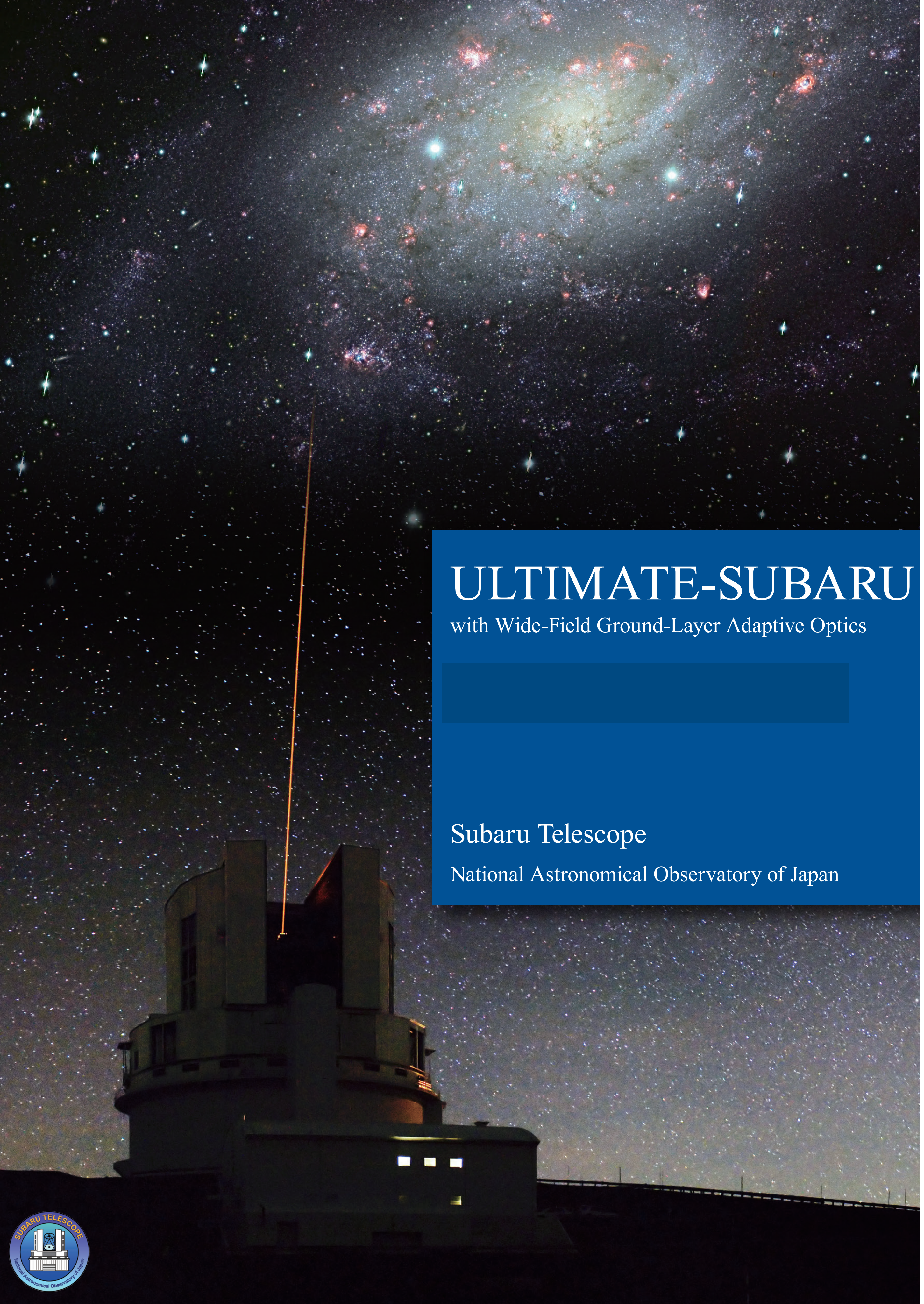


ULTIMATE-Subaru: Project Overview

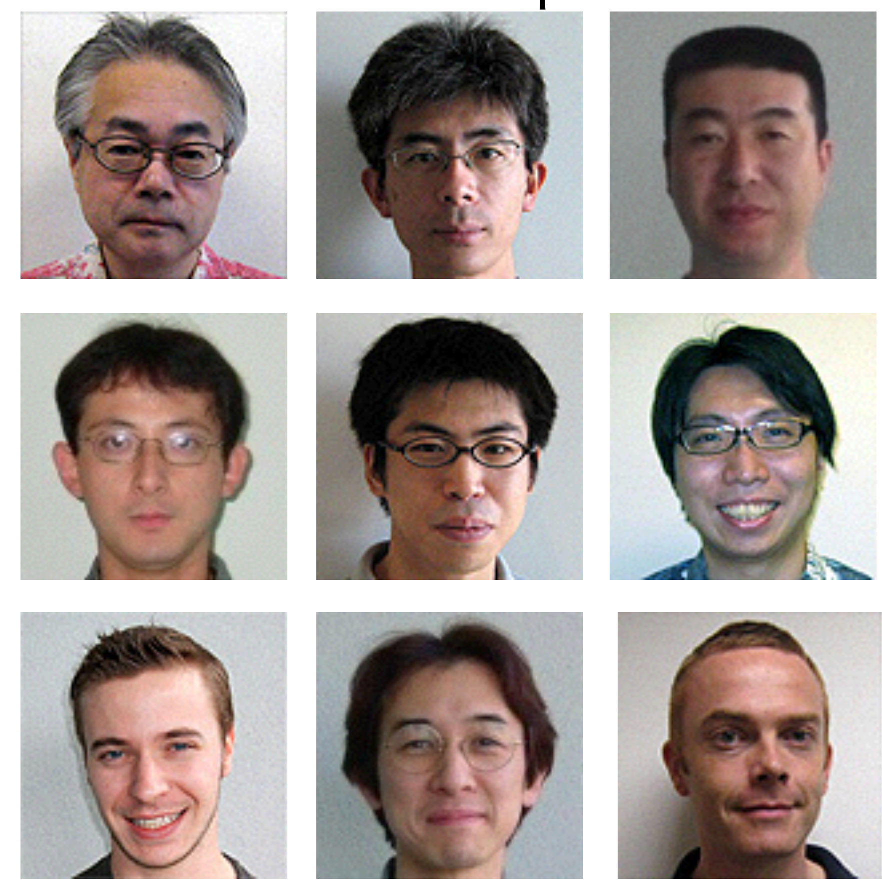
Yosuke Minowa
Subaru Next-Gen. AO working group

ULTIMATE-Subaru Science WS
2016/6/16-17 at Mitaka

ULTIMATE-Subaru working group

Masayuki Akiyama	Tohoku University
Nobuo Arimoto	Subaru Telescope
Christophe Clergeon	Subaru Telescope
Maximillian Fabricius	Subaru Telescope
Takashi Hattori	Subaru Telescope
Yutaka Hayano	National Astronomical Observatory of Japan
Ikuru Iwata	Subaru Telescope
Tadayuki Kodama	National Astronomical Observatory of Japan
Yusei Koyama	Subaru Telescope
Olivier Lai	Subaru Telescope
Yosuke Minowa	Subaru Telescope
Kentaro Motohara	University of Tokyo
Yoshito Ohno	Tohoku University ⟶ LAM
Shin Oya	National Astronomical Observatory of Japan
Hideki Takami	National Astronomical Observatory of Japan
Naruhisa Takato	Subaru Telescope
Ichi Tanaka	Subaru Telescope

Subaru Telescope



LAM

Tohoku Univ.

Univ. of Tokyo

NAOJ, Mitaka

Request from the community

- Recommendation from Subaru Science Advisory Committee (SAC, representative of the Subaru's community) as of 2009

1. Very wide-field optical imager

   HSC from 2013

2. Wide-field multi-objet spectrograph

   PFS from 2019

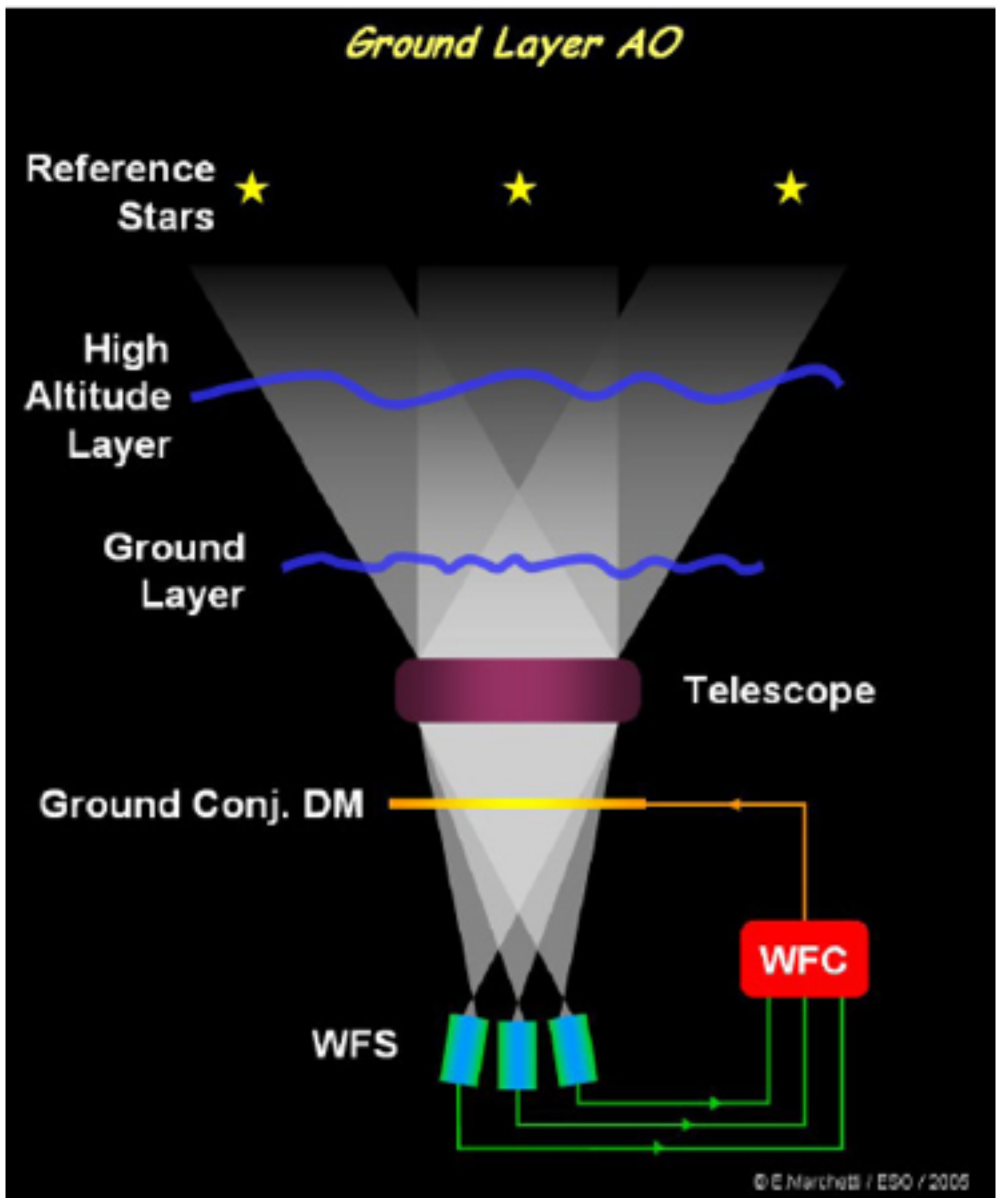
3. Wide-field near-infrared imager and multi-object spectrograph (including IFU).

   ULTIMATE-Subaru from 2023

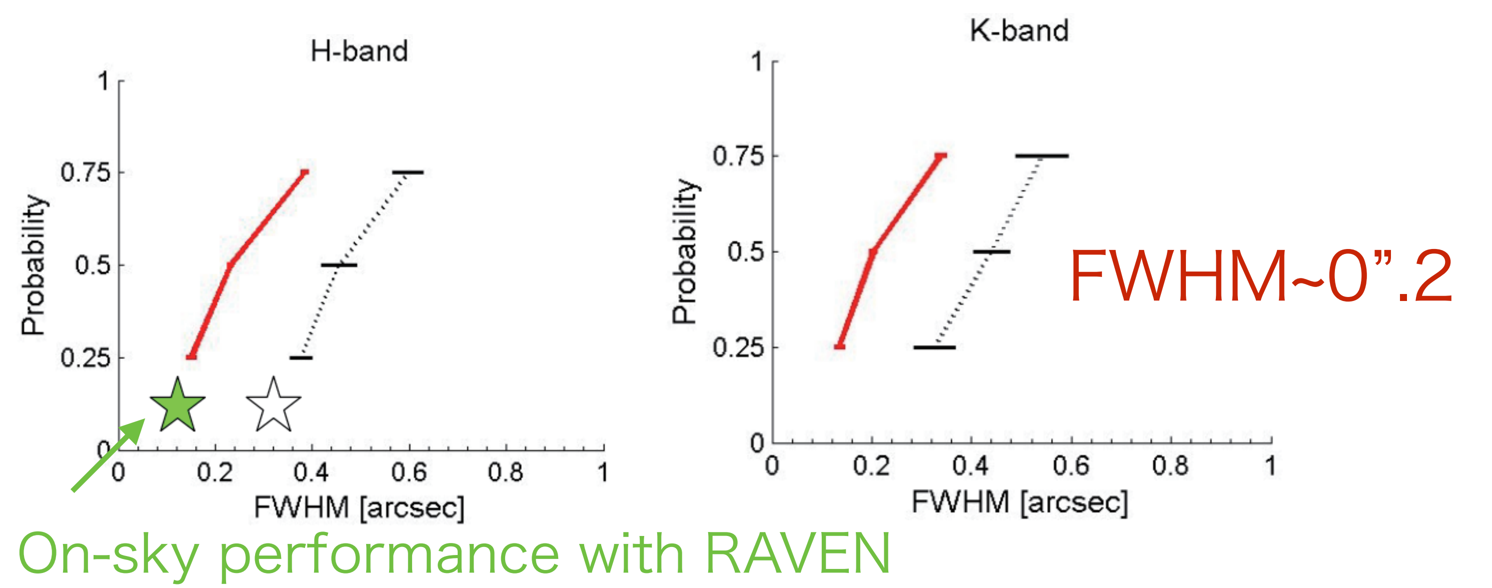
Community Science meeting for wide-field NIR instruments

- Subaru Next generation AO workshop, 2011/9/8-9@Osaka Univ.
  Discussion about wide-field AO system
- Galaxy Anatomy workshop, 2012/5/29-31 @ Subaru
  Science case with high spatial-resolution imaging/spectroscopy
- Subaru GLAO science workshop 2012, 2012/10/17-18 @Subaru
  Trade-off study between GLAO and MOAO
- Subaru GLAO science workshop 2013, 2013/6/13-14 @ Hokkaido Univ.
  GLAO science workshop (participants from Canada, Taiwan, Japan)
- Subaru GLAO mini-science workshop 2014, 2014/7/28-29 @ NAOJ, Mitaka
  GLAO science workshop on the Starbug IFU (participants from Australia, Japan)
- Subaru GLAO science workshop 2016, 2016/6/16-17 @ NAOJ, Mitaka NEW

Ground Layer Adaptive Optics
+
Wide-Field NIR instruments



GLAO performance simulation



Uniform seeing improvement over >15 arcmin FoV.

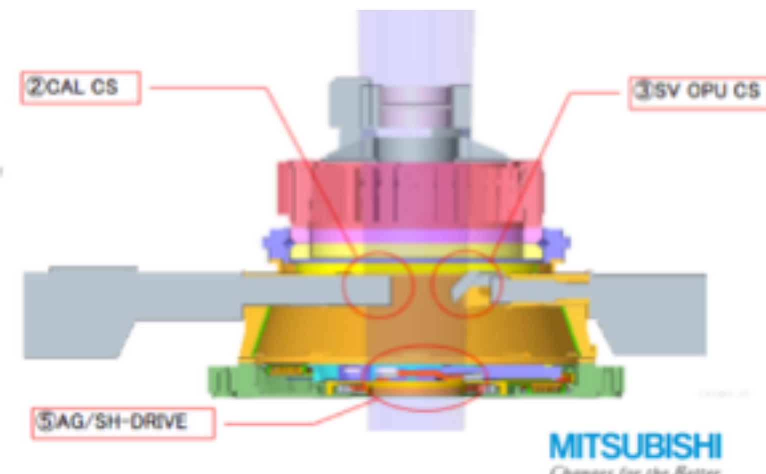
ULTIMATE-Subaru: GLAO+wide-field NIR instruments

System Overview

(3) Wavefront Sensors

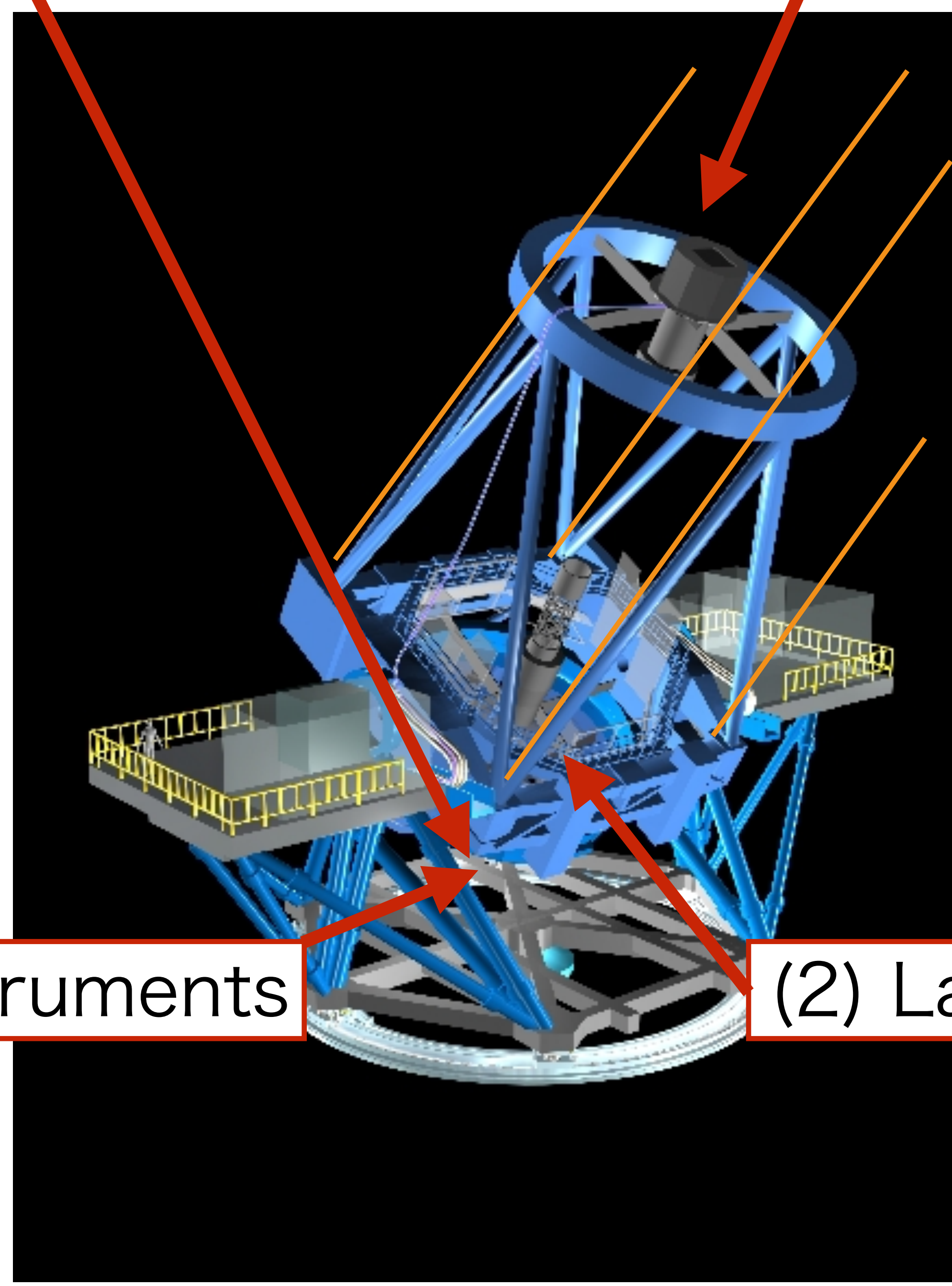
Subaru Cs. Focus

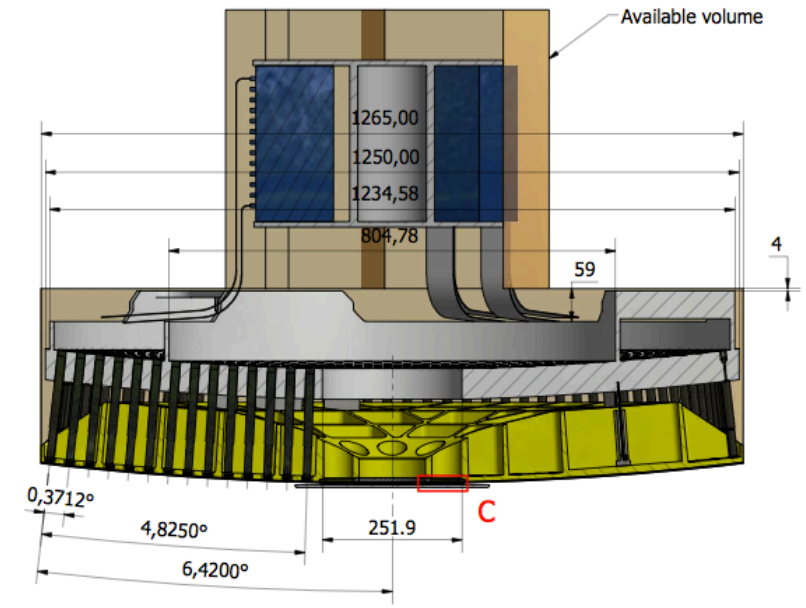
ϕ~16arcmin



NIR inst.

(1) Adaptive Secondary Mirror





Preliminary Subaru ASM design by Microgate

(4) Wide-field NIR instruments

- Imager
- Multi-Object Slit spec.
- Multi-Object IFU spec.

(2) Laser Guide Star system

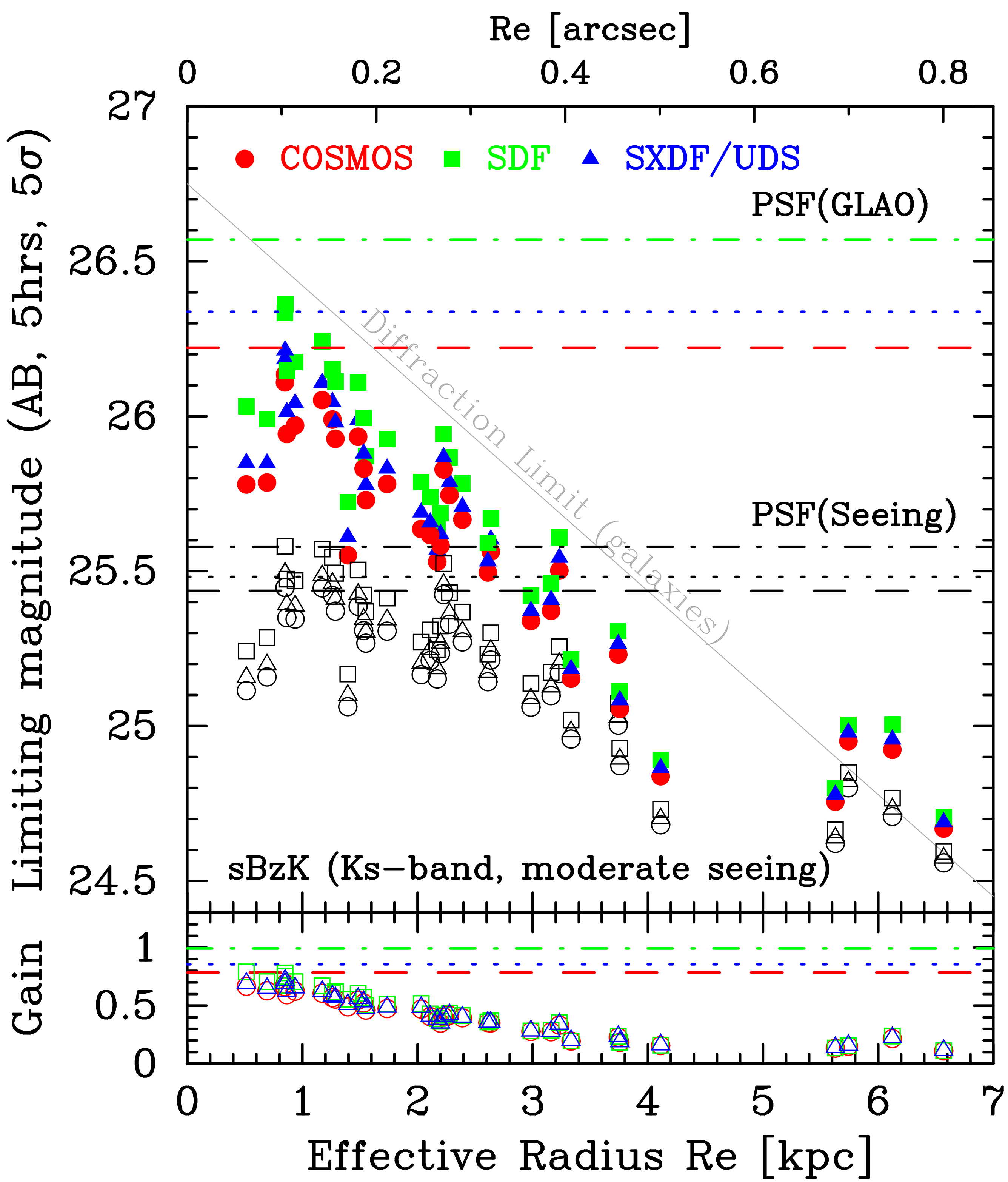
TOPICA fiber laser(589nm) x 2

Generate 4 laser guide stars

Key Technologies for GLAO

- (1) Adaptive Secondary Mirror
  - ASM from Microgate
  - 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
  - Rayleigh laser is an option, but sodium laser is preferable for future expansion to the Laser Tomographic AO (LTAO) system, which enables higher Strehl ratio in narrower FoV in visible wavelength.
- (3) 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 also demonstrated.
    - Imaka/UH88 (2016-): GLAO performance at wide FoV (12′ x 12′) . (Mark's presentation)

Why GLAO? : Sensitivity

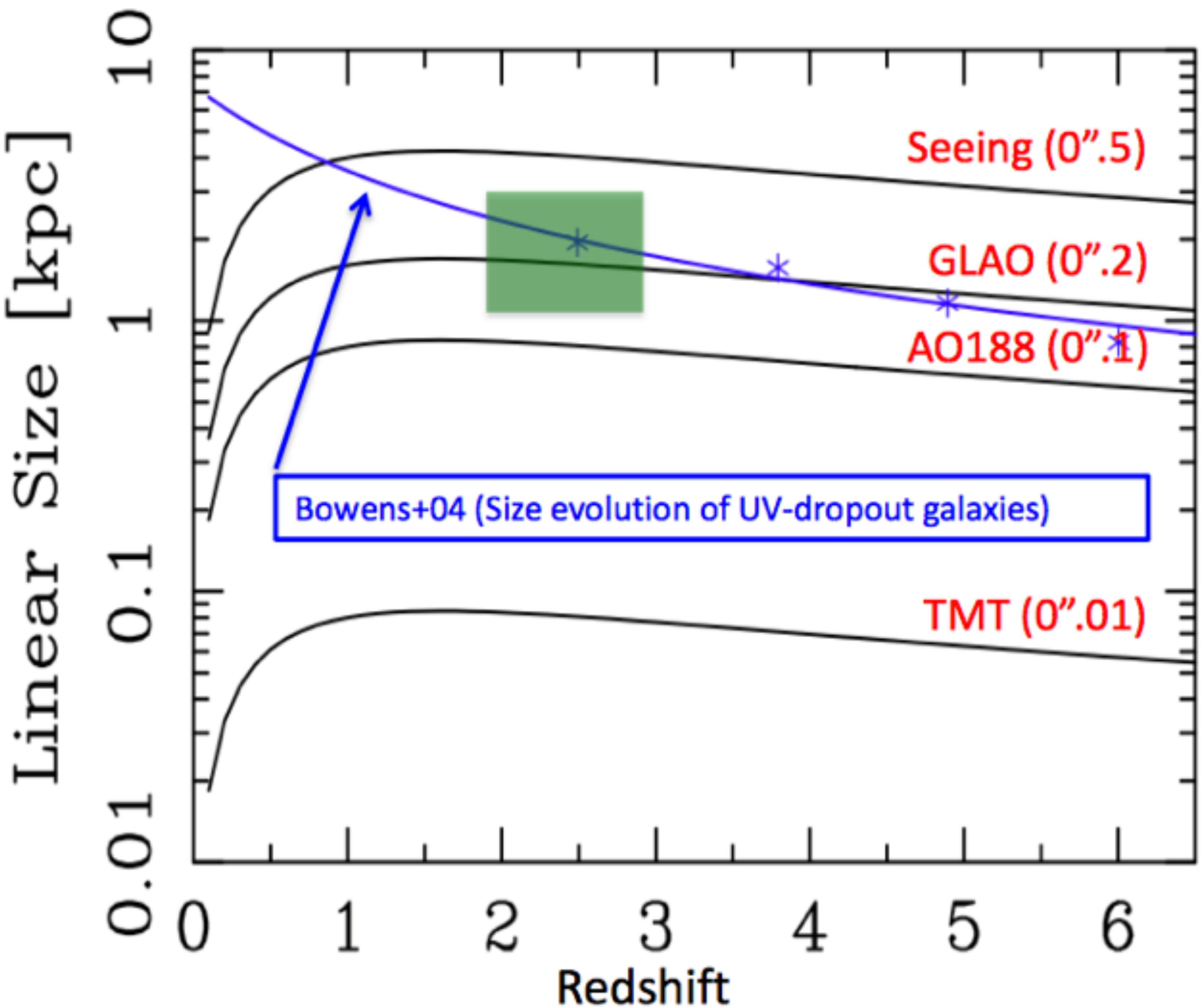


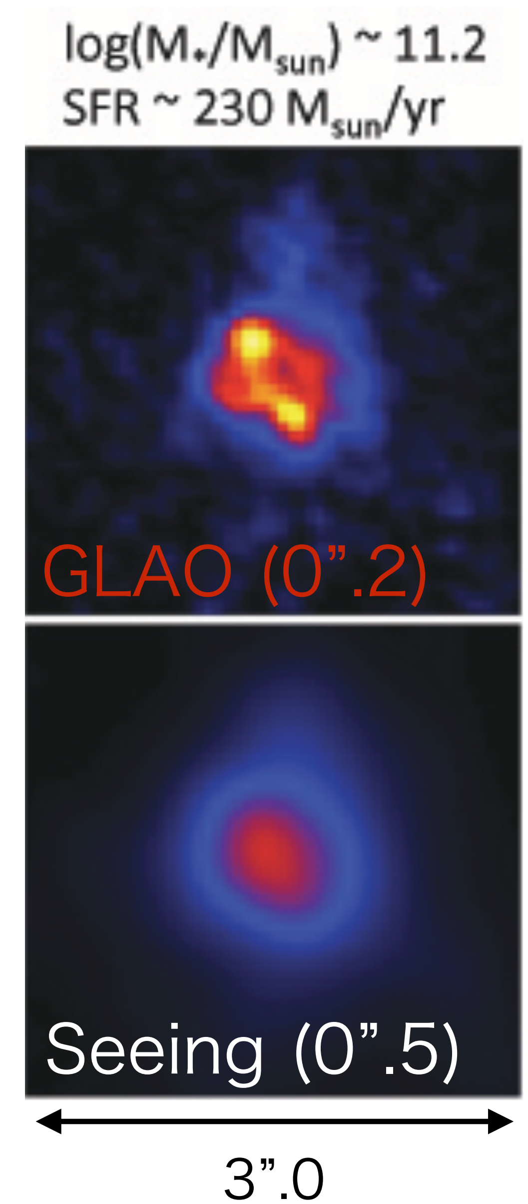
K-band Sensitivity improvement

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

GLAO survey is 3~4 times more sensitive (or faster) than the seeing limited survey

Why GLAO? : Spatial resolution

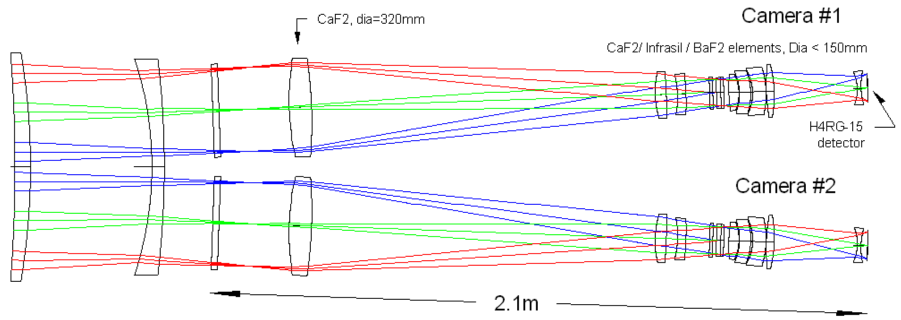


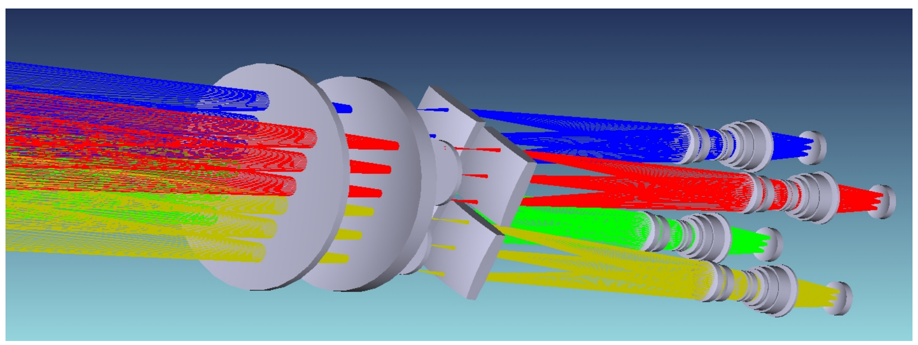


GLAO correction is essential for studying internal structure of galaxies at "Cosmic noon".

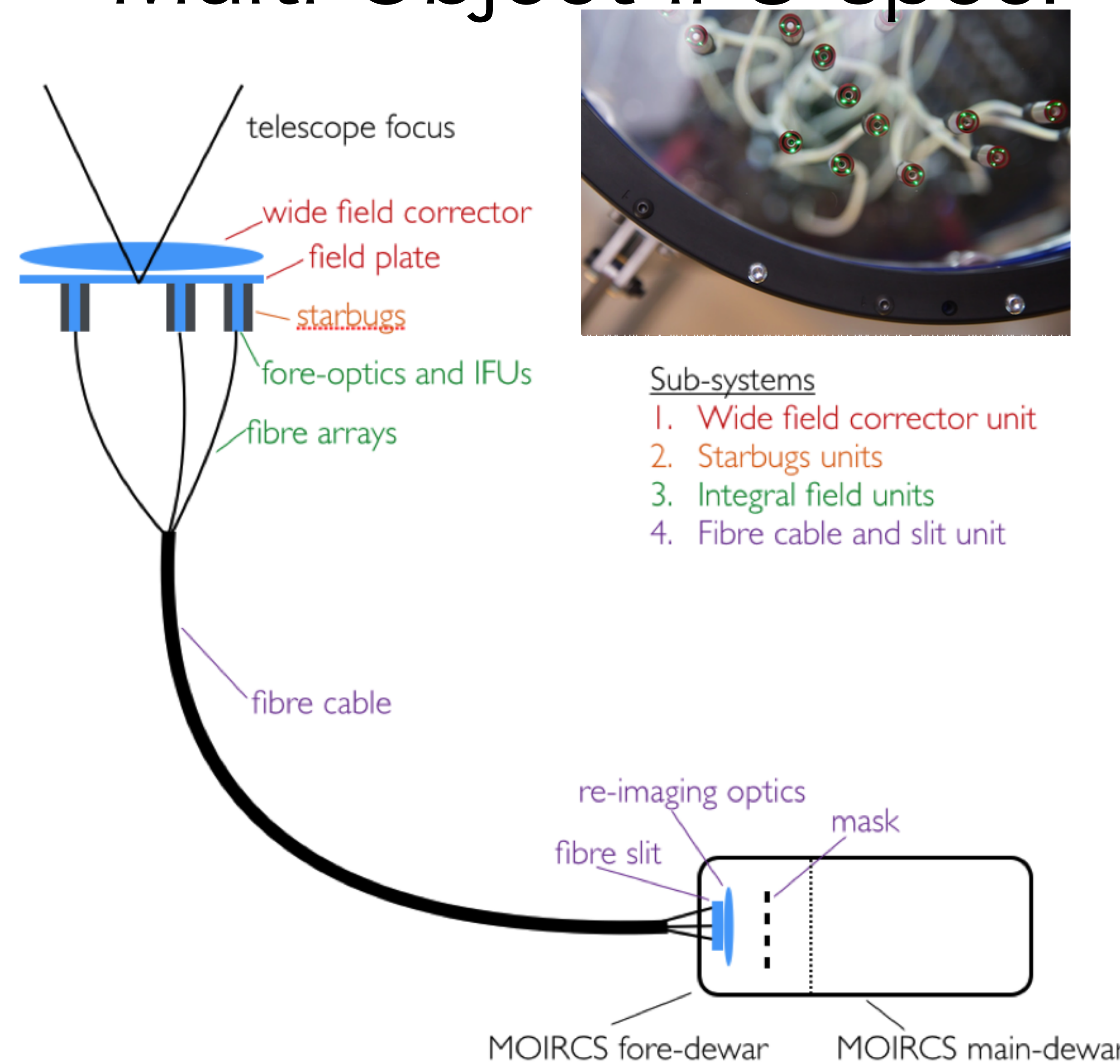
NIR instruments conceptual design

Imager

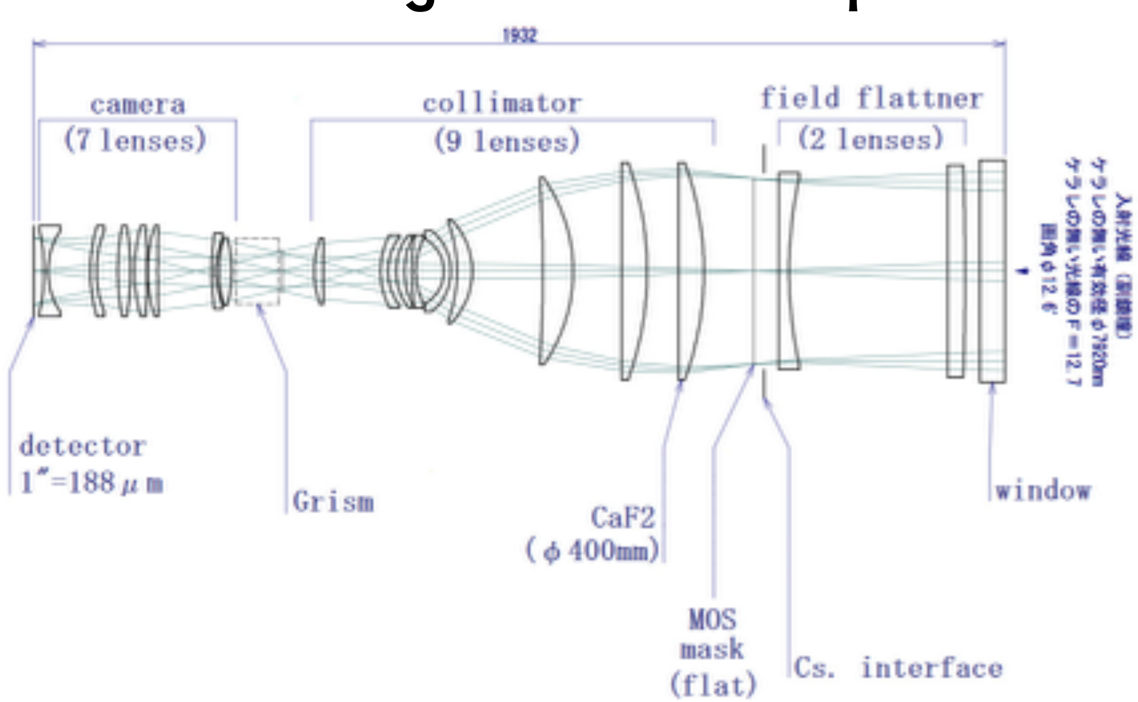




Multi-Object IFU spec.



Multi-Object slit spec.



Instrument overview for more details

Comparison with Wide-Field AO instruments at 8-10m class telescope in 2020s

Instrument/Tel.	FOV	Multiplicity	λ(μm)	R	AO, FWHM
Imager					
HAWK-I/VLT	7’.5x7’.5	-	0.9-2.5	-	GLAO(GRAAL),~0”.3
FLAMINGOS2/Gemini-S	2’.0x2’.0	-	0.9-2.5	-	MCAO(GEMS), <0”.1
ULTIMATE/Subaru	ϕ~15’	-	0.9-2.5	-	GLAO, ~0”.2
Multi-Object Slit Spectrograph					
MOSFIRE/Keck	6’.1x6’.1	<46	0.9-2.5	~3500	w/o AO,~0”.5
FLAMINGOS2/Gemini-S	2’.0x2’.0	?	0.9-2.5	~3000	MCAO(GEMS),<0”.1
ULTIMATE/Subaru	ϕ~15’	~100	0.9-2.5	~3000	GLAO, ~0”.2
Multi-Object IFU Spectrograph					
KMOS/VLT	ϕ~7’.2	24	0.9-2.5	~4000	w/o AO,~0”.5
MUSE/VLT	1’x1’	1	0.46-0.93	~4000	GLAO(GRAAL),~0”.3-0”.4
ULTIMATE/Subaru	ϕ~15’	8-13	0.9-1.8	~3000	GLAO, ~0”.2

- The most unique capability of ULTIMATE-Subaru is the widest FOV among the other AO instruments.

Comparison with TMT/Space instruments in 2020s

Instrument/Tel.	FOV	Multiplicity	λ(μm)	R	AO, FWHM
Imager					
IRIS/TMT	17”.2x17”.2	-	0.9-2.5	-	MCAO(NFIRAOS),~0”.01
NIRCam/JWST	2’.2x4’.4	-	0.5-5.5	-	Space, <0”.08
Euclid	0.5 deg^2	-	0.9-1.6	-	Space, ~0”.4
WFIRST	0.3deg^2	-	0.6-2.0	-	Space,~0”.2
ULTIMATE/Subaru	ϕ~15’	-	0.9-2.5	-	GLAO, ~0”.2
Multi-Object Slit Spectrograph					
TMT/IRMS	2’.1x2’.1	<46	0.9-2.5	5000	MCAO(NFIRAOS),~0”.01
NIRSPEC/JWST	3’.0x3’.0	>100	1.0-5.0	~2700	Space,<0”.08
ULTIMATE/Subaru	ϕ~15’	~100	0.9-2.5	~3000	GLAO, ~0”.2
Multi-Object IFU Spectrograph					
IRIS/TMT	<2”.2x4”.5	1	0.9-2.5	>4000	MCAO(NIFRAOS),~0”01
IRMOS/TMT	ϕ~5’.0	20(?)	0.9-2.5	>2000	MOAO, <0”.1
ULTIMATE/Subaru	Φ~15’	8-13	0.9-1.8	~3000	GLAO, ~0”.2

- Survey type space telescope would be the best for imaging, but less flexible

Other capabilities of ASM at Subaru

- TMT 1st gen. instruments will not offer the capabilities of
  - High dispersion spectrograph with R>10,000
  - Extreme Adaptive Optics system

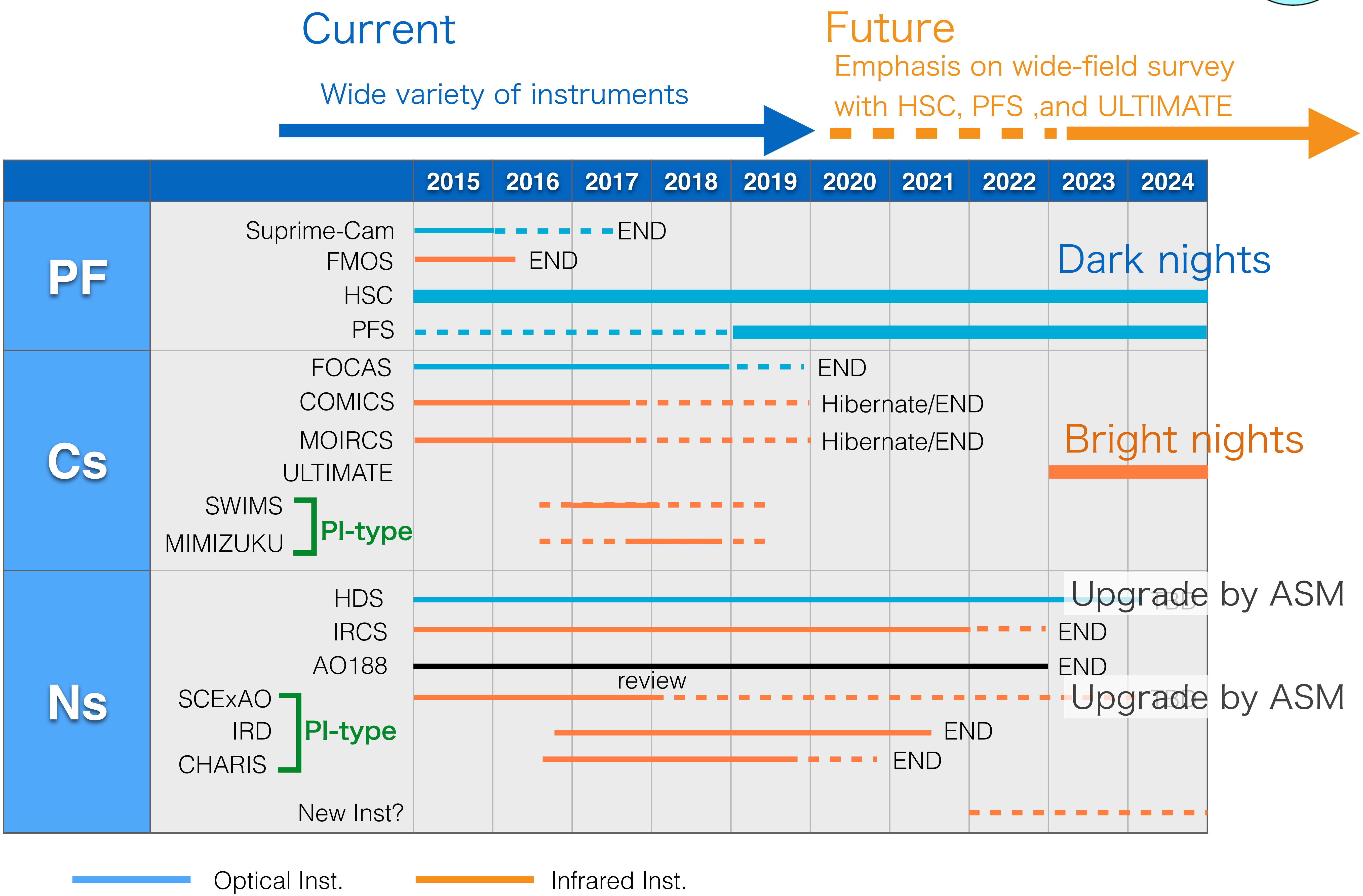
- HDS (visible high dispersion spectrograph) and SCExAO (Subaru Extreme AO system) are still unique after 2020 (or 2030?).

- ASM can improve the performance of HDS and SCExAO by using the ASM as Single Conjugate AO (or Laser Tomographic AO) .

- Both instruments are located at the stable Nasmyth platform.
  No instrument exchange required for using these instruments.

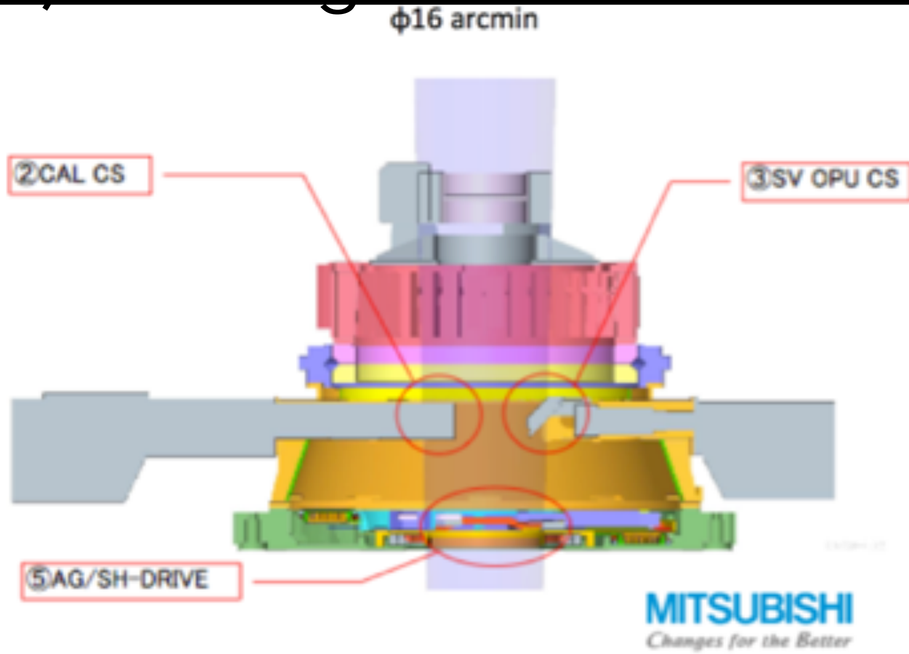
Olivier's Extreme AO presentation for more detail

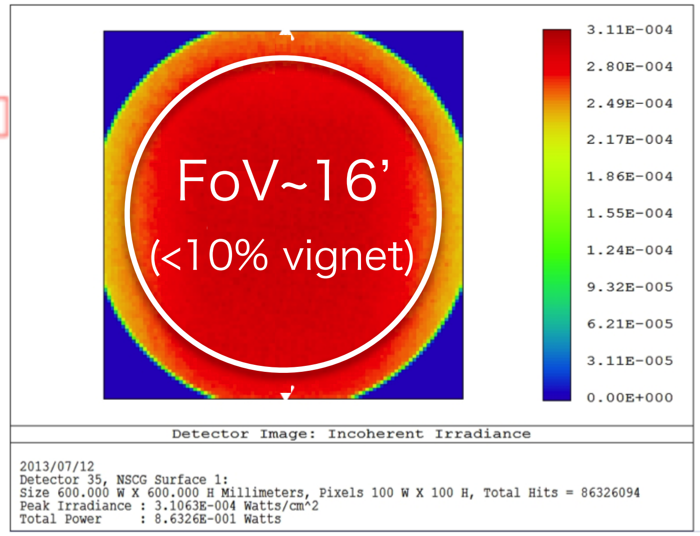
Subaru's Instrument Timeline



Impact to the observatory

(1) Cassegrain modification to obtain ~16' FoV

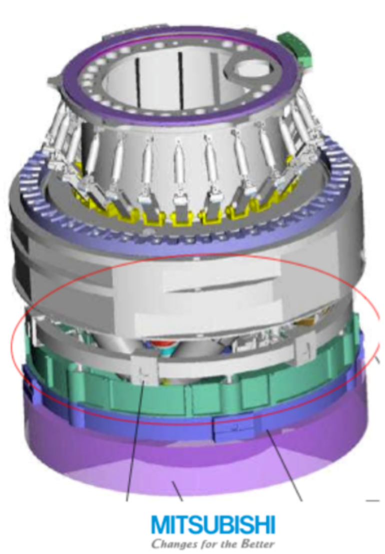


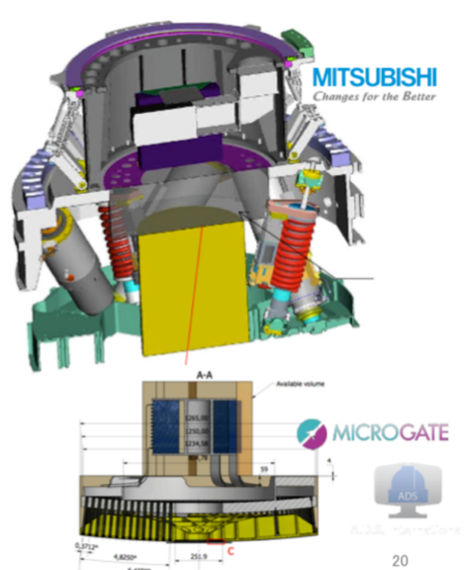


ADC, AG, Cal source, SV will be removed to obtain the largest FoV at Cs. focus.

Existing Cs. instrument (FOCAS, MOIRCS, COMICS) will not be able to use after starting the modification sometime around 2020.

(2) Modification of the IR secondary mirror



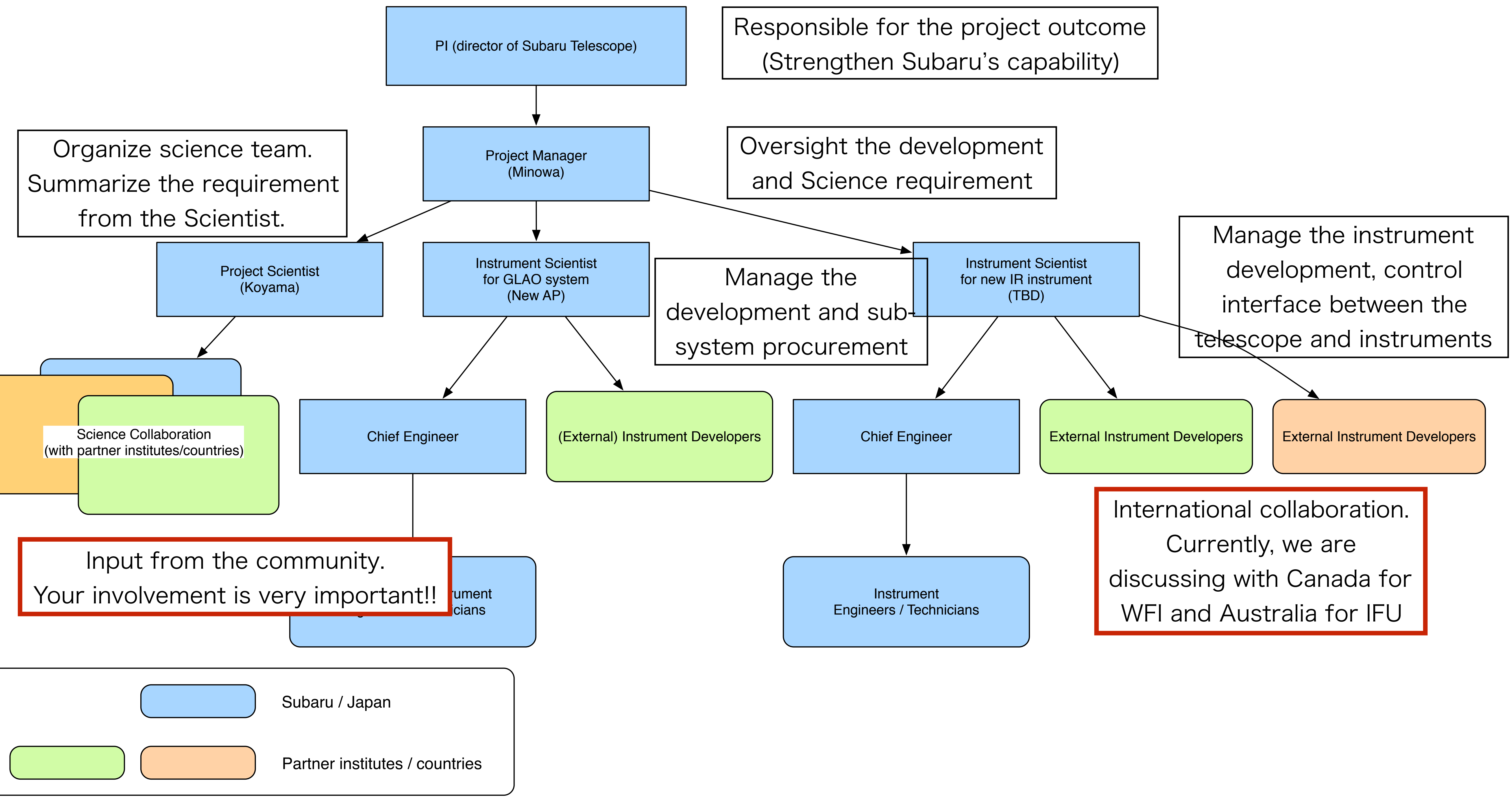


Adaptive secondary mirror (ASM) will be installed in the existing IR secondary mirror mount.

IR M2 will not be available for 0.5-1.0 year to modify and test for the ASM.

Minimize the down time by conducting the modification work during the primary mirror re-coating.

Team Organization



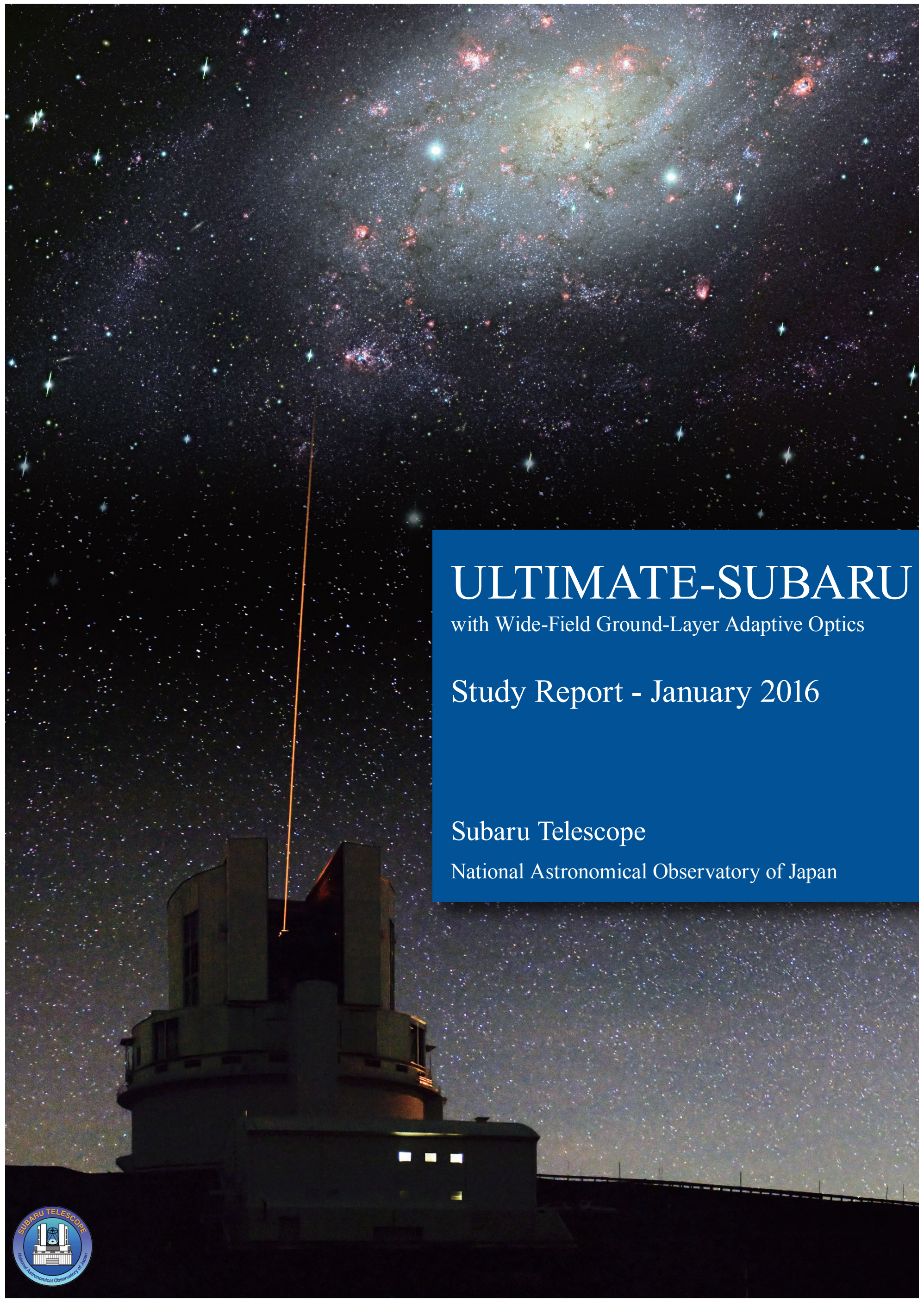
Cost estimation, Budget Resources

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~~)

ULTIMATE Study Report

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



- 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

ULTIMATE-Subaru project external review

- Recommendation from reviewers
  - Investigate science cases after 10 years from the competing instrument (especially VLT/GRAAL)
  - Estimated cost for developing the instrument is huge. Two phase implementation is suggested. (GLAO 1st, instrument 2nd)
  - Wide-field imager seems to be more attractive than the other instrument plans.
  - Re-use the existing facility instrument (such as MOIRCS) as a first light instrument for GLAO.

Doi-san's summary talk

ULTIMATE Subaru Timeline