2023年度光赤天連シンポジウム (2023/9/27-29)

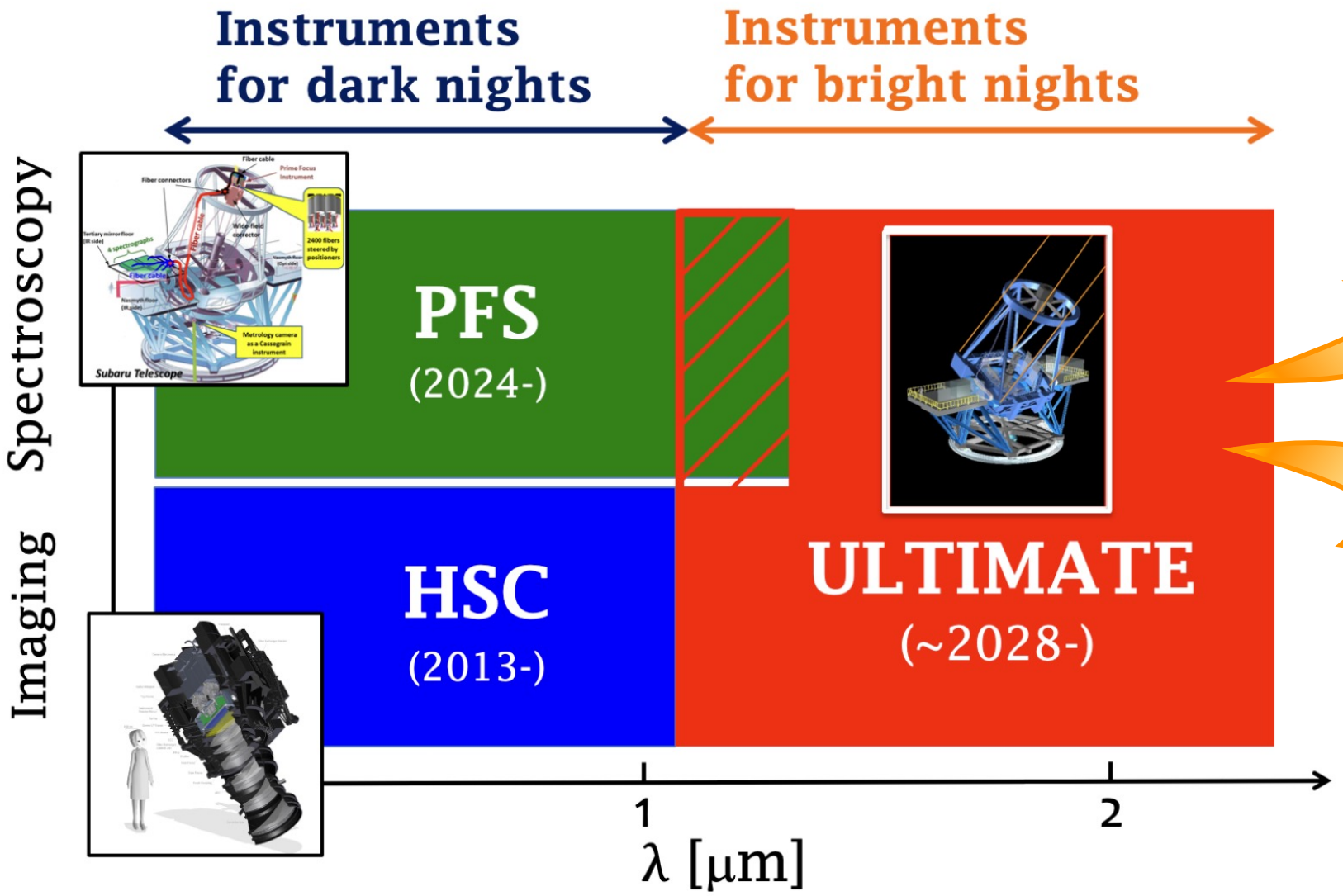
ULTIMATE-Subaru
プロジェクト報告

https://ultimate.naoj.org/index.html

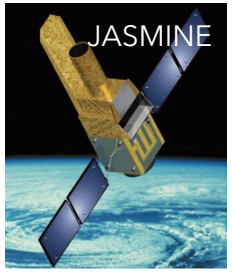
小山佑世 (国立天文台ハワイ観測所)

on behalf of ULTIMATE collaboration

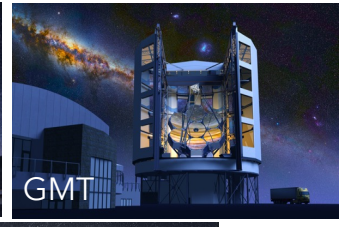
すばる望遠鏡のその先へ:「すばる２」とULTIMATE

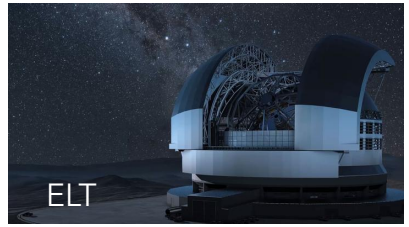


Great synergy with future space telescopes



Excellent target provider for 30m -class telescopes

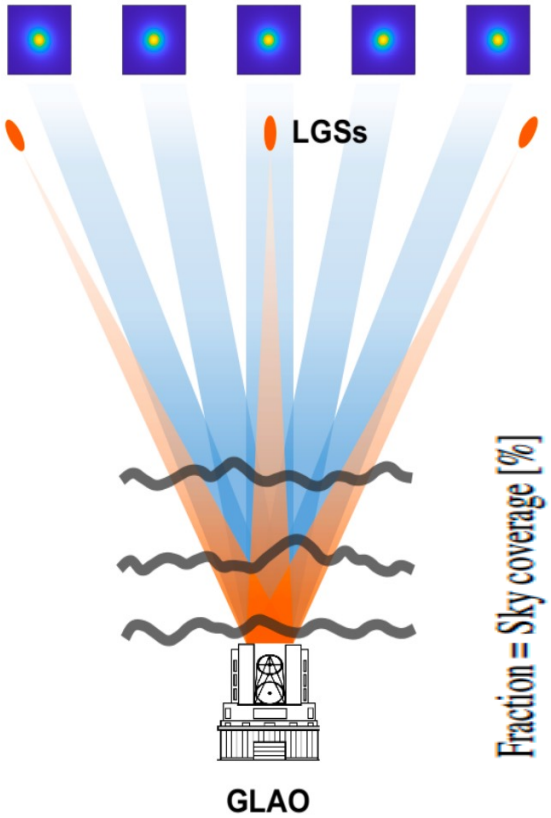




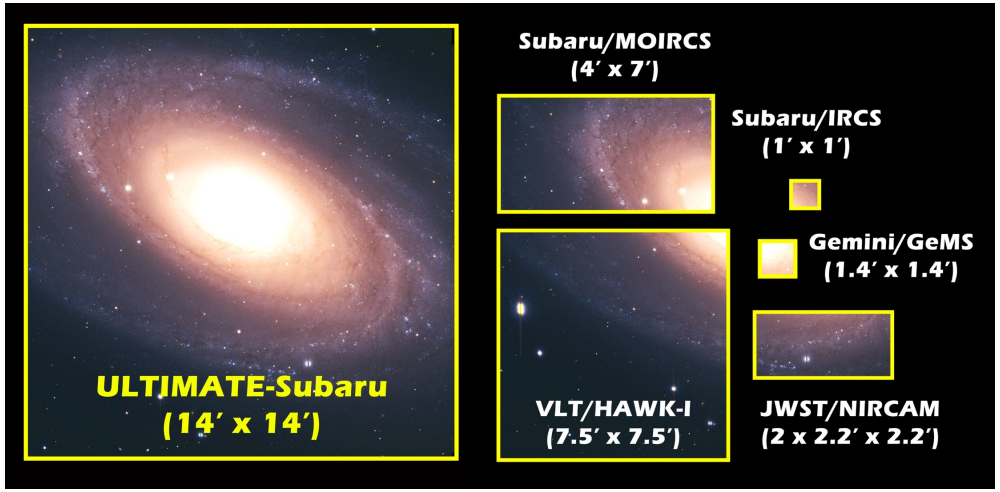
ULTIMATE-Subaru

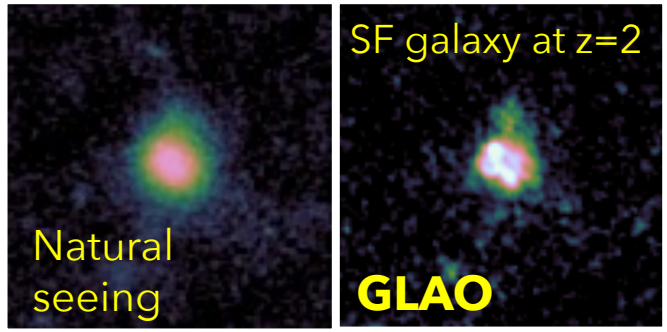
すばる広視野補償光学プロジェクト

「地表層補償光学(GLAO)」を搭載し、広い視野(約20分角)にわたって星像改善を目指す

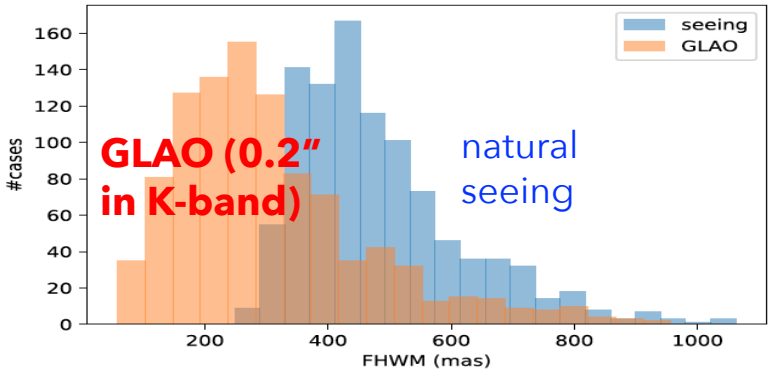


① 8m級望遠鏡で最大視野のAO+近赤外撮像

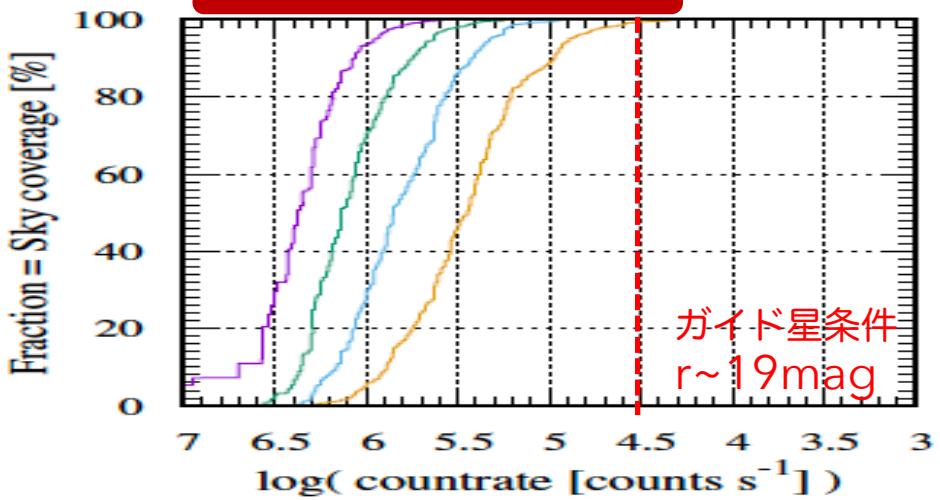




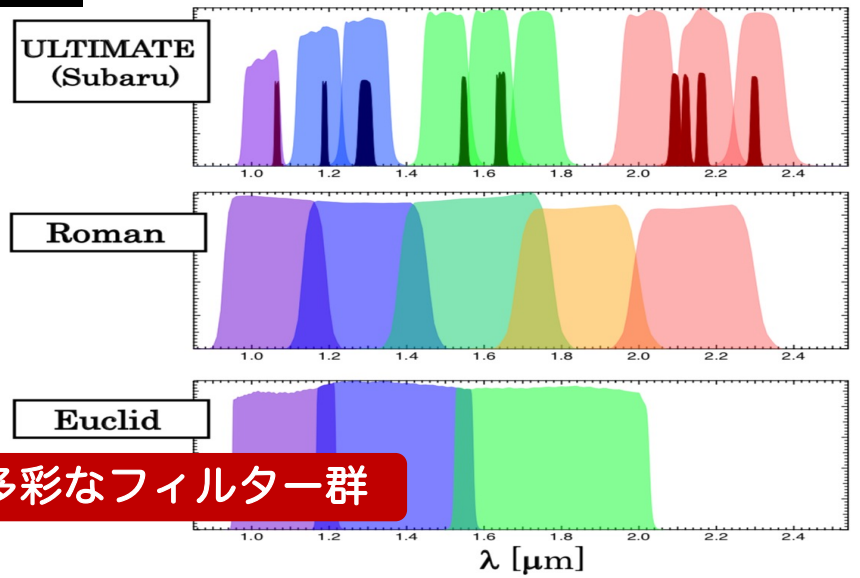
② 宇宙望遠鏡に匹敵する解像度



③ ほぼ全天で実現



④ 多彩なフィルター群



プロジェクトチーム構成(1): 装置開発チーム・プロジェクトコアチーム

ULTIMATE-Subaru project office

- Michitoshi Yoshida (NAOJ, Project PI)
- Yosuke Minowa (Subaru, Project Manager)
- Yusei Koyama (Subaru, Project Scientist)
- Takashi Hattori (Subaru, wide-field imager)
- Yutaka Hayano (Subaru, GLAO development)
- Junichi Katakura (Subaru, Project controller)
- Kentaro Motohara (NAOJ, wide-field imager, WFI)
- Hirofumi Okita (Subaru, Telescope upgrade)
- Yoshito Ono (Subaru, GLAO development)
- Ichi Tanaka (Subaru, MOIRCS upgrade lead)
- Yoko Tanaka (Subaru, GLAO optical design)
- Koki Terao (Subaru, GLAO development)
- Chihiro Tokoku (NAOJ, NINJA development)
- Shin Oya (NAOJ, GLAO development)
- Kenshi Yanagisawa (NAOJ, System engineer, wide-field imager)
- Hiroshige Yoshida (Subaru, GLAO/MOIRCS, software)
- Sadman Ali (Subaru, sensitivity WG)
- Masayuki Akiyama (Tohoku, GLAO development + science)
- Tadayuki Kodama (Tohoku, Science team lead)
- Hajime Ogane (Tohoku, GLAO/ULTIMATE-START)
- Masahiro Konishi (Univ. of Tokyo, wide-field imager)

ULTIMATE science core team

- Akio Inoue (Waseda)
- Tadayuki Kodama (Tohoku)
- Yusei Koyama (Subaru)
- Tomoko Suzuki (IPMU)
- Ken-ichi Tadaki (NAOJ)
- Kosuke Kushibiki (Tokyo)
- Sakurako Okamoto (Subaru)
- Shogo Nishiyama (Miyagi Univ. Educ.)
- Daisuke Suzuki (Osaka)
- Takafumi Kamizuka (Tokyo)
- Kumiko Morihana (Subaru)
- Yuhei Takagi (Subaru)
- Tsuyoshi Terai (Subaru)
- Takashi Moriya (NAOJ)

ANU team (Australia)

- Celine d'Orgeville (ANU, team lead)
- Doinne Haynes (ANU, project manager)
- Noelia Martinez Rey (ANU, project scientist)
- David Chandler (ANU, systems engineer)
- Nicholas Herrald (ANU, mechanical engineer)
- Israel Vaughn (ANU, Optical Engineer)
- Warrick Schofield (ANU, Mechanical Engineer)

ASIAA team (Taiwan)

- Shiang-Yu Wang (ASIAA team lead, project management)
- Masahiko Kimura (ASIAA, InR, Relay design)
- Chueh-Yi Chou (ASIAA, Relay design)
- Yin-Chang Chang (ASIAA, Relay design)
- Hsin-Yo Chen (ASIAA, InR design)

プロジェクトチーム構成(2): サイエンスチーム

Development Team
(AO & instruments)

ULTIMATE core
(project management team)

Project scientist
(Yusei Koyama)

ULTIMATE-Subaru
science team
(Aug 31 2023)

A. High-redshift Universe

Masayuki Akiyama
Yuichi Harikane
Takuya Hashimoto
Akio Inoue
Satoshi Kikuta
Tadayuki Kodama
Kotaro Kohno
Yusei Koyama
Mariko Kubo
Haruka Kusakabe
Yen-Ting Lin*
Yuichi Matsuda
Yoshiki Matsuoka
Yosuke Minowa
Takahiro Morishita
Rieko Momose
Tohru Nagao
Kimihiko Nakajima
Kazuyuki Ogura
Masato Onodera
Christian Rusu
Takatoshi Shibuya
Rhythm Shimakawa
Tomoko Suzuki
Ken-ichi Tadaki
Ichi Tanaka
Masayuki Tanaka
Jun Toshikawa
Yoshiki Toba
Hideki Umehata
Katherine Whitaker
Kiyoto Yabe

Multi-object IFU
F. Bian
J. Bryant
J. Bloom
A. Casey
S. Croom
S. Leslie
C. Lidman
D. Nataf
L. Kewley
I. T. Ho
A. Shaefer
T. Yuan
T. Zafar

B. Local Universe / Our Galaxy / Solar System

Daniela Calzetti
Masashi Chiba
Olivier Guyon
Arika Higuchi
Daisuke Iono
Miho Ishigaki
Takashi Ito
Takafumi Kamizuka
Hiroyuki Kaneko
Daisuke Kawata
Ji Hoon Kim
Masato Kobayashi
Jin Koda
Takuma Kokusho
Shinya Komugi
Yukihiro Kono
Shuhei Koyama
Yusei Koyama*
Kosuke Kushibiki
Patryk S. Lykawka
Yen-Ting Lin
Noriyuki Matsunaga
Tomonori Michiyama
Rie Miura
Yusuke Miyamoto
Kumiko Morihana
Kentaro Motohara
Takayuki Muto
Yoshikazu Nakada
Shogo Nishiyama
Yumiko Oasa
Keiji Ohtsuki
Sakurako Okamoto
Hiroki Onozato
Eric Peng
Tae-Soo Pyo
Toshiki Saito
Satoko Sorahana
Kazuo Sorai
Daisuke Suzuki
Masahiro Takada
Yuhei Takagi
Shunya Takekawa
Tsutomu T. Takeuchi
Tsuyoshi Terai
Kazufumi Torii
Junko Ueda
Chikako Yasui
Fumi Yoshida

C. Time Domain science

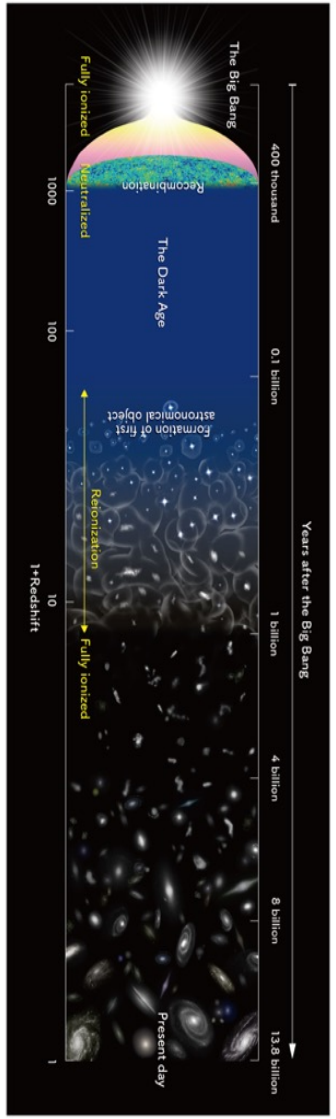
Akihiko Fukui
Naoaki Koshimoto
Yusei Koyama*
Chien-Hsiu Lee
Keiichi Maeda
Tomoki Morokuma
Takashi Moriya
Chow-Choong Ngeow
Masamune Oguri
Daisuke Suzuki*
Takahiro Sumi
Masaomi Tanaka
Kenneth C. Wong

NINJA / LTAO
Yusei Koyama*
Yoshiki Matsuoka*
Takashi Moriya
Kentaro Motohara*
Yosuke Minowa*
Tohru Nagao*
Yoshito Ono
Masami Ouchi
Shinobu Ozaki
Masaomi Tanaka*
Masayuki Tanaka*
Chihiro Tokoku
Koki Terao
Nozomu Tominaga
Kenshi Yanagisawa
Michitoshi Yoshida

Science Goal (1): ULTIMATE for *Deep* Universe

Unveiling the life of galaxies across cosmic time and environment from elementary scale

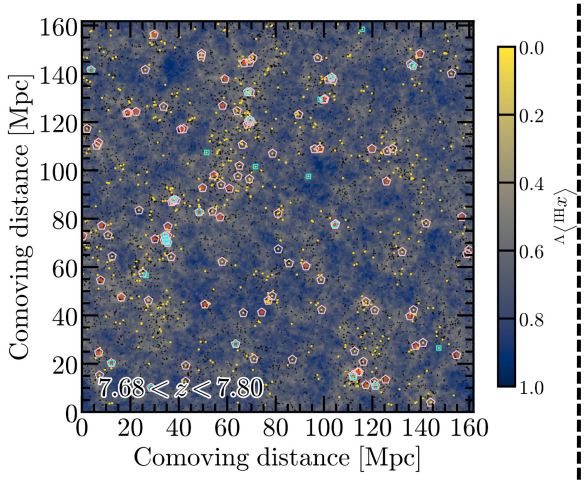
見たことのない宇宙を、この手に



1) Birth of Galaxies

Deep & Wide NB

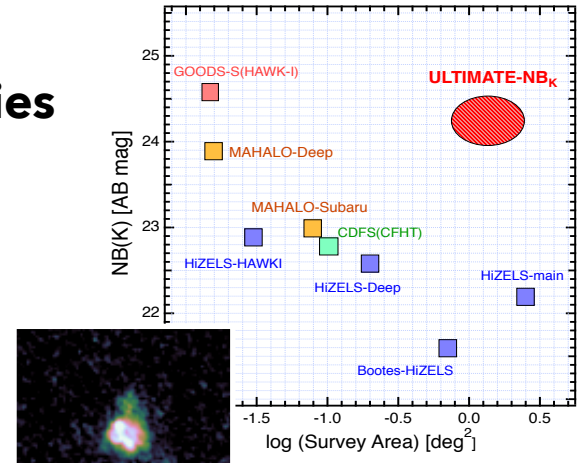
Unprecedentedly deep and wide NB imaging to search Lyα emitters in the epoch of cosmic reionization (at z>>7)



2) Growth of Galaxies

Sharp & Wide NB

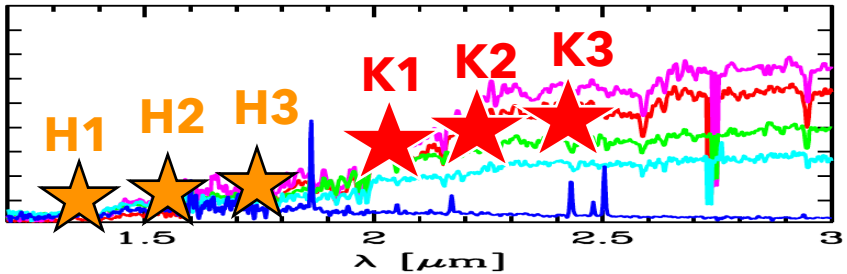
Stellar build-up inside the galaxies at the cosmic noon (z~2-3) epoch with deep and sharp NB(Hα/[OIII]) imaging in K-band.



3) Death of Galaxies

Deep & Wide MB

Understand the nature and environment of massive (quenched) galaxies by detecting the most massive galaxies at z~4-5 with deep/wide MB(K) imaging.

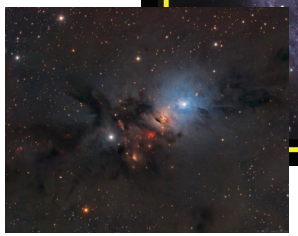


SEDs of z=4 galaxy

4) Nearby Galaxies & Galactic SF Regions

Sharp & Wide JHK+NB

- Spatially resolve nearby galaxies (D<10Mpc) into stars and star-forming regions.
- Sharp/deep imaging of SF regions in the Milky Way to study the IMF.



Science Goal (2): ULTIMATE for *Transient* Universe

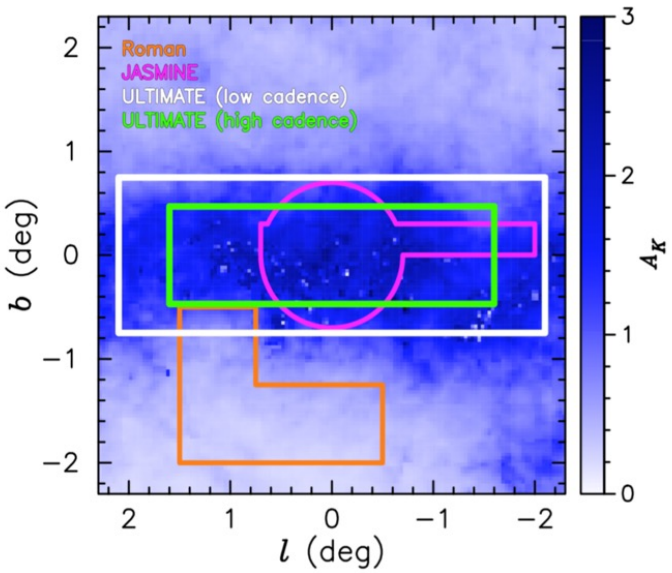
Understanding the evolution of stars, blackholes, and planets near and far

激動する宇宙を、究める

1) Galactic Center

Sharp & Wide JHK + NB

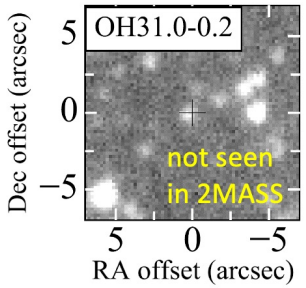
- High/low cadence survey toward the Galactic Center with ULTIMATE, to reveal hidden objects (blackholes and free-floating planets) in the Galactic Center with microlensing and astrometric approach.
- Synergy with JASMINE, Roman.

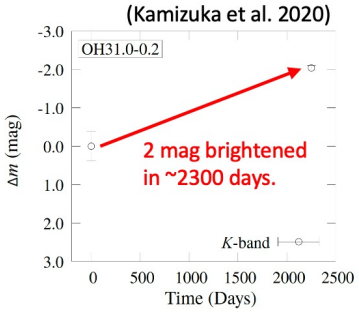


2) Galactic Plane

Sharp & Wide NB/MB

- Revealing the Milky Way structure and hidden stellar evolution (e.g. OH/IR stars).
- Paβ/Brγ imaging for cataclysmic variables, to reveal the Galactic Diffuse X-ray Emission

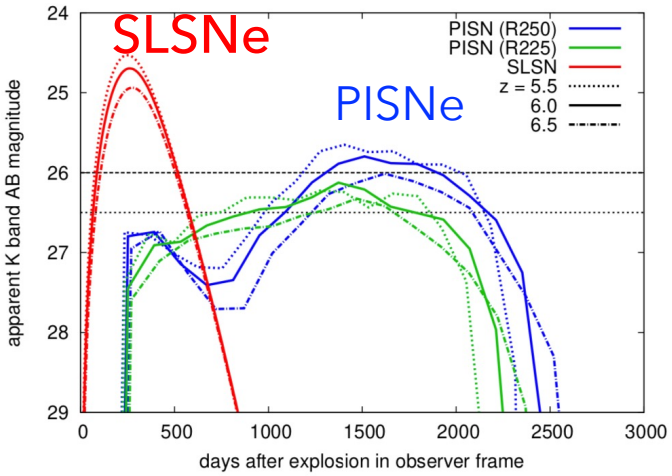




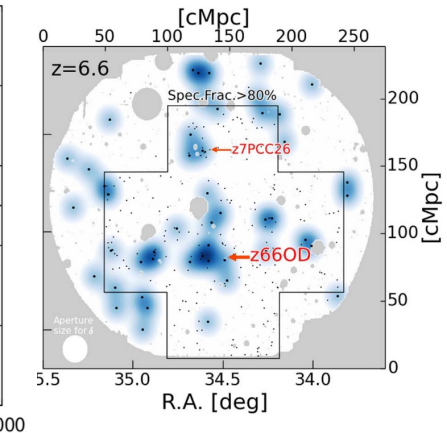
3) High-z Supernovae

Deep K-band imaging

- SNe search at z>6 – visiting ~1-deg^2 every 180-days down to K > 26 mag (AB) will allow us to detect PopIII pair-instability SNe at z>6.
- Boost the SNe detectability by targeting protoclusters/overdense regions identified by HSC (and Euclid/Roman) survey.



Moriya+2019

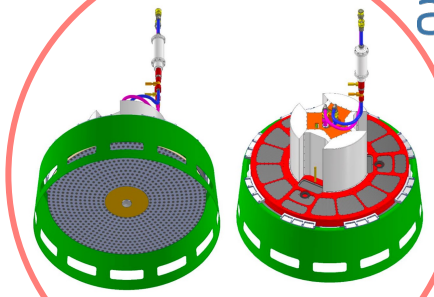


Harikane+2019

ULTIMATE-Subaru – GLAO + WFI

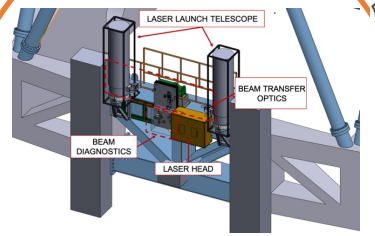
2019年度より、国立天文台の
「Aプロジェクト」として活動中
2028年のファーストライトを予定

ASM design



Adaptive Secondary

Australian National University — Optical/Mechanical design



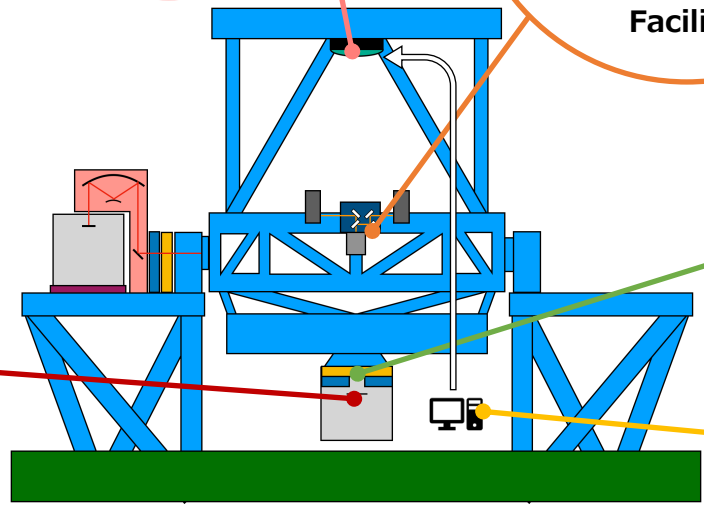
Laser Guide Star Facility

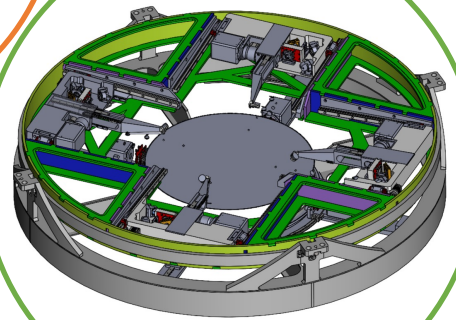
Prototyping

Wide-field Imager (WFI)

National Astronomical Observatory of Japan

東京大学 THE UNIVERSITY OF TOKYO





Wavefront Sensor

Australian National University — Mechanical design

Optical design

Prototyping

Real-time Controller + Control system

RTC based on the CACAO developed for SCExAO

- 科研費基盤S「すばる望遠鏡トモグラフィー補償光学で明かす銀河骨格の確立過程」(2017-2021年度, 代表: 秋山正幸)
- 科研費基盤S「高感度広帯域近赤外線分光で読み解く重力波源における元素合成」(2021-2025年度, 代表: 吉田道利)
- 科研費基盤B「JWSTと究極の多波長・高解像観測による銀河団銀河の形態発現プロセスの解明」 (2023-2025年度, 代表: 小山佑世)
- 研究拠点形成事業「地上・宇宙望遠鏡の連携による近赤外線広視野深宇宙探査時代の国際研究拠点形成」(2021-2025年度, 代表:吉田道利)
- 国際先導研究「宇宙における天体と構造の形成史の統一的理解」(2022-2028年度, 代表: 宮崎聡)

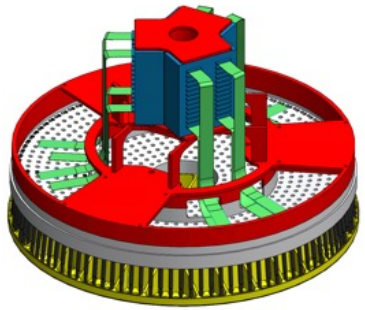
GLAO subsystem overview and status

2022年11月にGLAOの Preliminary Design Review (PDR) を実施 → 合格

Adaptive Secondary Mirror (ASM)

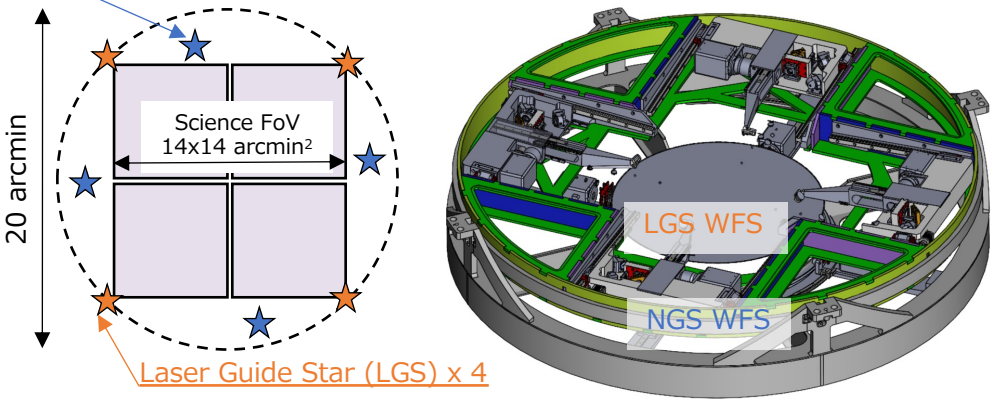
- Φ=1260mm deformable mirror with 924 actuators
- Adopt the well-developed technology from AdOptica/Italy.
- Final design completed in FY2021
- Fabrication started in FY2022

- ASM will be installed in the existing Infrared Secondary Mirror mount



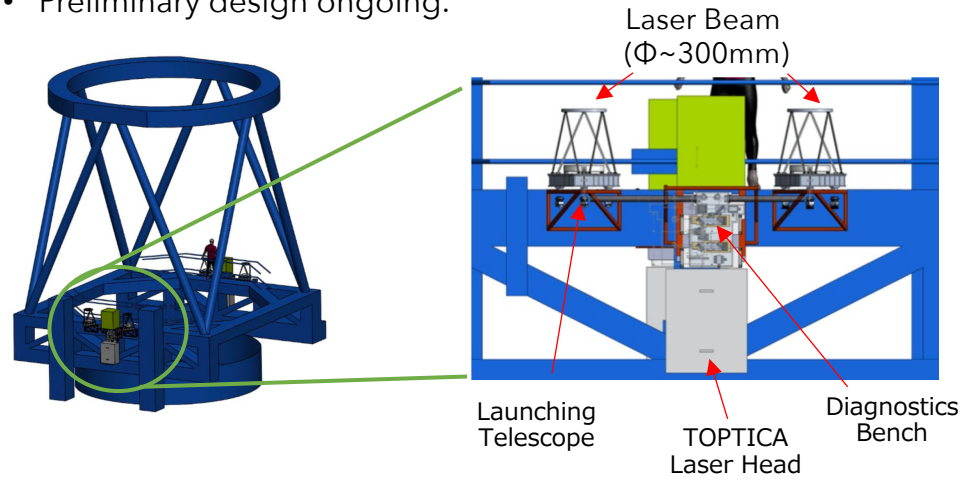
Wavefront Sensors (WFS)

- Equip with the 4 LGS WFSs to measure the turbulence at the ground layer and another 4 NGS WFSs to measure the low-order error that cannot be measured with the LGS.
- Preliminary Design completed in FY2021.



Laser Guide Star Facility (LGSF)

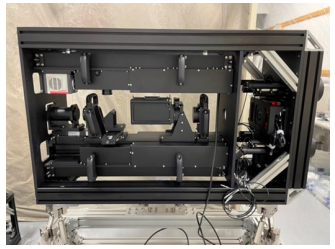
- Use 2 TOPTICA high-power lasers (22W) to generate 4 Laser Guide Stars.
- Launch the laser beams from the side of the telescope.
- Preliminary design ongoing.

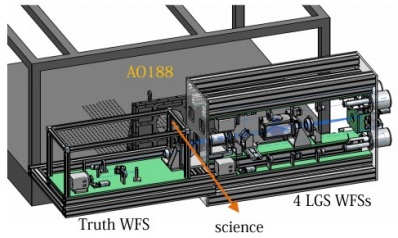


Key Technology Prototyping

- **ULTIMATE-START** - a Laser Tomography AO (LTAO) Wavefront Sensor with 4 x SH-WFS - has been developed for testing the camera, real-time control, etc. for the future GLAO system.
- TOPTICA laser guide star has been integrated at Subaru to provide 4 laser beams for LTAO.
- LTAO will be initially commissioned with AO188, and later be used with the ASM, providing a narrow-field (<10") LTAO mode in ULTIMATE.

TOPTICA laser commissioned at Subaru





LTAO WFS (ULTIMATE-START)

GLAO Preliminary Design Review (Nov 2022)

審査員(アルファベット順)

- **Julia Bryant**
  (Univ. of Sydney / Australia)
- **Mark Chun [Chair]**
  (Univ. of Hawaii / USA)
- **Jerome Paufique**
  (ESO)
- **Hideki Takami**
  (NAOJ / Japan)
- **Peter Wizinovich**
  (Keck Observatory / USA)
- **Takehiko Wada**
  (JAXA / Japan)

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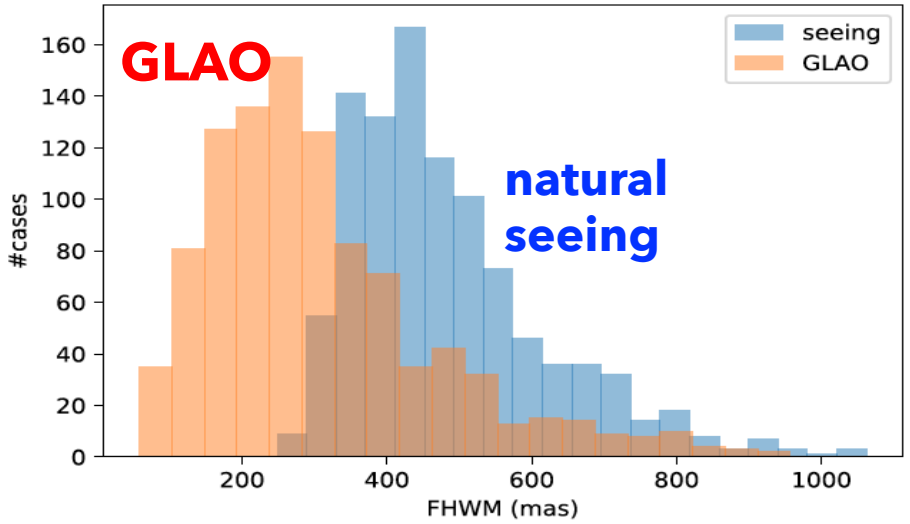
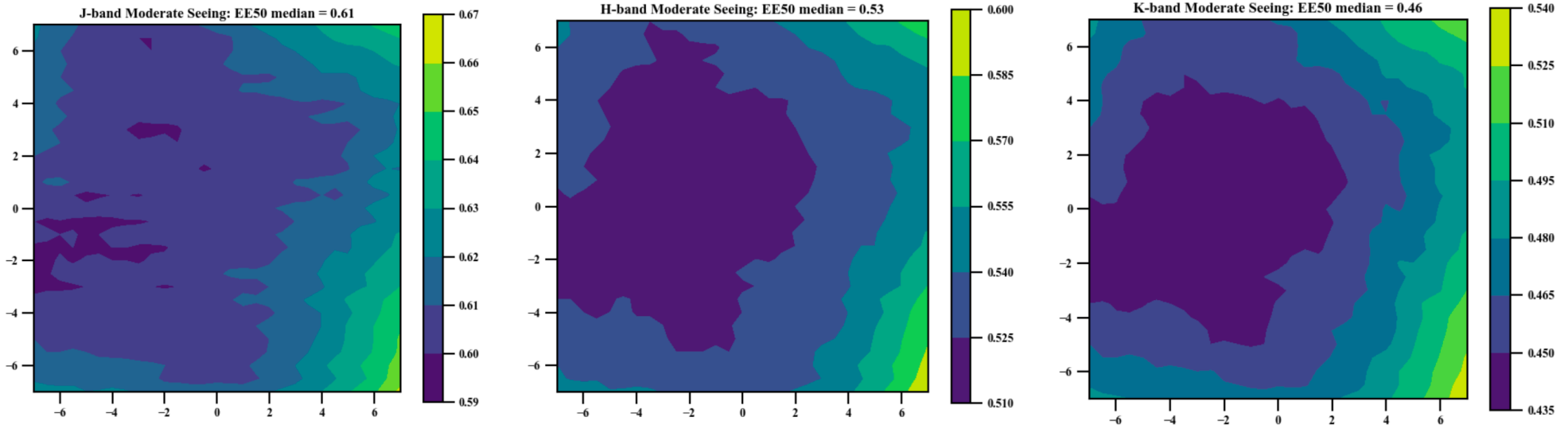
Expected GLAO performance

Wavelength (μm)	Good Seeing (25%) FWHM [arcsec]	β	EE50 [arcsec]	Moderate Seeing (50%) FWHM [arcsec]	β	EE50 [arcsec]	Bad Seeing (75%) FWHM [arcsec]	β	EE50 [arcsec]
GLAO + Science instrument									
J (1.26)	**0.24**	1.46	**0.46**	0.34	1.43	0.61	0.51	1.47	0.84
H (1.65)	0.21	1.49	0.40	0.28	1.44	0.53	0.42	1.45	0.75
Ks (2.15)	0.19	1.63	0.36	**0.24**	1.55	**0.46**	0.36	1.52	0.68
Natural Seeing + Science instrument									
J (1.26)	0.41	1.69	0.61	0.54	1.78	0.77	0.68	1.52	0.99
H (1.65)	0.38	1.81	0.57	0.49	1.74	0.72	0.63	1.66	0.93
Ks (2.15)	0.36	1.88	0.54	0.46	1.82	0.68	0.59	1.73	0.88



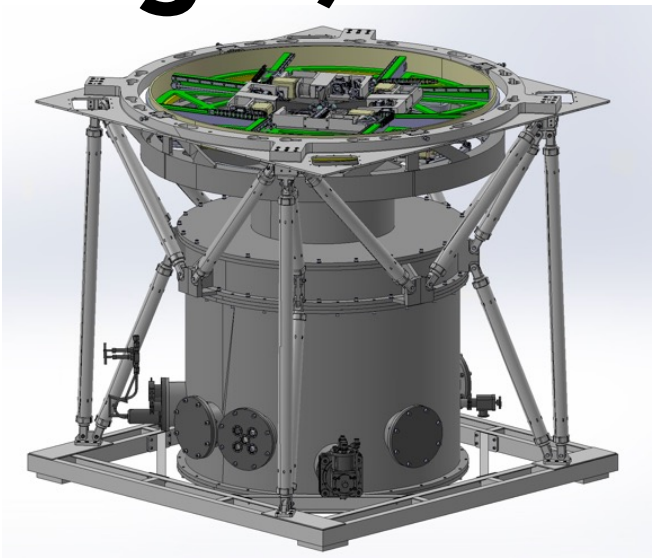
PSF uniformity (ΔPSF~10% over the entire 14′x14′ FoV)



Minowa et al. (2020)

ULTIMATE-WFI (Wide-Field Imager)

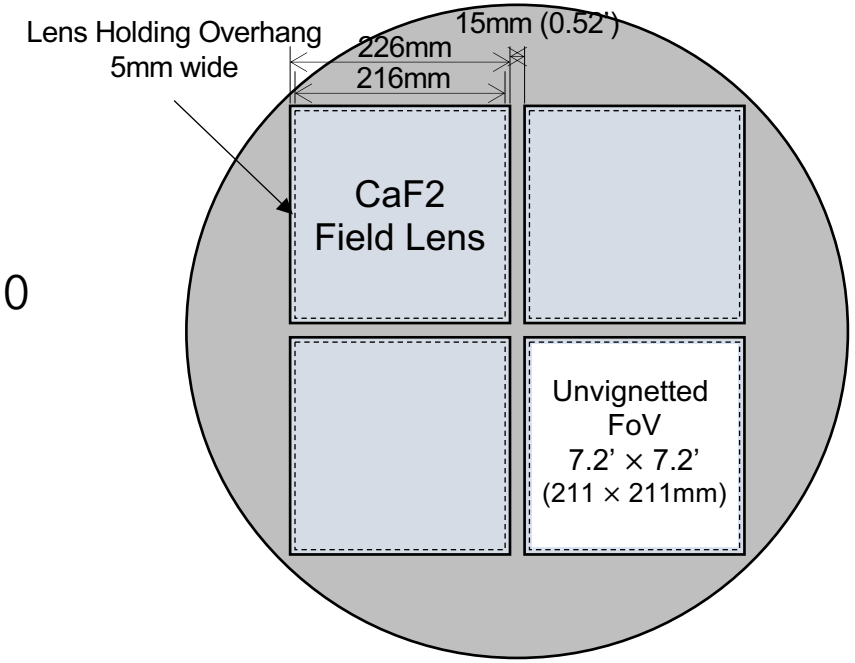
- 本体開発予算は大型科研費を申請中
- MBフィルターの製作は国際先導研究で予算措置済



Item	Requirements
Field of View	$15'.7 \times 15'.7$
Effective Field of View	$207\square'$ $(4\times7'.2\times7'.2)$
Pixel Sampling	$0''.11$/pix
Wavelength Coverage	0.9–2.5μm
Image Quality	FWHM$\leq 0''.10$
Number of Filters	15
Total Length	1500mm after the telescope focal plane

2021年に概念設計審査 (CoDR) に合格

Motohara+2020



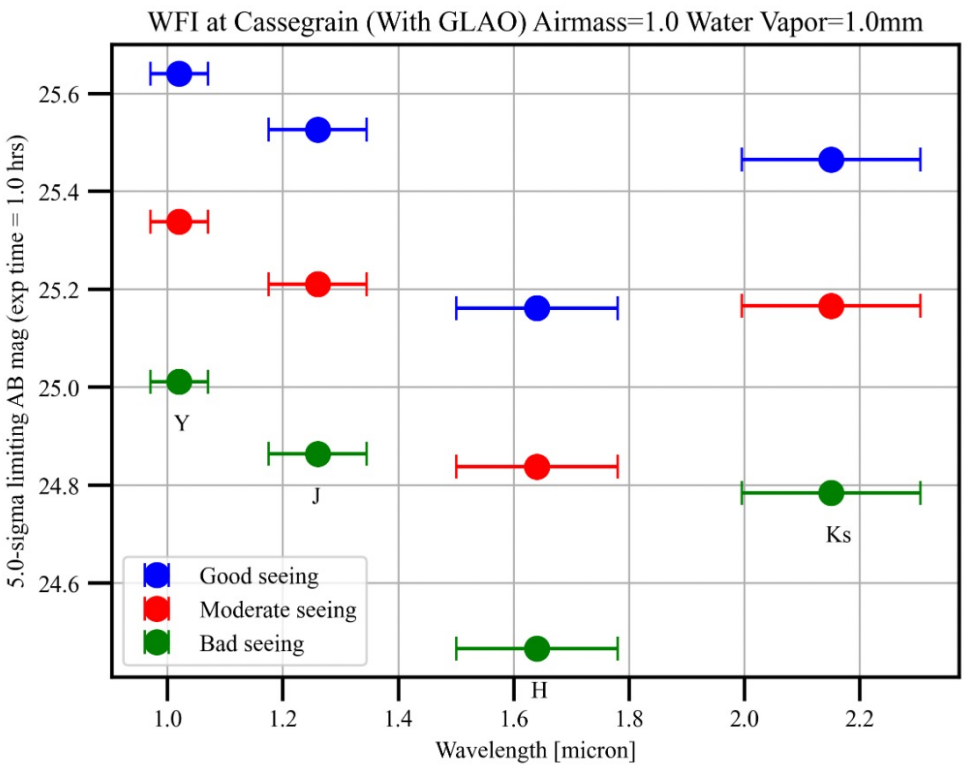
- **Four-barrel optical design**
  - Field is divided into four parts with independent relay optics
- **3 filter wheels to accommodate max. 15 filters per barrel**
  - Accept many filters (BB, MB, NB)
  - Design for easy filter replacement during downtime

Sensitivity – GLAO + WFI (broad-bands)

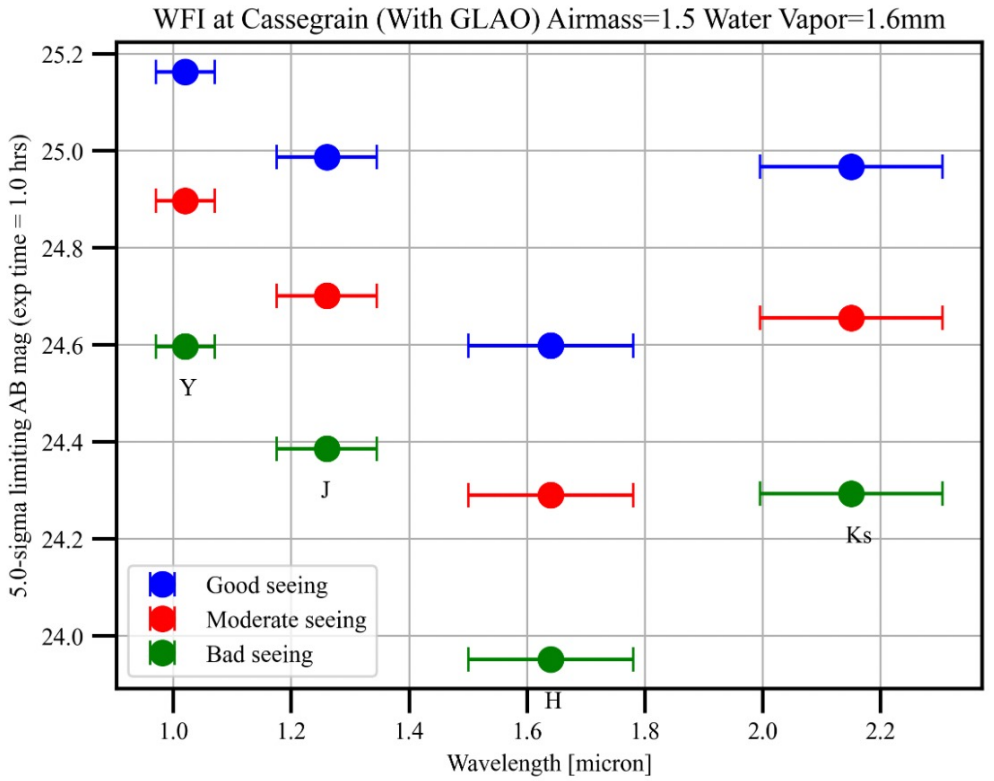
Point source sensitivity (5σ, 1-hour) for ULTIMATE BB/MB/NB filters:

- We can reach Ks = 25-26 mag (AB) with reasonable observing time.
- ~0.5 mag higher sensitivity than no-AO cases in K-band (~0.3-0.5 mag in Y/J/H).

理想的な条件



現実的な条件



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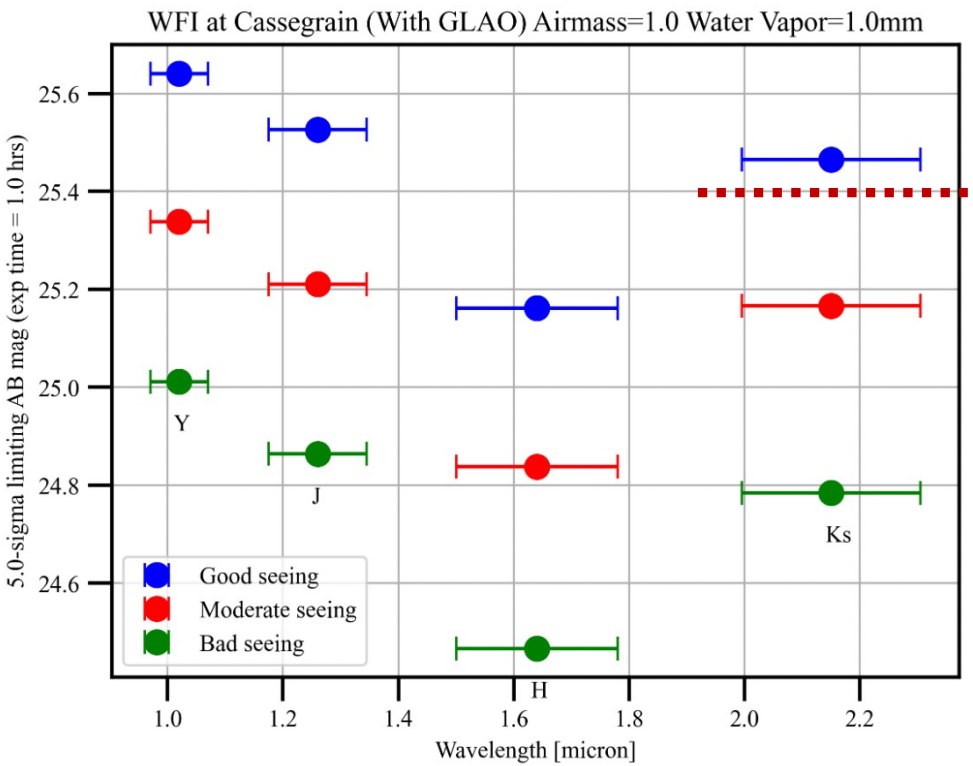
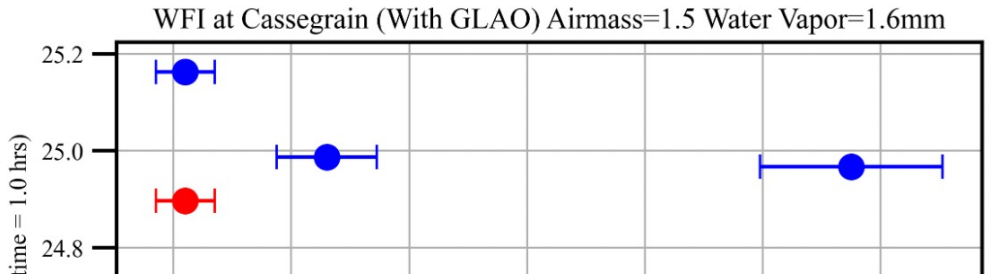
理想的な条件



Roman
Ksバンド
感度

現実的な条件



WIDE FIELD INSTRUMENT: IMAGING		
Filter	**Wavelength (μm)**	**Point-source sensitivity (AB Mag) 5σ in 1 hour**
F062 (R)	0.48–0.76	27.9
F087 (Z)	0.76–0.98	27.6
F106 (Y)	0.93–1.19	27.5
F129 (J)	1.13–1.45	27.5
F146 (I/H)	0.93–2.00	27.9
F158 (H)	1.38–1.77	27.4
F184 (H/K)	1.68–2.00	26.7
F213 (Ks)	1.95–2.30	25.4

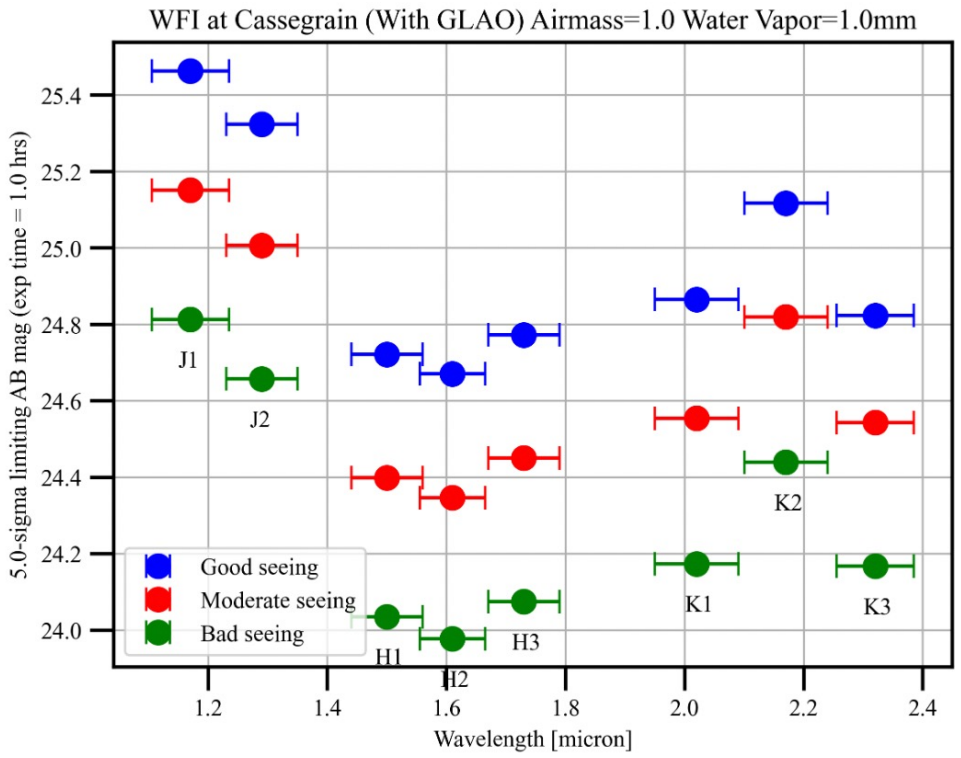
Roman Science and Technical Overview (ver. Summer 2023)

Sensitivity – GLAO + WFI (MBs/NBs)

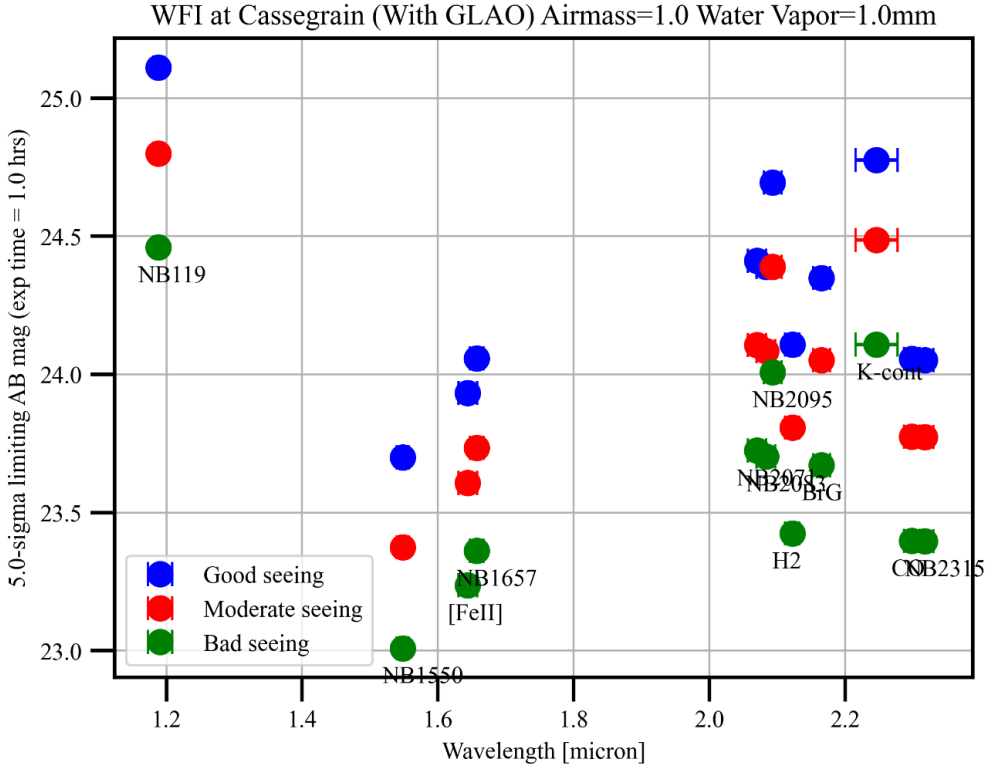
Point source sensitivity (5σ, 1-hour) for ULTIMATE BB/MB/NB filters:

- We can reach Ks = 25-26 mag (AB) with reasonable observing time.
- ~0.5 mag higher sensitivity than no-AO cases in K-band (~0.3-0.5 mag in Y/J/H).

MBs



NBs



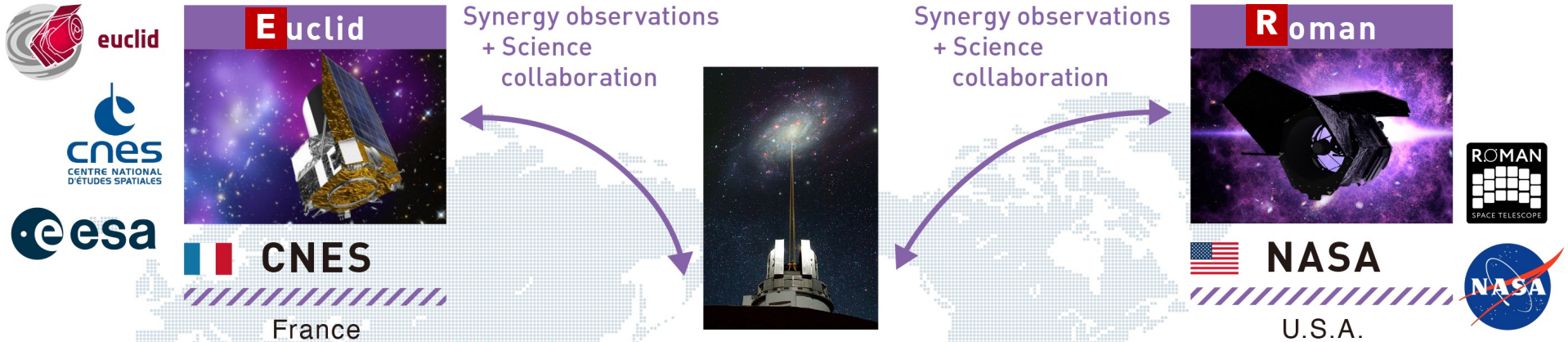
Only for best conditions – please expect ~0.3-0.5 mag shallower depths in the case of lower elevations.

研究拠点形成事業 2021年4月～2026年3月, 代表: 吉田道利 (国立天文台)

「地上・宇宙望遠鏡の連携による近赤外線広視野深宇宙探査時代の国際研究拠点形成」

- 2021～2022年度にかけてオンラインセミナーを６回開催
- 2023年3月に対面ワークショップを開催
- 2024年度中に２回目のワークショップを開催予定

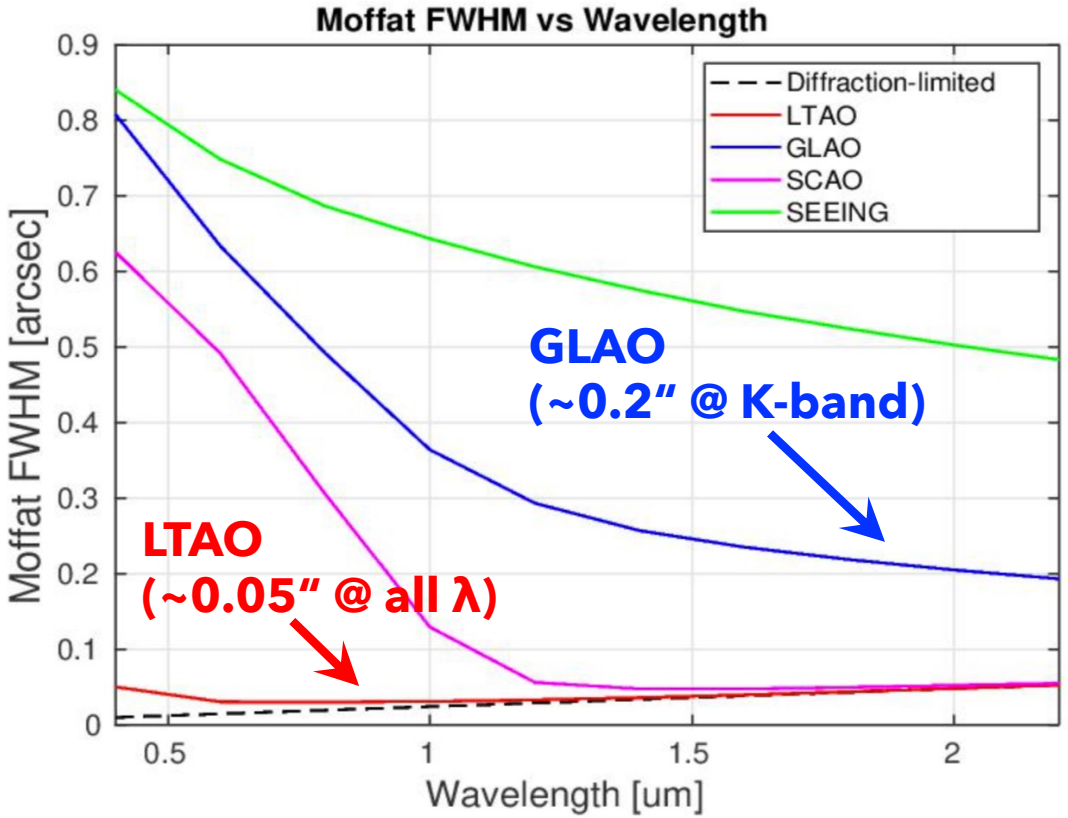
世話人: M.Yoshida/H. Miyatake/T. Moriya/D. Suzuki/Y.Koyama



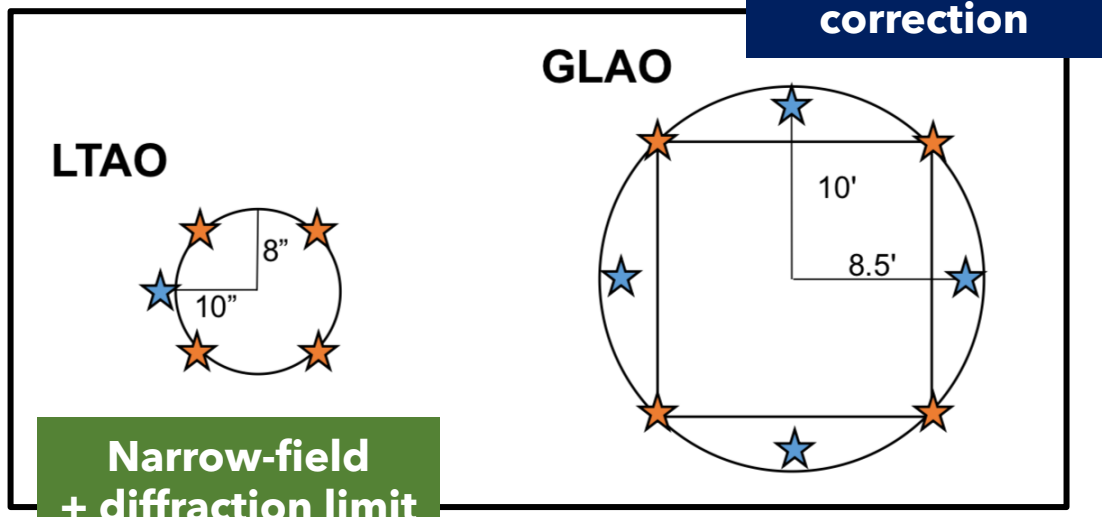
ULTIMATE "narrow-field (LTAO)" mode

- ULTIMATE is **not only** for wide-field science.
- Our "LTAO" mode can deliver ultimately high spatial resolution and high sensitivity for your favorite target!

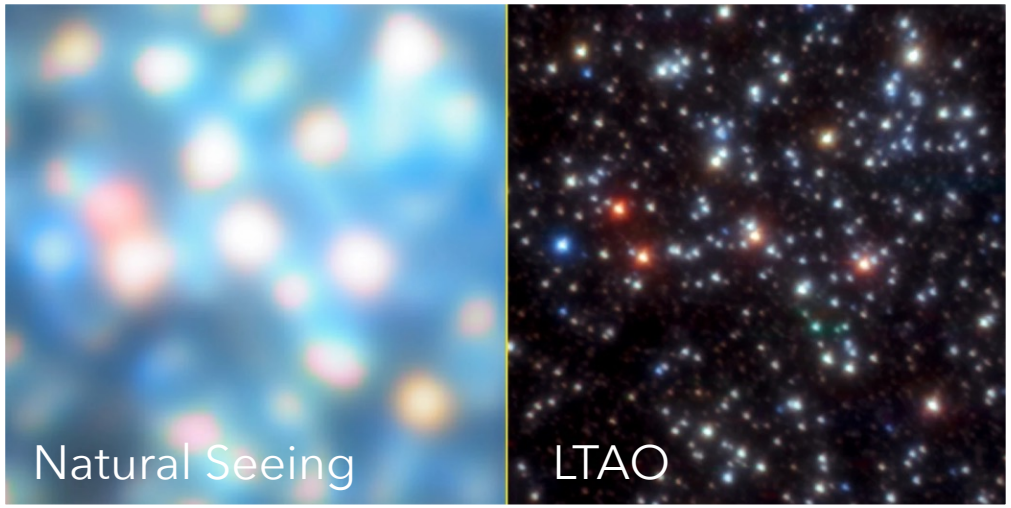
See O. Guyon's talk fore more details about narrow-field capabilities



Wide-field + moderate correction



Narrow-field + diffraction limit



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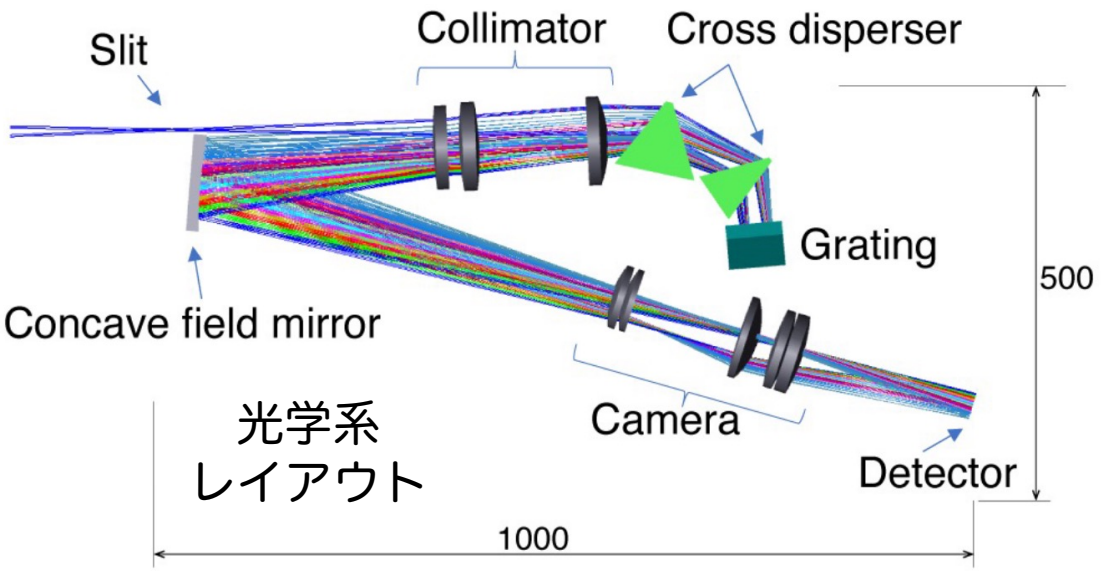
NINJA

Near-INfrared and optical Joint Spectrograph with Adaptive optics

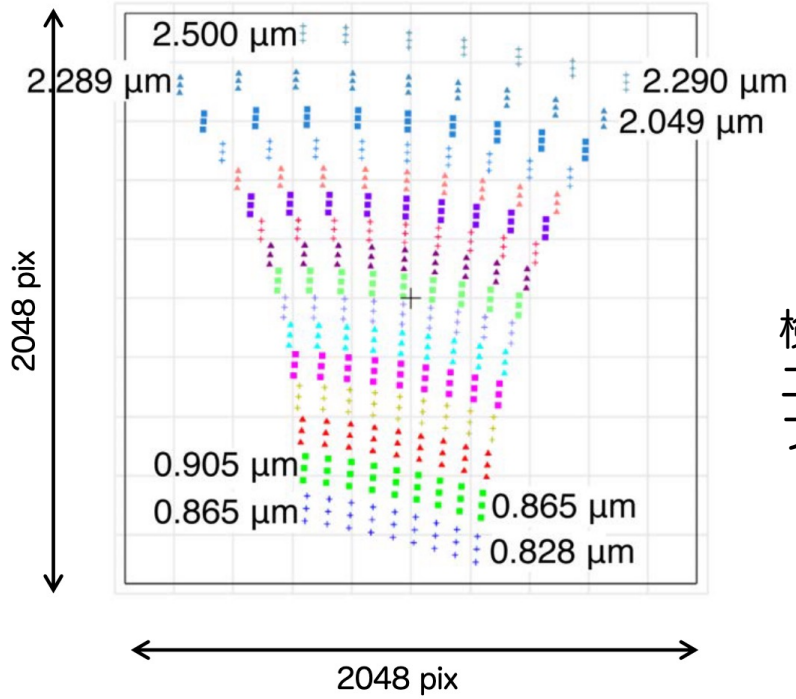
ポスターもご参照ください (Tokoku et al.)

- LTAO対応, 高感度広帯域分光装置
- **科研費(基盤S)**による開発
  - 「高感度広帯域近赤外線分光で読み解く重力波源における元素合成」
  - 2021～2025年度, 代表: 吉田道利 (国立天文台)
- すばるのPIタイプ装置として提案予定 (2026年度運用開始を目標)

波長範囲	0.83 – 2.5 μm
F比	13.9
スリット幅	0.35″ (0.19 mm) (TBD)
スリット長	5″ (2.7 mm)
コリメータ焦点距離	597.7 mm
瞳径	43.0 mm
グレーティング溝密度	56 lines/mm
グレーティングブレーズ角	33 degrees
検出器	HAWAII-2RG 1枚
検出器画素数	2048 x 2048 pix
検出器画素サイズ	18 μm/pix
サンプリング(0.35″スリット)	3.3 pix
波長分解能	R~3300



光学系
レイアウト



検出器上の
エシェル
フォーマット

NINJAメンバー: 東谷千比呂, 吉田道利, 守屋堯, 本原顕太郎, 尾崎忍夫, 柳澤顕史, 大野良人, 美濃和陽典, 寺尾航暉, 早野裕, 小山佑世, 冨永望, 大内正己, 田中賢幸 (国立天文台), 田中雅臣, 秋山正幸 (東北大学), 長尾透, 松岡良樹 (愛媛大学), 櫛引洸佑, 安田彩乃, 幸野友哉 (東京大学)

Tokoku et al. (2022)

Summary

- ULTIMATE = すばる２時代の明夜を担う次世代広視野補償光学 x 赤外線観測装置
- 2017年度: ”ULTIMATE-START”始動 [科研費, 代表: 秋山正幸]
- 2018年度: GLAOシステム Conceptual Design Review
- 2019年度: 国立天文台Aプロジェクト (すばるGLAOプロジェクト)
- 2021年度: 本格的な予算措置スタート
- 2021年度: SUPER-IRNET, NINJA始動 [科研費, 代表: 吉田道利]
- 2021年度: 観測装置 Conceptual Design Review
- 2022年度:「すばる２」始動, 可変副鏡の製作開始
- 2022年度: GLAOシステム Preliminary Design Review
- 2022年度: 国際先導研究スタート [科研費, 代表: 宮崎聡]

ファーストライト(2028年を予定)まであと５年！いよいよサーベイプランの
検討が本格化するこのタイミングで、是非サイエンスチームにご参加ください。