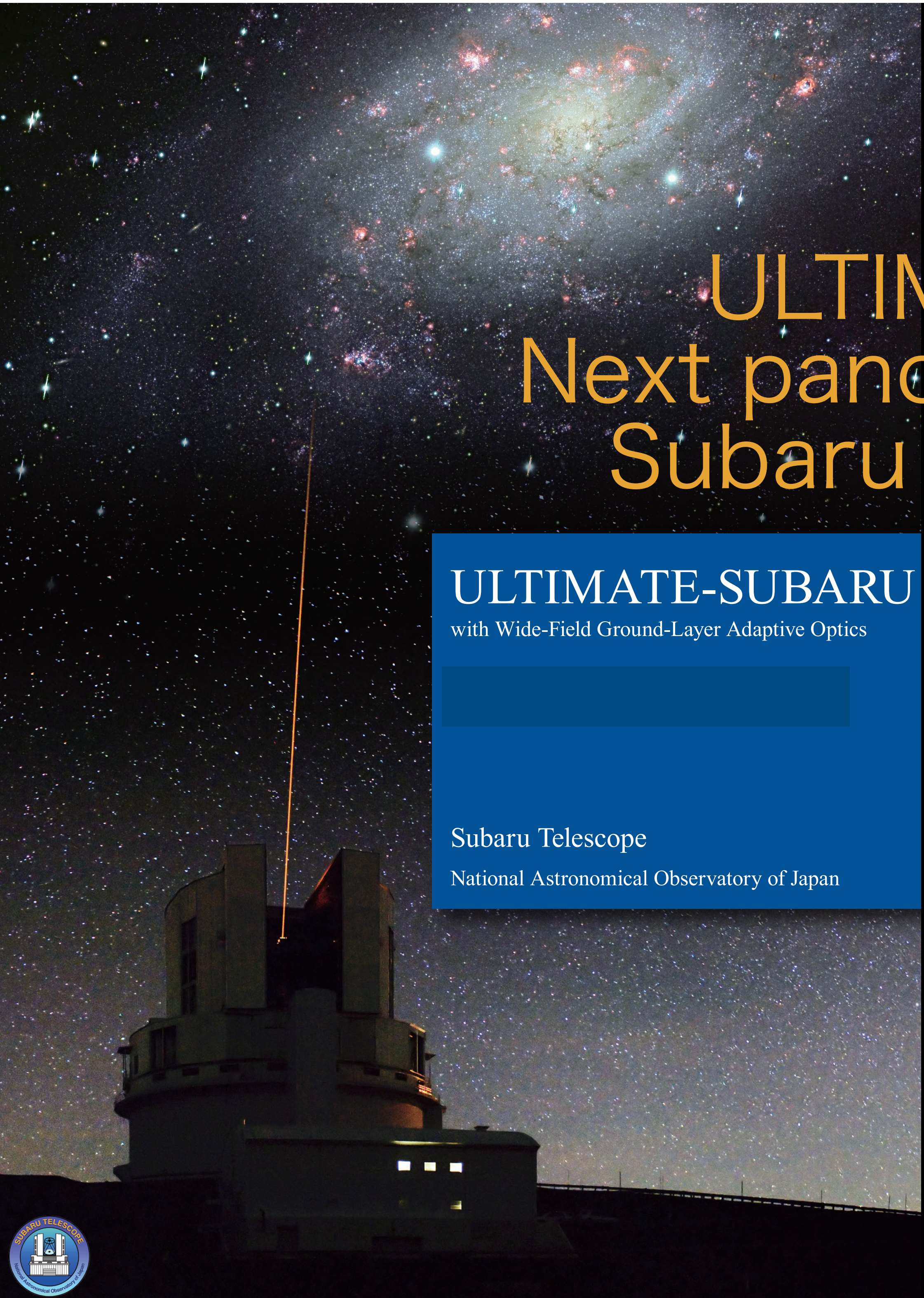
ULTIMATE-Subaru: Next panoramic strategy of Subaru in near-infrared



Yosuke Minowa
(Subaru Telescope)

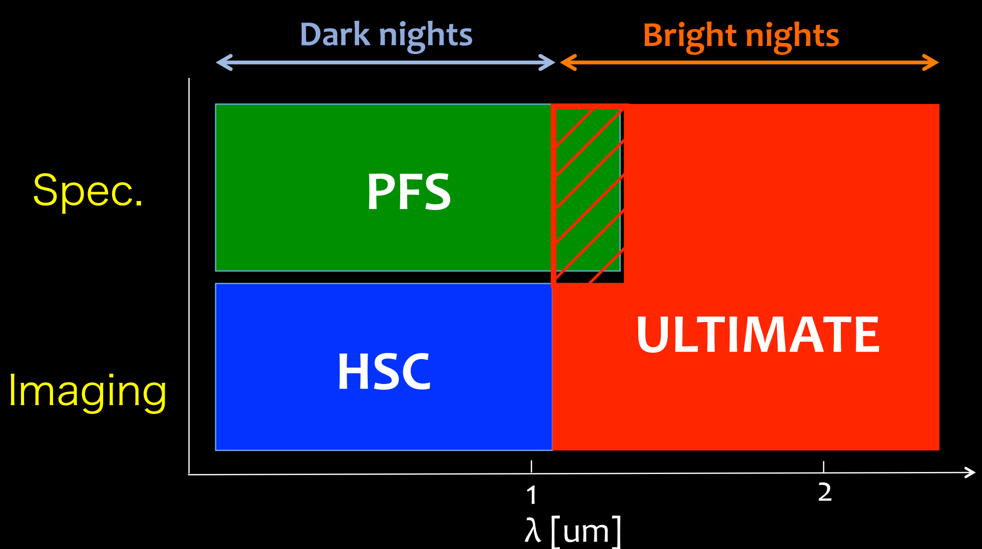
ULTIMATE-Subaru working group

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)

Subaru's Wide-Field Strategy toward 2020s

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)

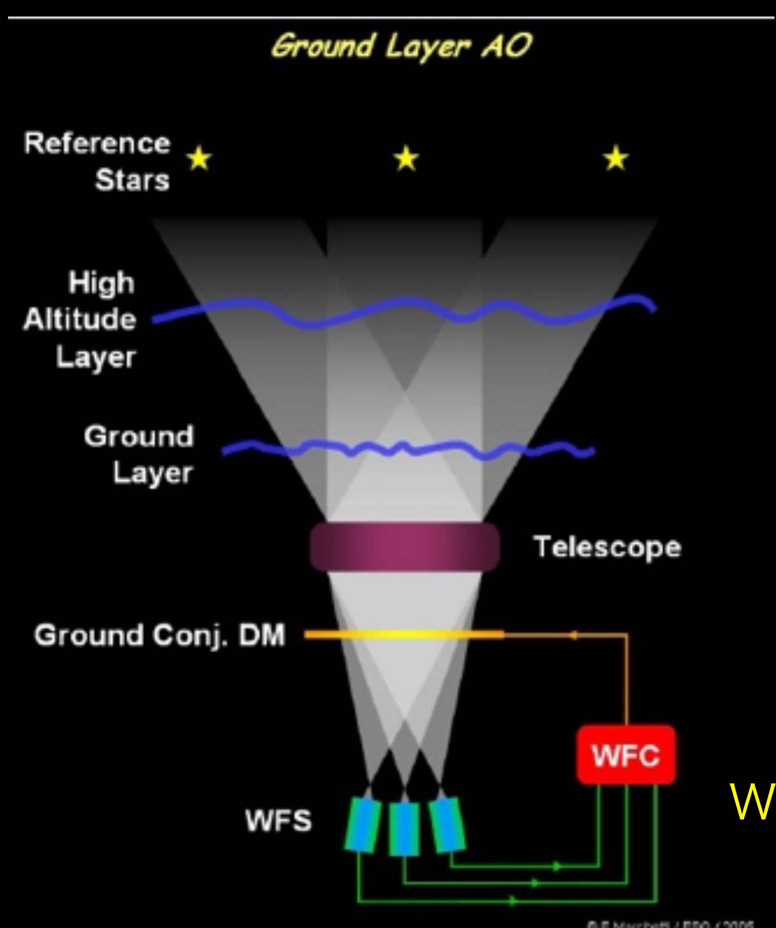


Extend Subaru's survey capability to near-infrared

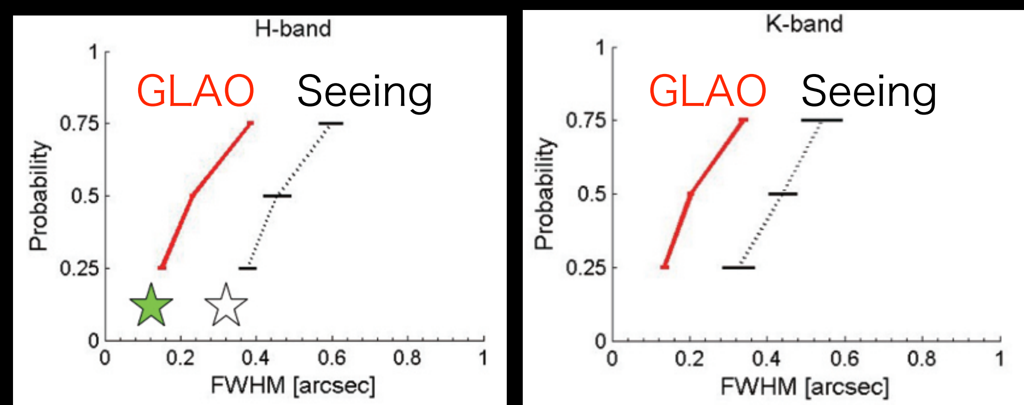
Secure budget,
Support from Community, etc.

What is ULTIMATE-Subaru?

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



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

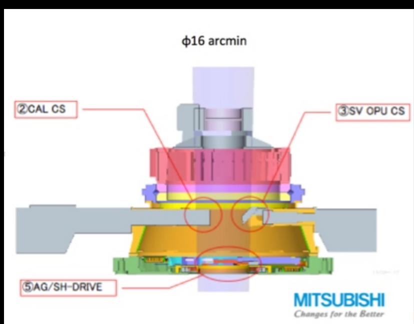
(Seeing 0".8 —> GLAO 0".4 at K, FoV~7'.5)

ULTIMATE-Subaru: System Overview

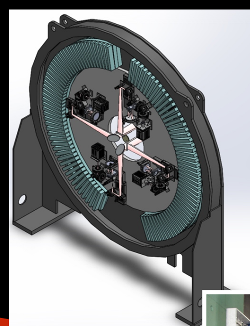
Ground-Layer AO+Wide-Field NIR instruments

(3) Wavefront Sensors

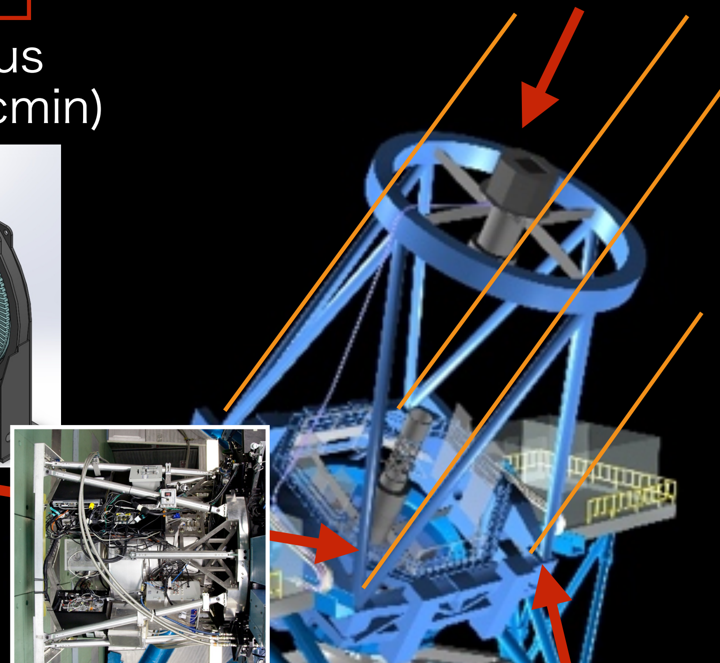
Cs. Focus
(FoV~20 arcmin)

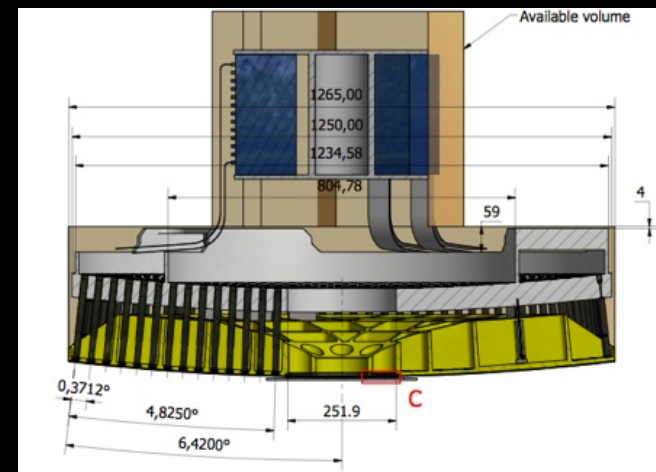


Ns. Focus
(FoV~6 arcmin)



(1) Adaptive Secondary Mirror

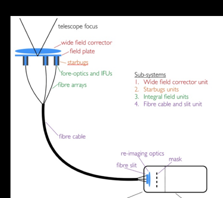


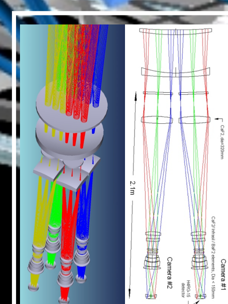


Preliminary Subaru ASM
design by Microgate ADS

(4) Wide-field NIR instruments

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





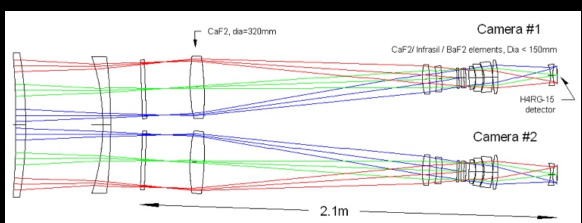
(2) Laser Guide Star system

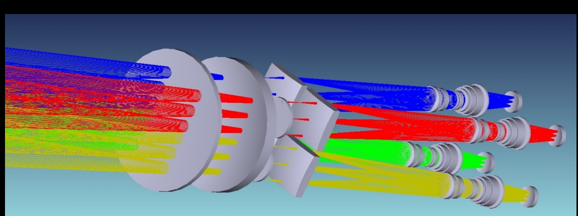
TOPICA fiber laser(589nm) x 2
Generate 4 laser guide stars

ULTIMATE Wide Field Imager (WFI)

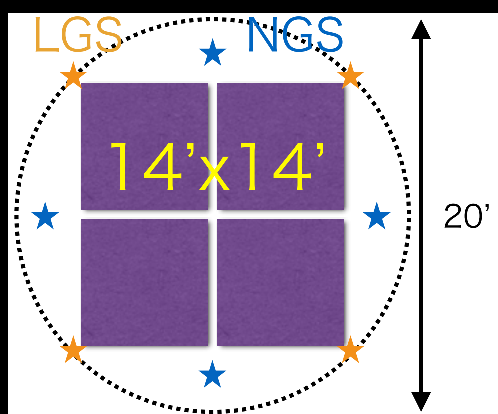
Baseline Specification

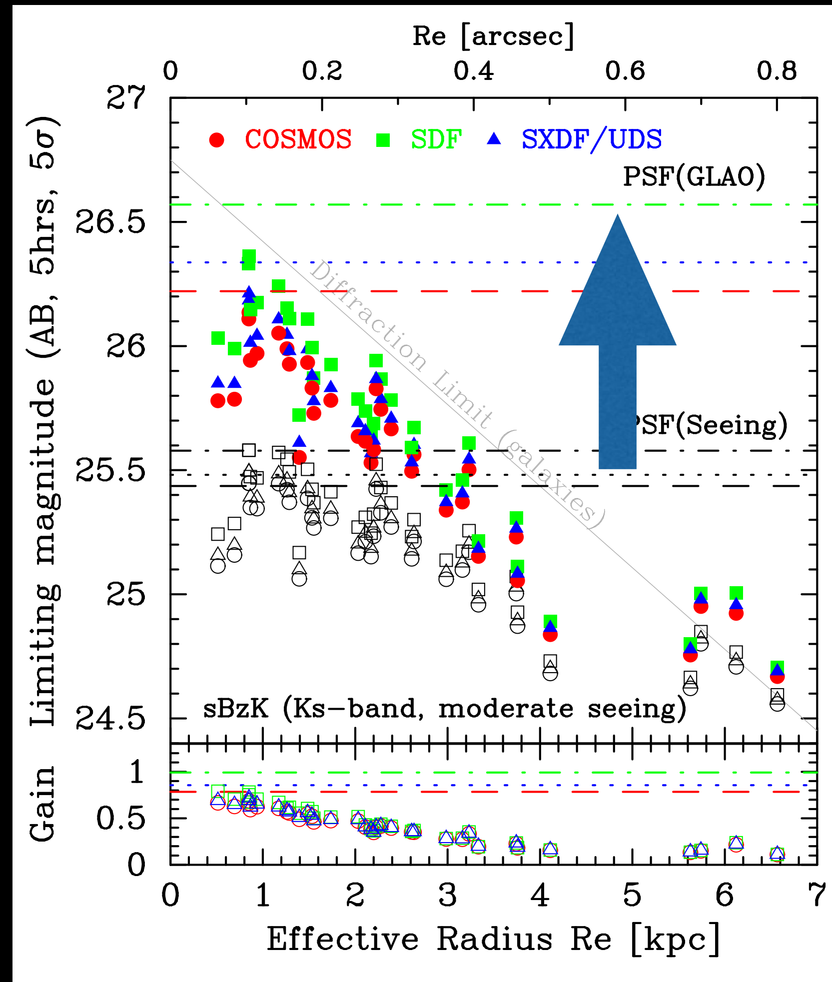
Wavelength Coverage	0.8-2.5 μm
Plate scale	0”.1/pixel
FoV	14’x14’
Filter	YJHK/MB/NB (+tunable filter)
Detectors	4 x H4RG
Efficiency	> 40%





Conceptual design by J. Patzder (HIA)





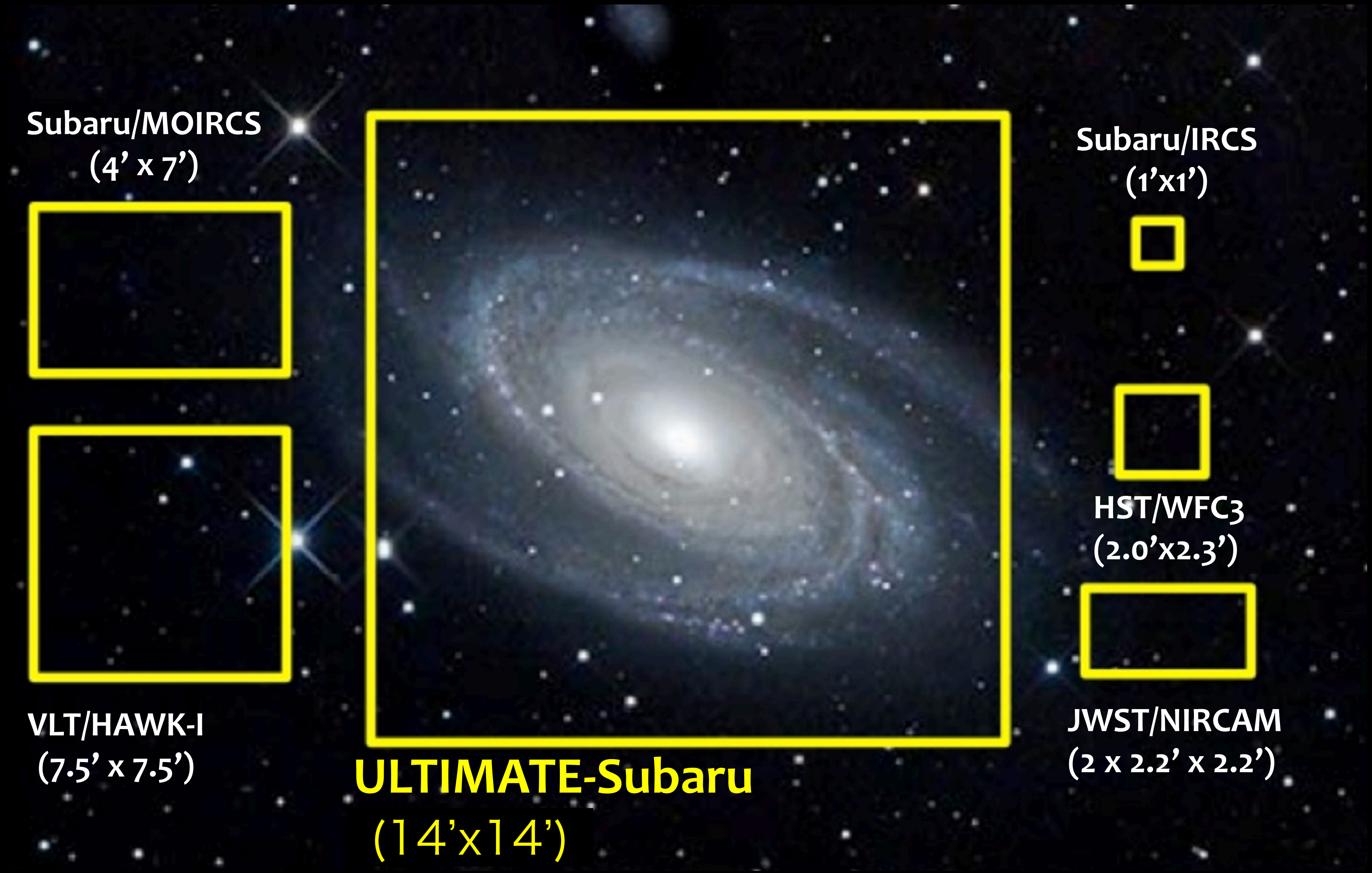
K-band Sensitivity improvement

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

3~4 times more sensitive (or faster)

ULTIMATE-WFI: Uniqueness

Widest FoV among NIR facilities in 2020s
available at λ>2.0μm

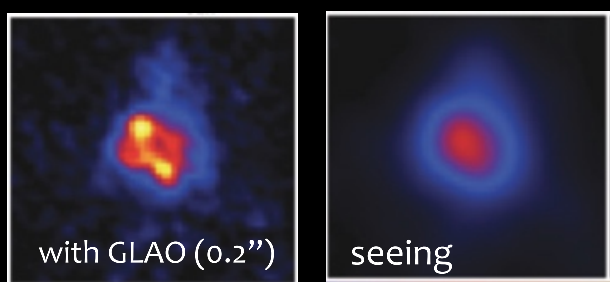


ULTIMATE-WFI: Key Science Case

Wide-field, high-resolution narrow-band imaging survey

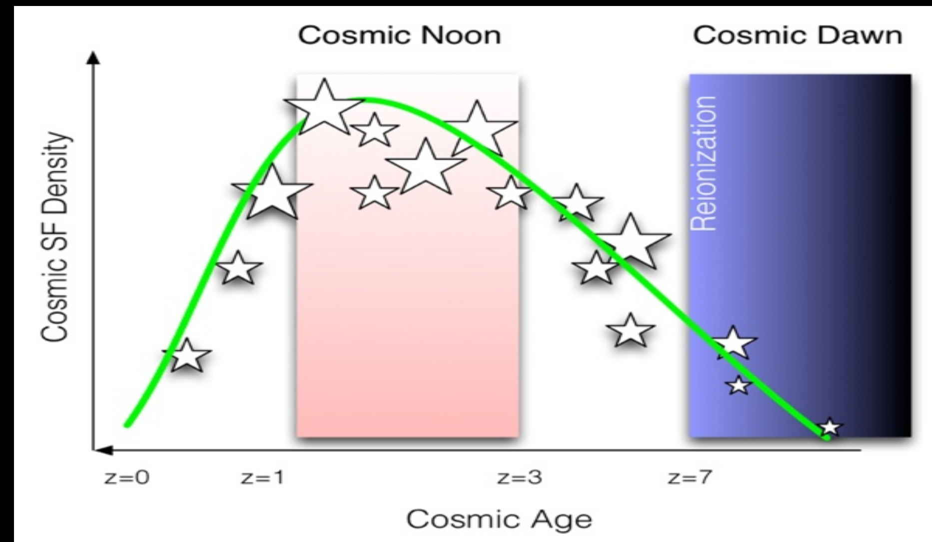
(1) Complete census of galaxy evolution

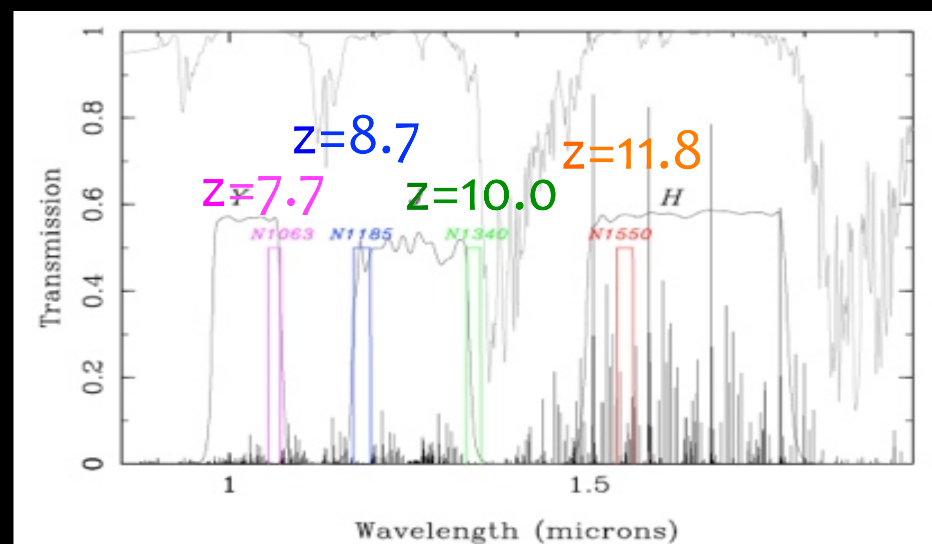
- Hα/[OIII] emission line survey at z=2-3 down to 10^9 M_{sun} in stellar mass.
- Stellar build-up history
- Quenching mechanism
- Mass and environmental dependency



(2) Exploring very high-z galaxies

- Lyα emission line survey at z=8, 9, 10…
- History of cosmic re-ionization
- Sensitivity of ULTIMATE-WFI in J-band NB is comparable to the JWST NIRCAM NB imaging.

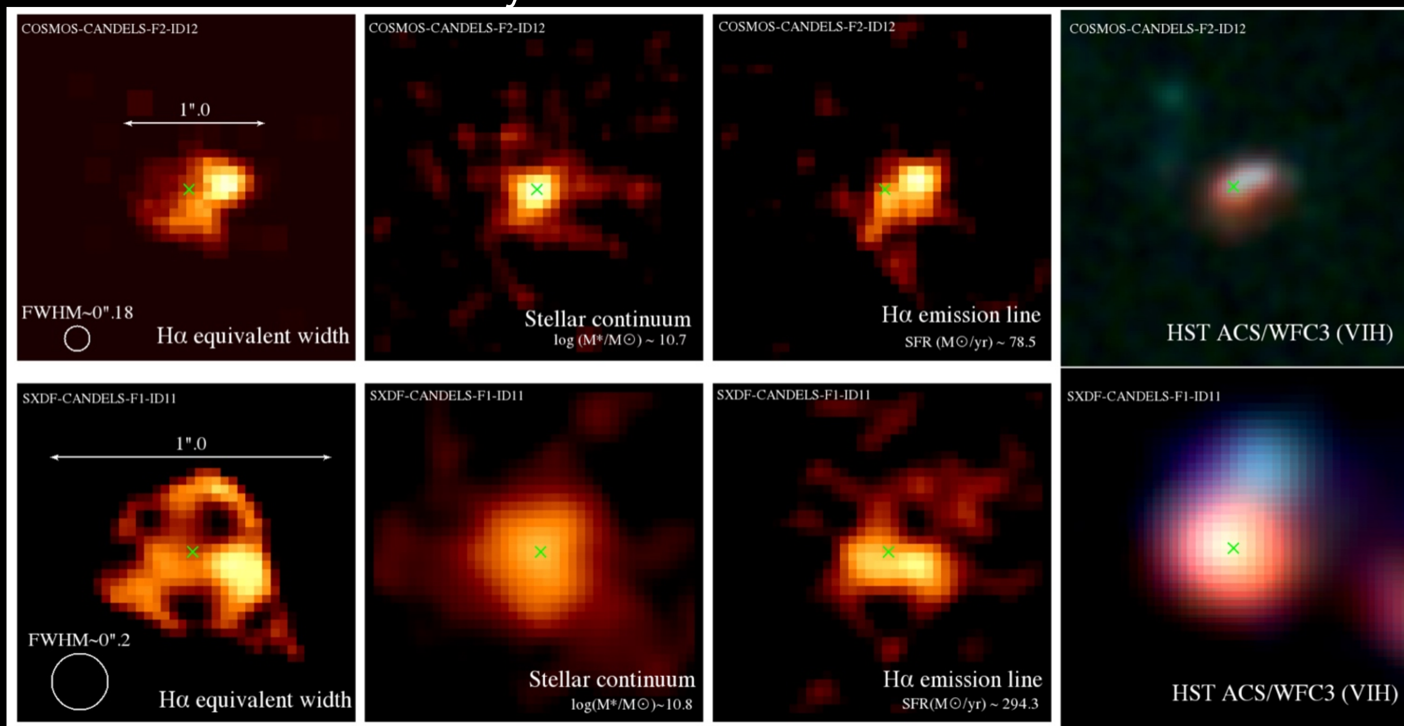




ULTIMATE-WFI: Key Science Case

Mapping star-formation in galaxies at z=2-3 with Hα/[OIII] emission line with GLAO+NB imaging in K-band

Preliminary results from GANBA-Subaru



IRCS+AO188 NB+K images of star-forming galaxies at z~2 in FWHM~0".2 resolution.

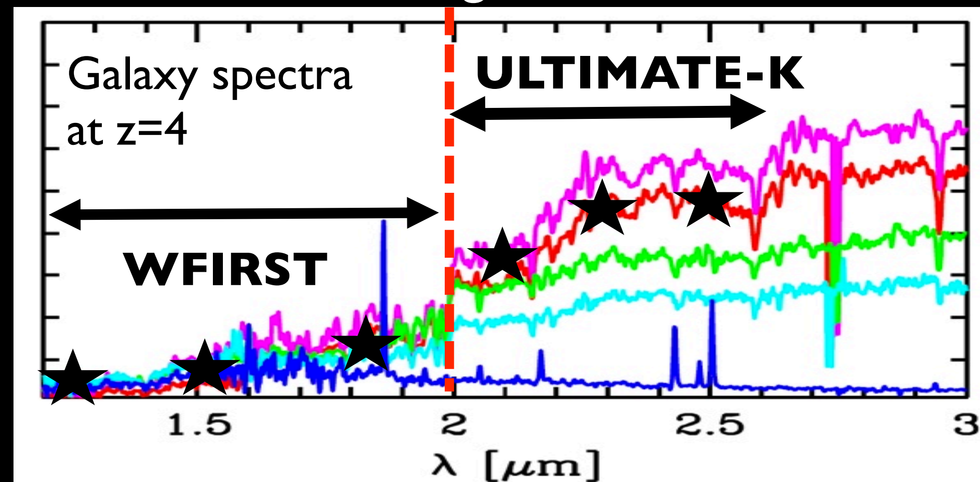
ULTIMATE NB survey will provide >1000 of spatially-resolved Hα/[OIII] maps of SF galaxies at z=2-3 down to 10^9 M_{sun}

ULTIMATE-WFI:
Key Science Case

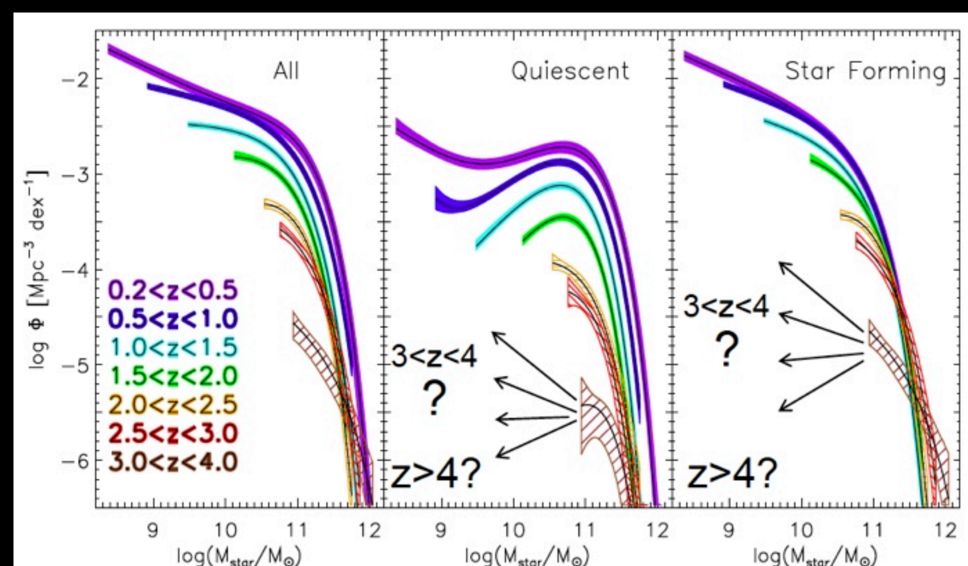
ULTIMATE-K imaging survey

- Wide-field K-band (BB and MB) survey is still unique in the era of WFIRST
- Provide >1mag deeper and ~10 times wider survey data than UKIDSS.
- Synergy between WFIRST (JH) and ULTIMATE-K is powerful to detect galaxies at z=4-5 (especially for rare objects such as quiescent galaxies)
- LBG technique to detect z~15 galaxies?

Balmer break galaxies at z=4-5



Stellar-mass function to z~5



Muzzin et al. (2013)

ULTIMATE-WFI: Preliminary Survey Plan

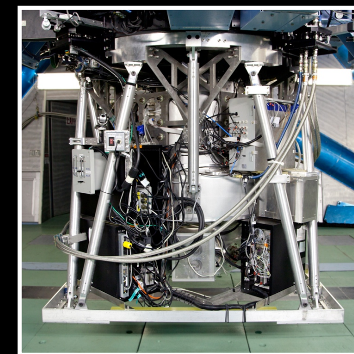
- Several NBs (in JHK), MB+BB (in K) imaging using ~300 nights to conduct survey for galaxies at z=2-3 in Hα/[OIII], z=4-5 in Balmer break, and z>8 in Lyα.
- 2 deg^2 survey in well-known deep field such as COSMOS/SXDF
- Assume J and H-band data will be taken by WFIRST
- If we concentrate only K-band (ULTIMATE-K), we can extend the survey field up to 20 deg^2

Survey type	Filters	Exp. time per FoV [hrs] (including overheads)	Limit mag. (5σ, AB)	N. of nights
NB imaging	$NB_J\times2$	8.0 (10.0)	27.0	64
	$NB_H\times2$	4.0 (5.0)	24.2	32
	$NB_K\times2$	4.0 (5.0)	24.1	32
MB imaging	*K1*	10.0 (13.0)	26.1	42
	K2	10.0 (13.0)	26.1	42
	K3	10.0 (13.0)	26.1	42
BB imaging	*K*	9.0 (13.5)	26.7	45
Total time	–	–	–	299

ULTIMATE-MOIRCS (multi-object slit spectrograph)

- MOIRCS will be reused for the first-light instrument for GLAO
- Move to Nasmyth IR platform for better stability in spec. mode
- New Grism will be installed for better total efficiency
- With GLAO, MOIRCS can reach the sensitivity better than MOSFIRE
- Extension of PFS spectroscopic survey to z>2 with ULTIMATE

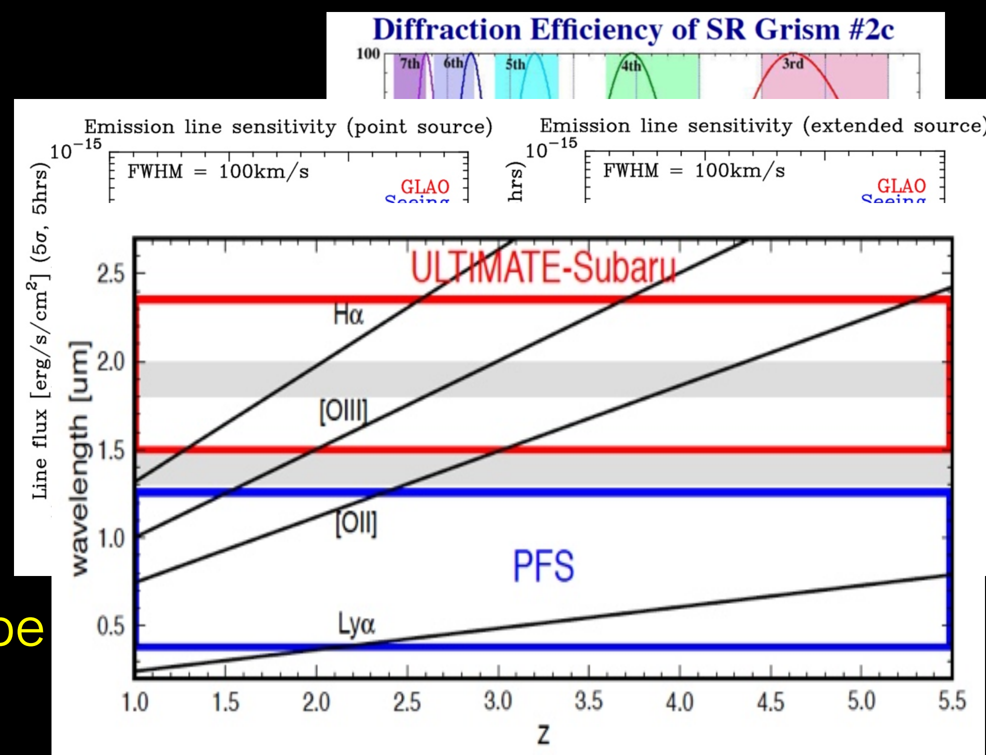
MOIRCS at Ns.



Baseline Specification

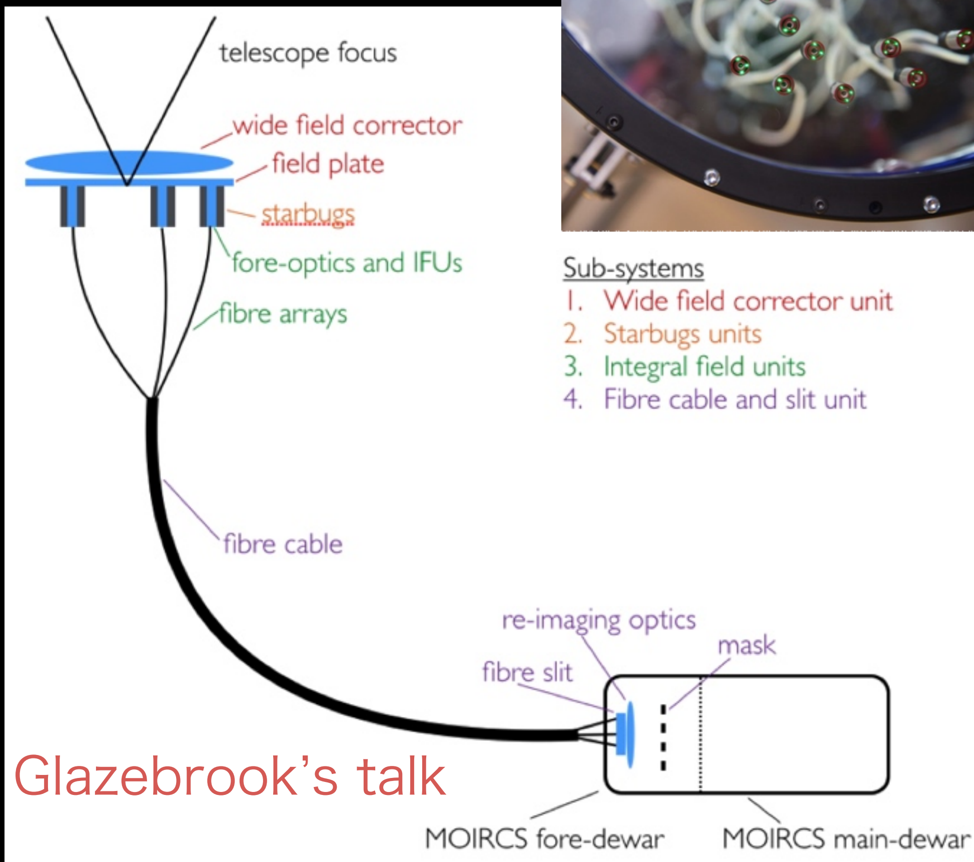
Wavelength Coverage	0.8-2.5 μm
Plate scale	0".1/pixel
FoV	ϕ~6'
Spectral resolution	R~3000 (0".2 slit)
No. of slits	40~60
Detectors	2 x H2RG
Efficiency	> 30%

Expected to be



ULTIMATE-MIFS (Multi-IFU spectrograph)

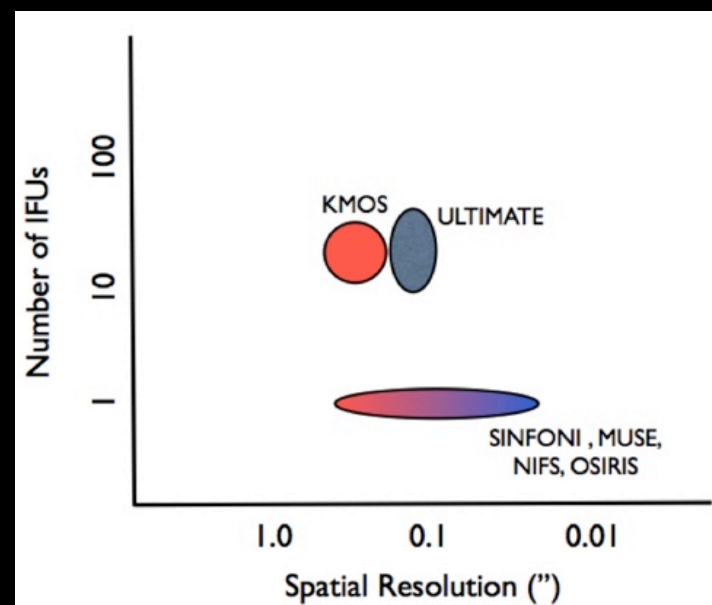
AAO developed Concept of
Fiber bundle multi-IFU system
(Ellis, S et al. 2016)



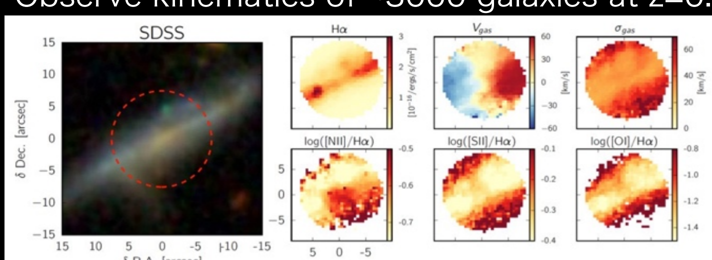
Glazebrook's talk

Baseline Specification

IFUs	
Number of IFUs	8-13[a]
Number of elements per IFU	61 Hexagonally packed
Spatial sampling per element	0.15 arcsec
Total field of view per IFU	1.18 square arcsec
Total patrol area	$\phi \sim 15$ arcmin[b]
Minimum separation between IFUs	25 arcsec
Spectrograph (MOIRCS)	
Wavelength coverage	0.9-1.8 μm
Spectral resolving power	500-3000
Dispersion	1.6 Å per pix (J), 2.1 Å per pix (H)
Sampling	2-5 pixels in FWHM
Combined properties	
Total efficiency	9% (J), 12% (H)



Observe kinematics of ~3000 galaxies at z=0.5-1.0

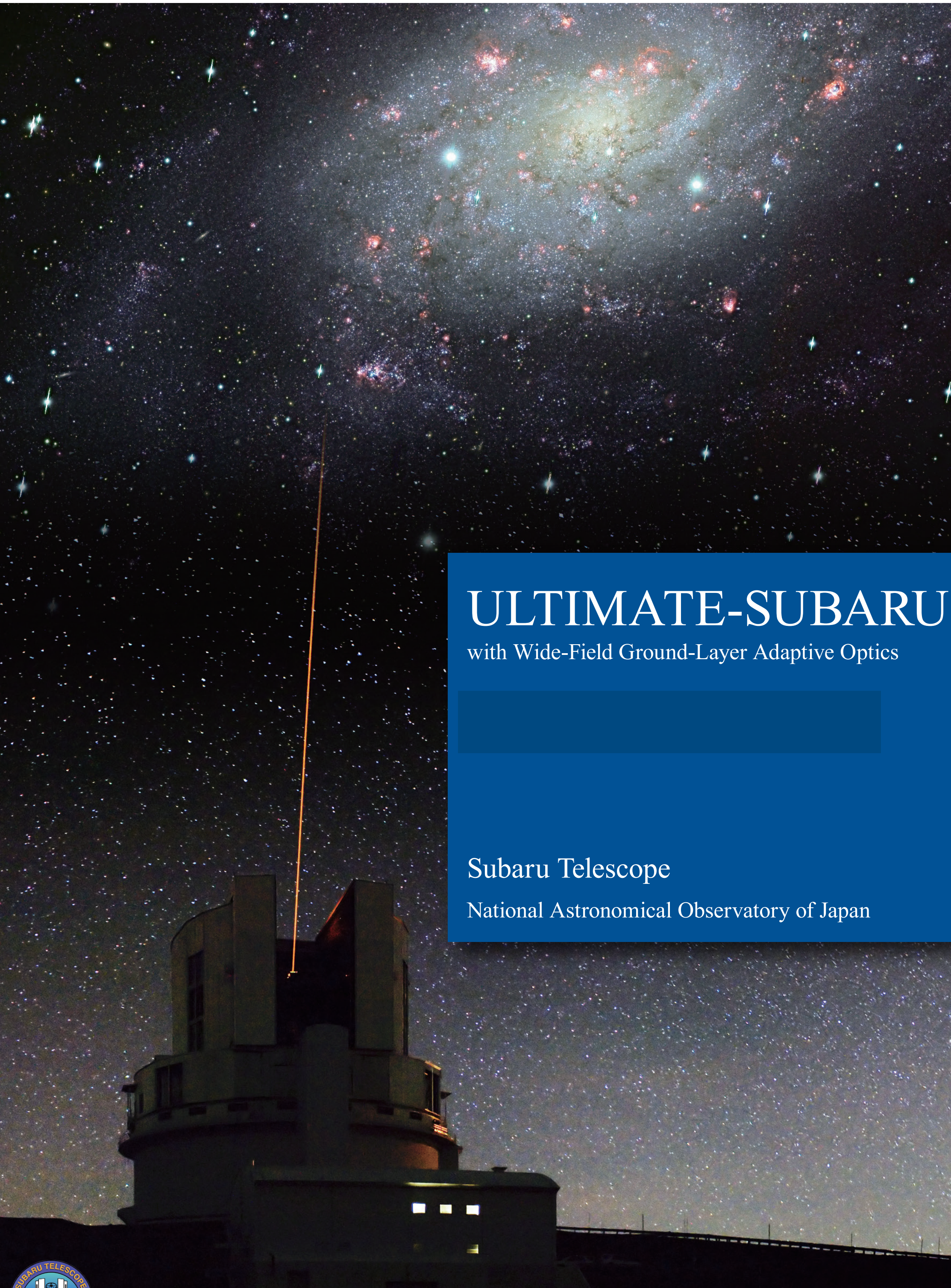


- quenching mechanism
- feedback process
- galaxy transformation (e.g. mergers)

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 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>
</table>

Slide courtesy of Y. Matsuoka

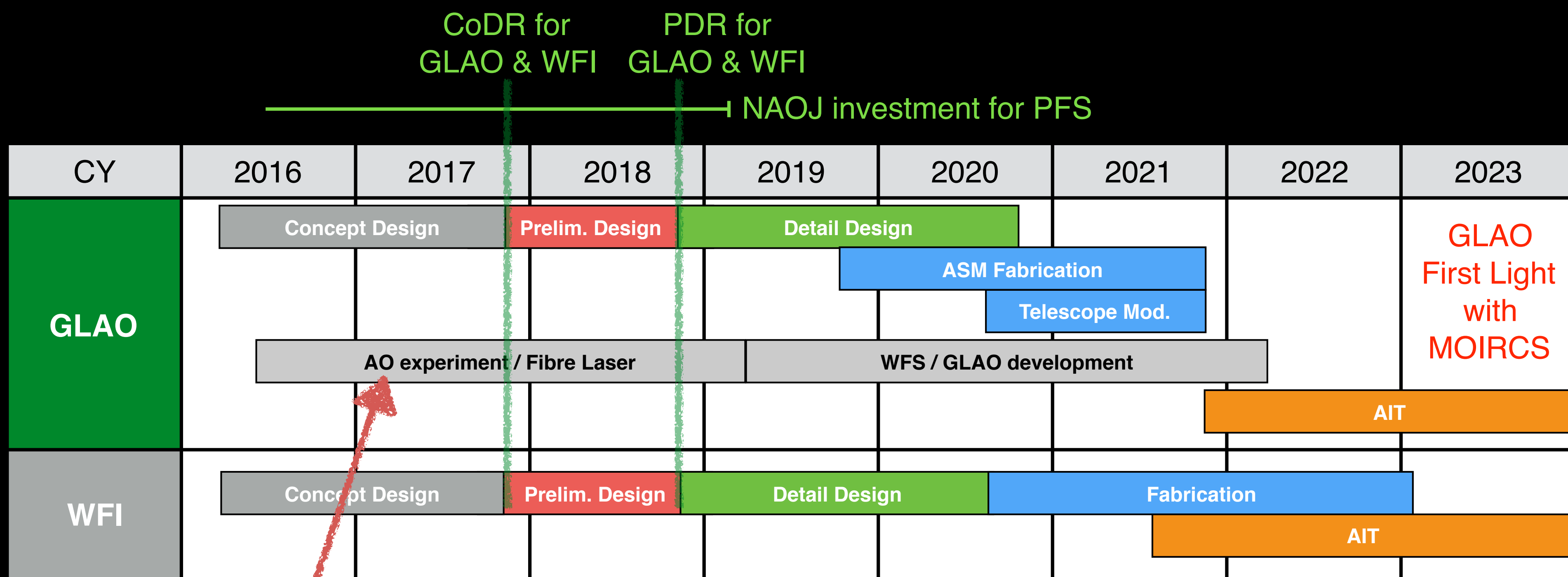


ULTIMATE-Subaru Study Report 2016

- 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

ULTIMATE Subaru: Timeline



Prototyping key components using the existing AO188 system

- WFS upgrade using modern detector system
- High-power fiber laser implementation to the telescope
- Real-time system test using GPU

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, will be reviewed at the end of 2017. Expected first light of GLAO is 2023.
- Multi-Object fiber-bundle IFU spectrograph (M-IFS) is being planned in collaboration with Australia. Instrument concept is designed by AAO.
- Imaging survey using ~300 nights to map the galaxy evolution from z=1-8 is being planned.
- Not only high-z science, we are collecting various science cases such as local star-forming region, galactic archaeology, and near-by galaxies. Any input from cosmology?
- Any kind of participation in the ULTIMATE-Subaru project, Science case, Instrument development, is very welcome.