform

ULTIMATE-WFI: Uniqueness

Widest FoV among NIR facilities in 2020s available at $\lambda > 2.0\,\mu$m



Comparison with TMT/Space telescope in 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>Surveys</td><td>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></td><td></td><td>PFS
R~3000</td><td></td></tr>
</table>

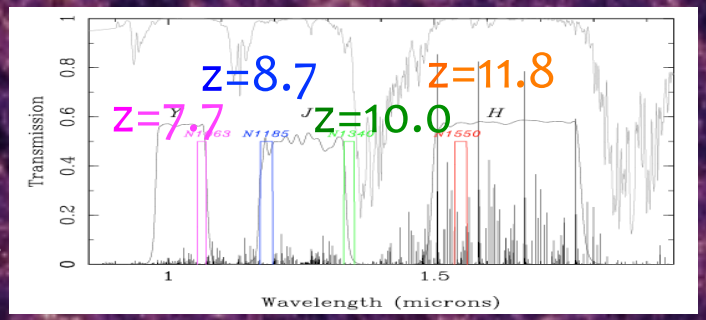
Slide courtesy of Y. Matsuoka

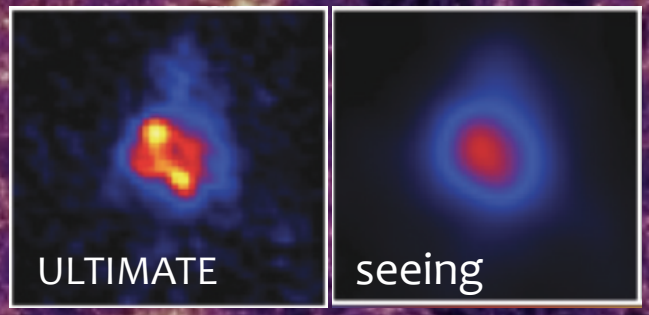
Key science : Evolution of the Universe

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

1. First galaxies (birth)

- Unprecedentedly deep NB imaging to detect galaxies a "cosmic dawn" (z>>7).
- Go beyond the depths of JWST.
- Extension of HSC optica NB survey



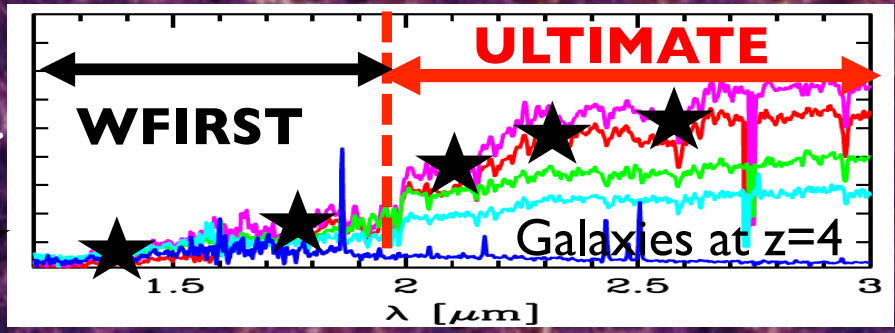


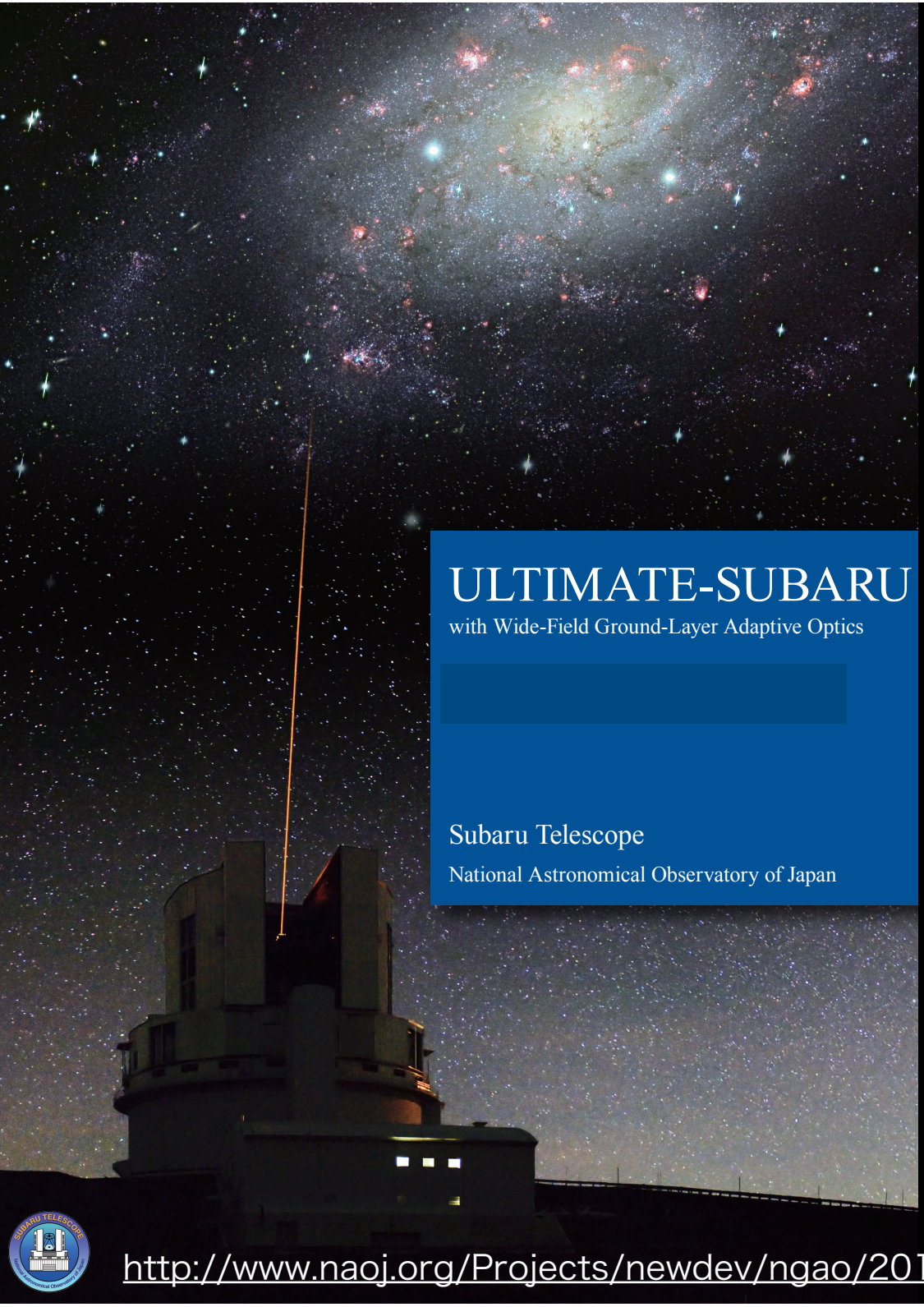
2. Stellar build-up (life)

- 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.





ULTIMATE-Subaru Study Report 2016

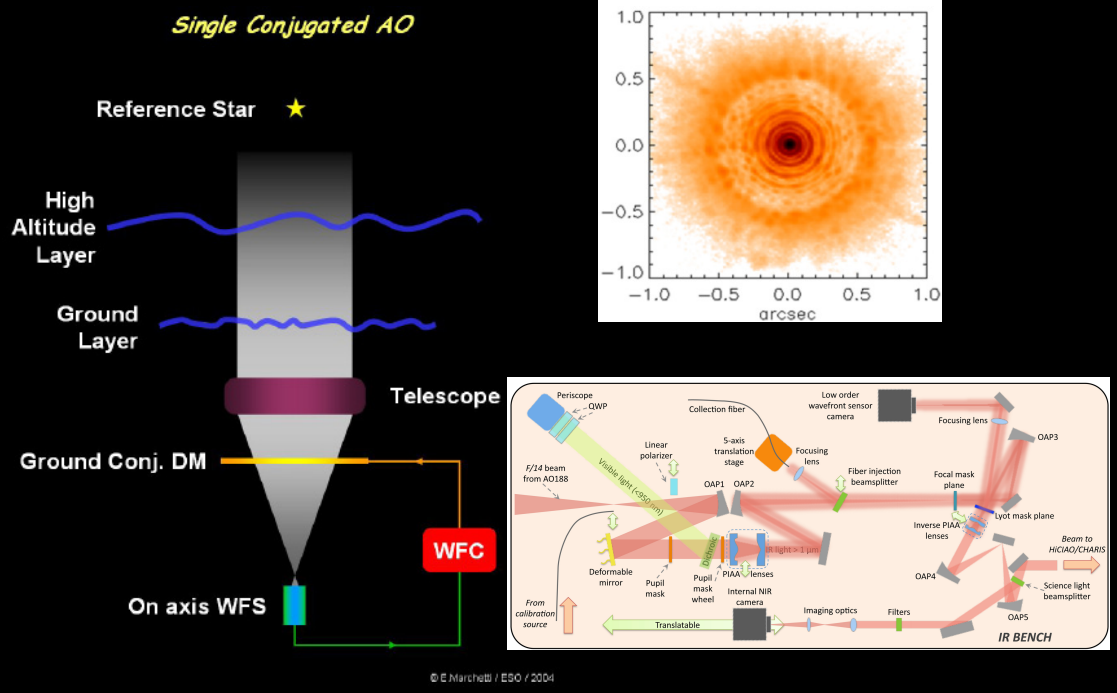
- Science Case
  - High-z galaxies **(Key Science)**
  - Low-z galaxies
  - Galactic
- Adaptive Optics
  - Performance modeling
  - System modeling
  - Interface with telescope
- Instruments
  - Wide-Field imager
  - Multi-Object Slit spectrograph
  - Multi-Object IFU spectrograph
- Development Plan
  - Team organization
  - Budget
  - Timeline

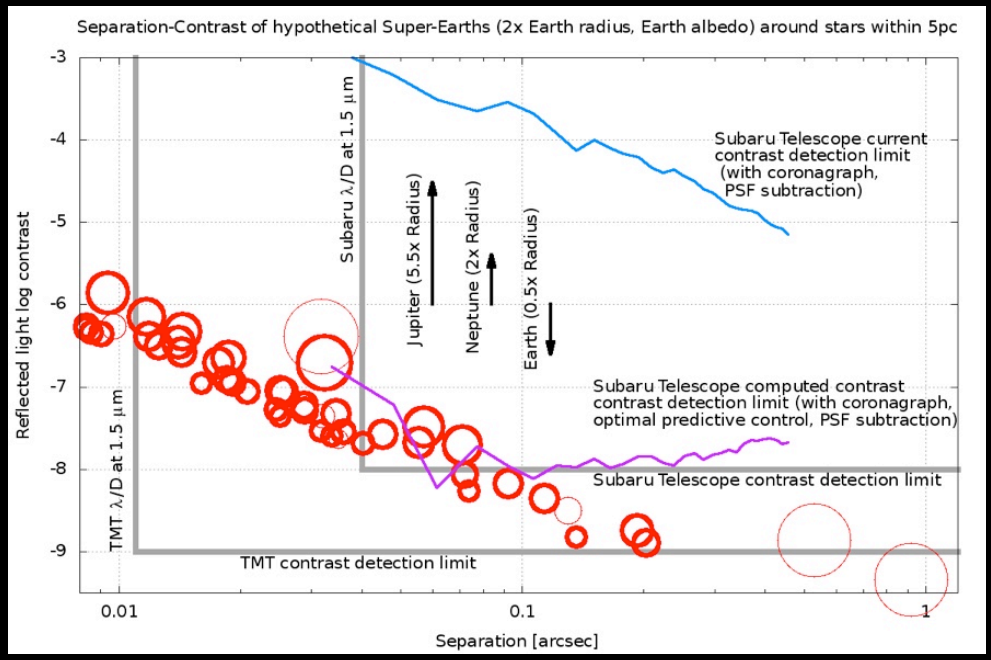
http://www.naoj.org/Projects/newdev/ngao/20160113/ULTIMATE-SUBARU_SR20160113.pdf

Other capabilities of ULTIMATE

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

Extreme AO
x
High-contrast instrument





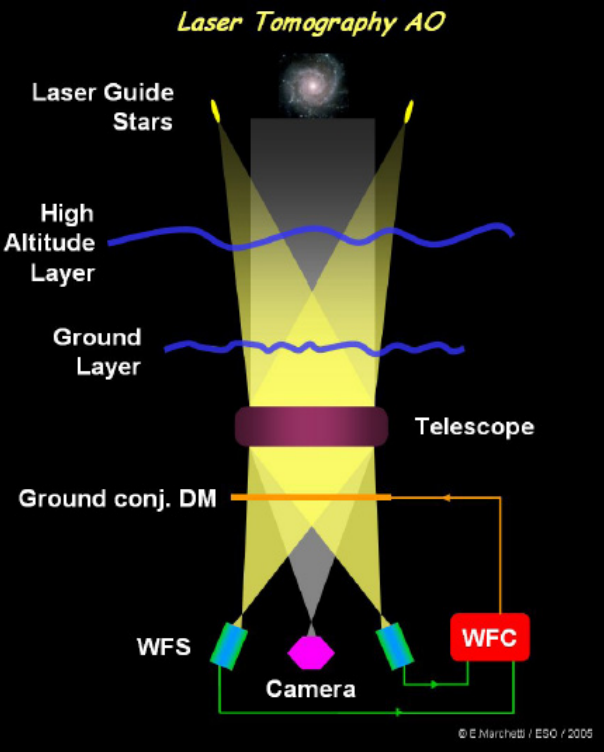
Detectability of Habitable Super-Earth around nearby low-mass stars(Guyon 2016)

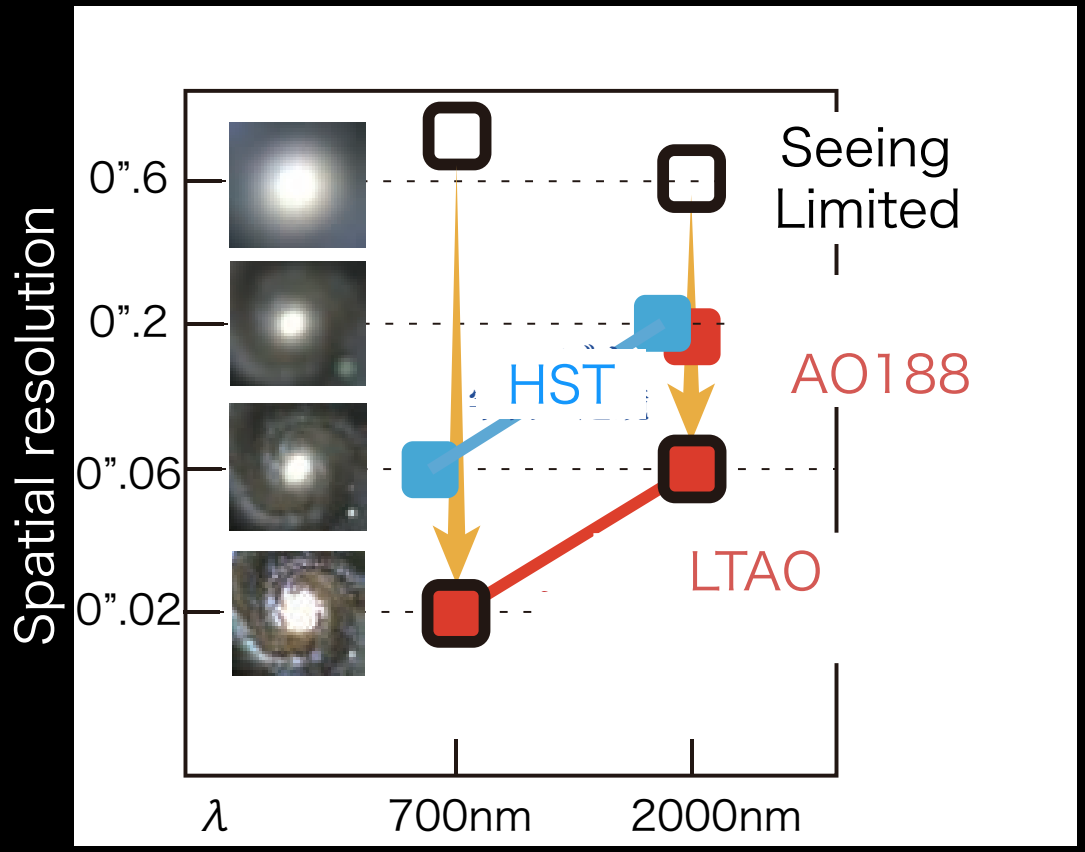
ASM (~1000 actuators)+SCExAO will provide superb Strehl ratio from visible to mid-infrared.

Other capabilities of ULTIMATE

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

Laser-tomographic AO
x
Visible instrument



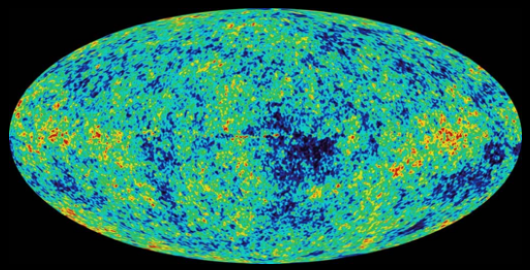


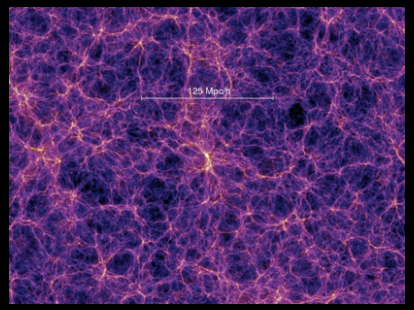
(Akiyama 2016)

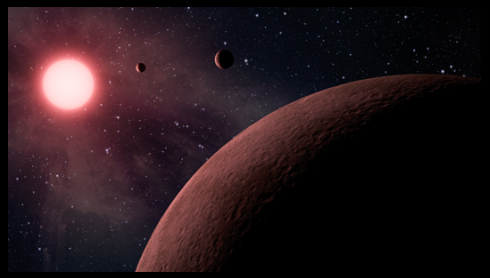
High-resolution visible observation with HDS or FOCAS at Nasmyth platform is possible with LTAO at 8-m class telescope, especially for extragalactic objects.

Subaru's Science in 2020

3 Fundamental Questions in Astronomy







Origin of the Universe → Evolution of the Universe → Origin of Life

Subaru will answer these questions using HSC, PFS, and ULTIMATE

HSC/PFS

ULTIMATE

GLAO/LTAO

ExAO

ULTIMATE development prioritization

Optimize the system for GLAO

A. GLAO at Cs focus (for WFI and M-IFS)
- First light will be done with MOIRCS at Cs.
- Commission WFI first, then M-IFS.

B. GLAO at NsIR focus (for

- MOIRCS as a first light instrument or new MOS spectrograph like Keck/MOSFIRE

C. LTAO at Nasmyth focus

- Visible instruments at Ns focus (HDS, FOCAS, K3DII)

D. ExAO at Ns focus (as a woofer for SCExAO or thermal IR instrument)

Team Organization

PI: Subaru Director

Project Manager
Y. Minowa

Project Scientist
Y. Koyama

AO Scientist
Y. Minowa, C. Clergeon, Y. Hayano
(hiring a new assistant professor)
M. Akiyama (Tohoku)

Instrument Scientist
T. Hattori, I. Ikuru, I. Tanaka, Y. Minowa,
M. Akiyama (Tohoku), K. Motohara (Tokyo)

Science working group
Y. Koyama, T. Kodama,
Extrernal contributors

External collaboration
on AO development

External collaboration
on Instrument development

External collaboration
on Science

Cost estimation, Budget Resources

Items	Cost (USD)	Budget
(1) ASM system	$6M	NAOJ operation budget as a part of Telescope upgrade
(2) Laser system	$1-4M	JSPS Grant-in-aid (Partly purchased by NAOJ budget for AO188)
(3) WFS unit	$3.5M	JSPS Grant-in-aid
(4) Real time system	$0.2M	JSPS Grant-in-aid
(5) Telescope modification	$10M	NAOJ operation budget as a part of Telescope upgrade
(6) NIR instruments	$5-15M	JSPS grant-in-aid & International collaboration
(7) Human resources	$2M	NAOJ operation & JSPS Grant-in-aid
(8) Contingency	$5M	NAOJ operation budget
Total	$40-50M	

(2), (3), (4): Applying for JSPS Grant-in-Aid (Innovative Areas and Category S)
(3), (6): Expecting the contributions from International partners

Phased approach to realize ULTIMATE

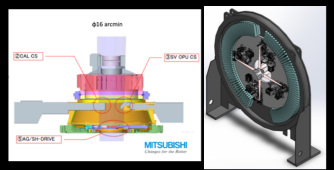
	Prototyping Existing instrument upgrade	GLAO	Instrument
~FY2017	· RAVEN (MOAO/GLAO pathfinder) · MOIRCS detector upgrade	· Preliminary performance simulation	· M-IFS conceptual design
FY2017	· AO188 RTS upgrade development · 1st Fiber Laser procurement · Multi-WFS prototype development · MOIRCS new grism development · FOCAS IFU commissioning (?)	· Comprehensive GLAO simulation to optimize the specification · WFS conceptual design · ASM feasibility study · LGS relay system design	· WFI conceptual design · WFC conceptual design · MOIRCS performance model at NsIR · M-IFS prototype development
FY2018	· 1st fiber laser commissioning · 2nd fiber laser procurement · AO188 new RTS commissioning	GLAO and WFI CoDR · WFS preliminary design · ASM feasibility study · IRM2 modification plan · Calibration system design	· WFI preliminary design · M-IFS prototype on-sky test
FY2019	· AO188 WFS upgrade (EMCCD) · Multi-WFS prototype on-sky test · MOIRCS new grism commissioning(?)	· LTAO/ExAO performance model GLAO and WFI PDR	
FY2020	NAOJ investment for PFS end · AO188 EMCCD commissioning · AO188 upgrade (IR pyWFS)	· GLAO sub-system detailed design GLAO, WFI, and M-IFS FDR	· WFI detail design · M-IFS detail design
FY2021	· AO188 IR pyWFS commissioning	· ASM fabrication · WFS system fabrication · CAL system fabrication	· WFI fabrication · M-IFS fabrication
FY2022	· Cassegrain instrument decommission	· Integrate LGS and RTS · IRM2, telescope modification	
FY2023		· GLAO AIT with MOIRCS	· Move MOIRCS to NsIR
FY2024			· WFI, M-IFS AIT
FY2025		GLAO Science Observation	

ULTIMATE-Subaru: international collaboration

(3) Wavefront Sensors

Cs. Focus (FoV~20 arcmin)

Ns.IR Focus (FoV~6 arcmin)



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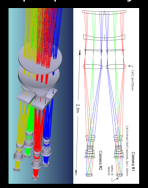
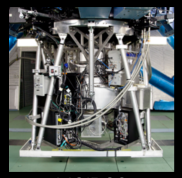
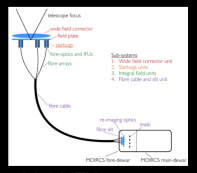


Imager concept

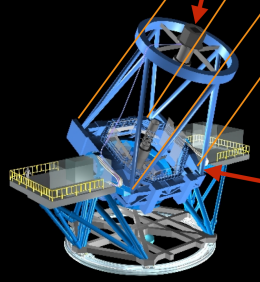


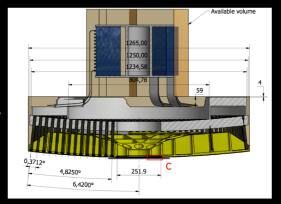
MOIRCS



Multi-IFU concept

(1) Adaptive Secondary Mirror





Preliminary Subaru ASM design by Microgate ADS

(2) Laser Guide Star system

TOPICA fiber laser(589nm) x 2

Generate 4 laser guide stars

(1) ASM

- Subaru is going to develop ASM with Adoptica and Mitsubishi.
- Feasibility study by Adoptica will start soon.

(2) Laser

- Subaru, Keck, and Gemini are going to have MOU for operating and maintaining the TOPTICA fiber laser system
- Subaru and ANU (F. Rigaut, C. D'Orgeville) will collaborate on the development of the laser steering system

(3) WFS

- Subaru, ANU (F. Rigaut), and Tohoku (M. Akiyama) are starting the comprehensive simulation work to optimize the GLAO specifications.
- Maunakea site data will be provided from UH (M. Chun).
- WFS concept design will be done by ANU, Tohoku, and Subaru.
- WFS prototype development for tomography demonstration by Tohoku.

(4) Instruments

- M-IFS conceptual study done by AAO (A. Sheinis, S. Ellis)
- WFI conceptual optical design done by HIA (J. Pazder)

Any interest from EAO members?

ULTIMATE-Subaru: Summary

- ULTIMATE-Subaru is a Subaru's next generation facility instrument plan after PFS.
- 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.
- Conceptual design of the GLAO and imager is ongoing in collaboration with Australia, will be reviewed at the end of 2017. Expected first light of GLAO is early 2020s.
- ULTIMATE main science is a wide-field survey for galaxy evolution with GLAO, but it will also provide ExAO and LTAO modes, which allow broader science cases.
- Not only high-z science, we are collecting various science cases such as local star-forming region, galactic archaeology, near-by galaxies, and exoplanets.