2022年度光赤天連シンポジウム (2022/9/20-22)

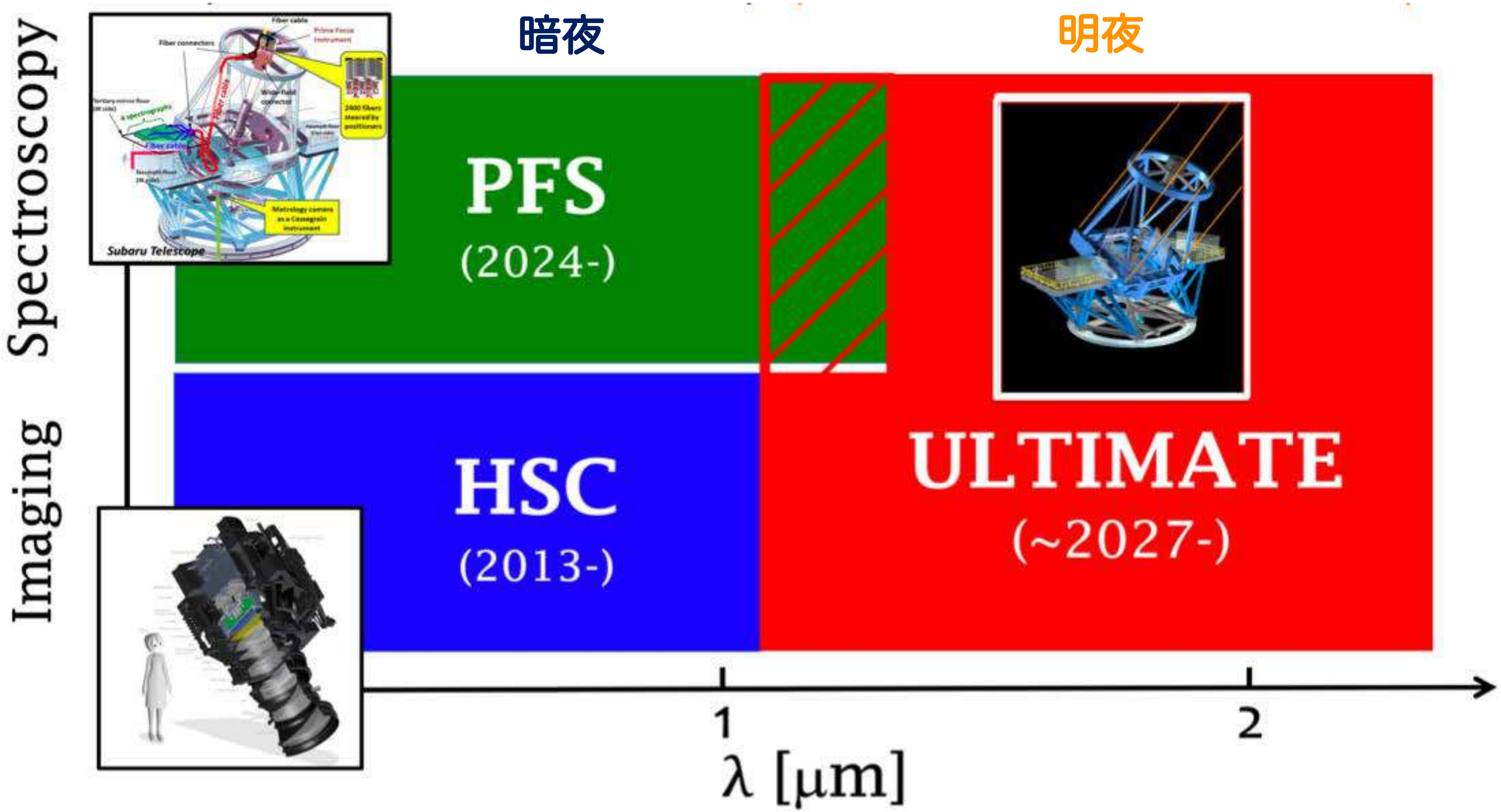
ULTIMATE-Subaru
プロジェクトの現状と課題

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

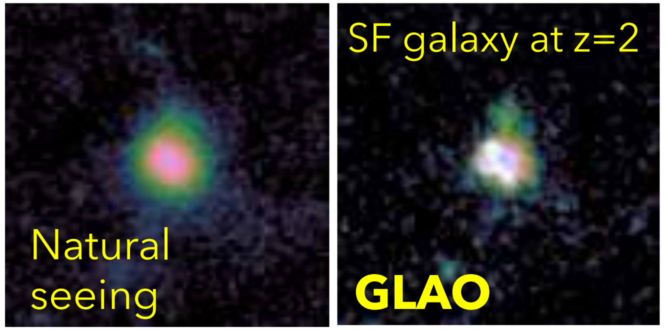
広視野観測のDNAを受け継ぎ、ULTIMATEは観測波長と大気揺らぎの壁を超える！

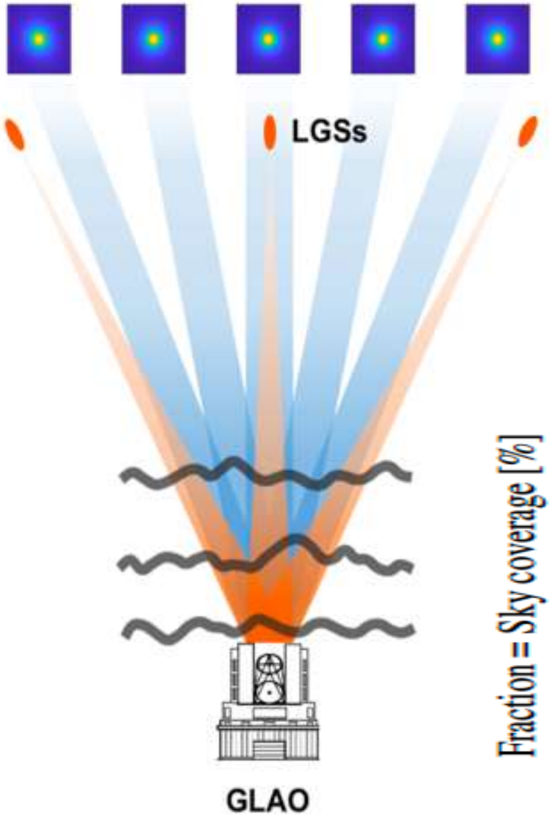


ULTIMATE-Subaru

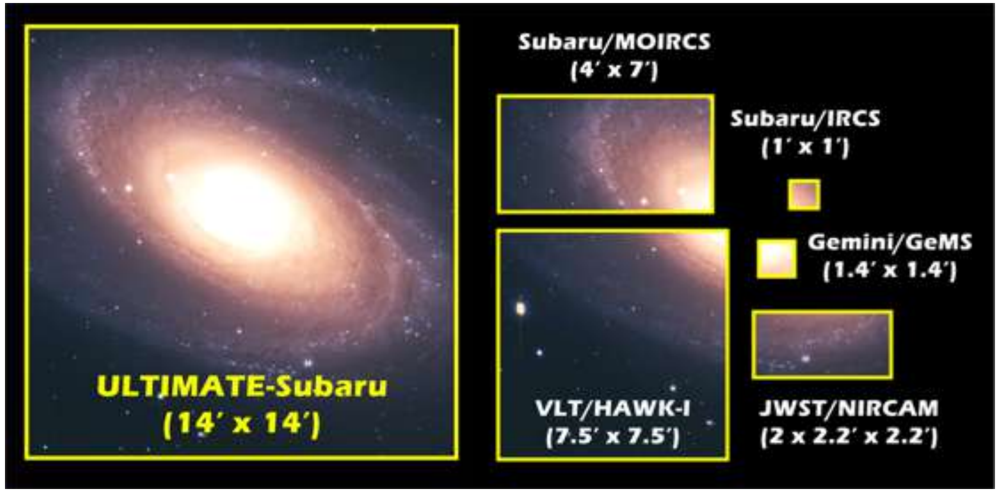
すばる広視野補償光学プロジェクト

「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。

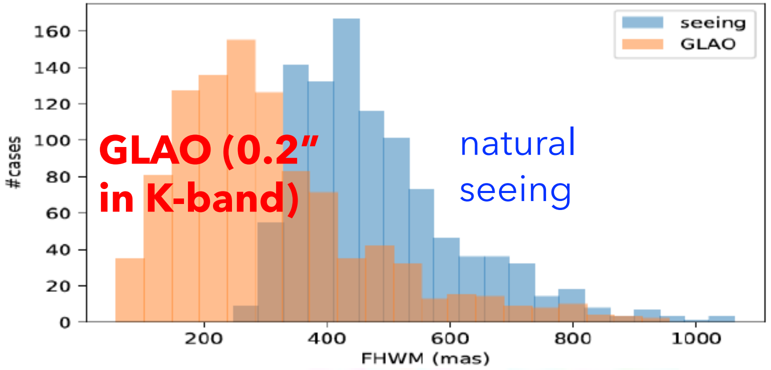




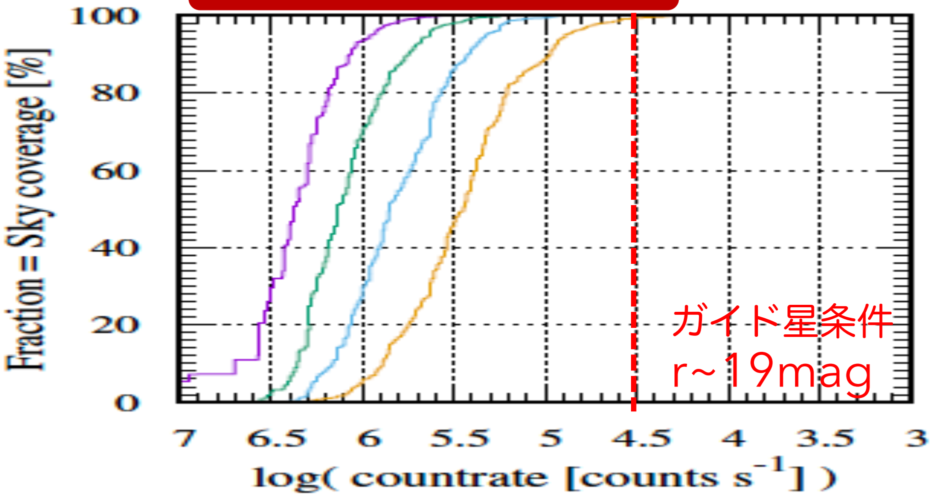
① 8m級望遠鏡で最大視野のAO+近赤外撮像



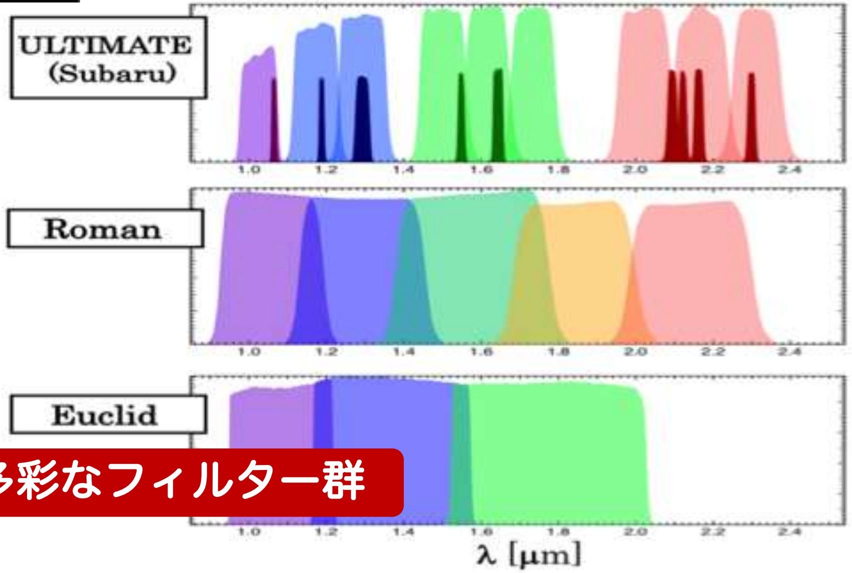
② 宇宙望遠鏡に匹敵する解像度

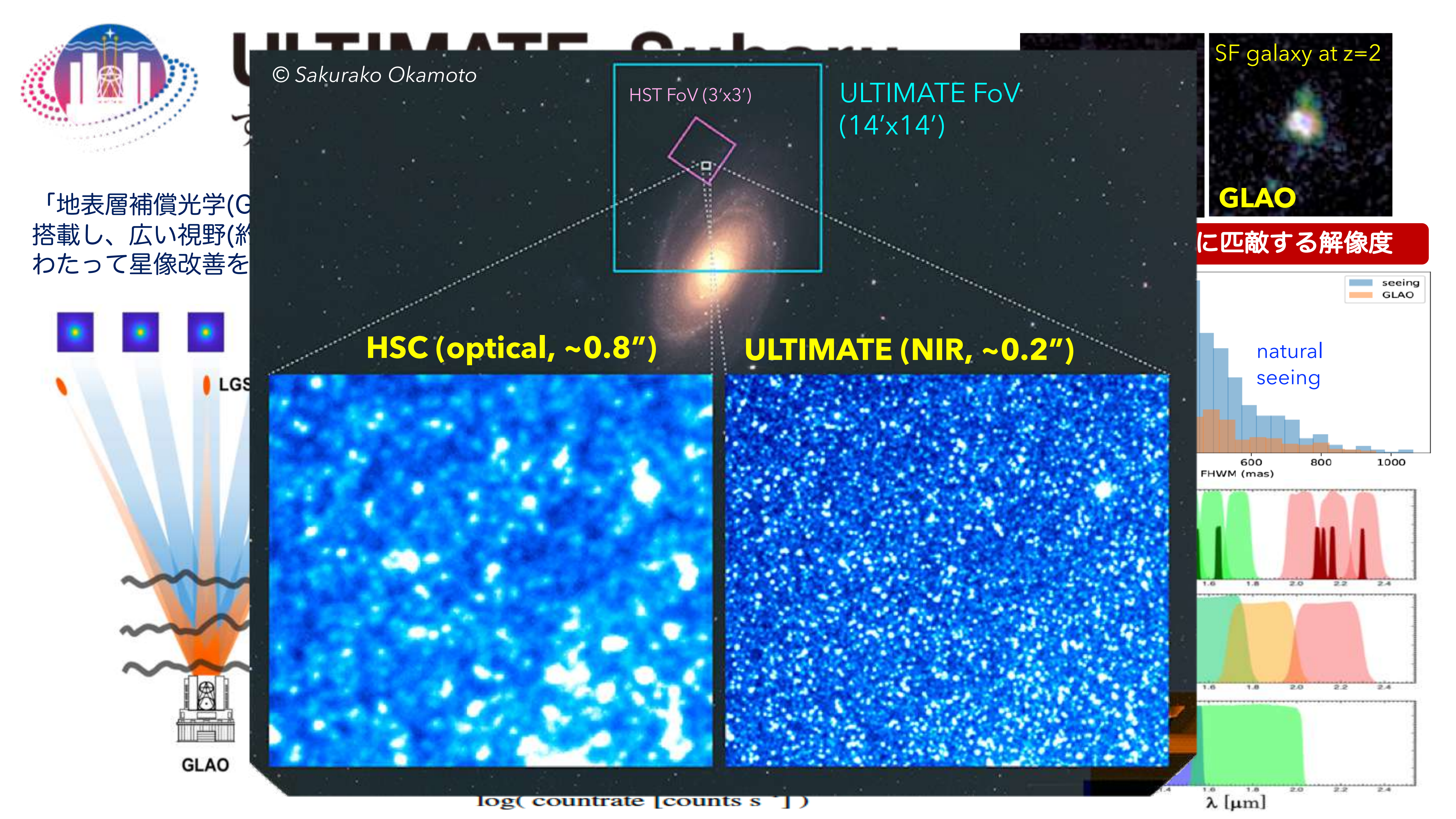


③ ほぼ全天で実現



④ 多彩なフィルター群




© Sakurako Okamoto
HST FoV (3′x3′)
ULTIMATE FoV
(14′x14′)
HSC (optical, ~0.8″)
ULTIMATE (NIR, ~0.2″)
SF galaxy at z=2
GLAO
に匹敵する解像度
seeing
GLAO
natural
seeing
600
800
1000
FHWM (mas)
GLAO
λ [μm]

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)
- Takuji Yamashita (NAOJ)
- 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
(Sep 16th 2022)

A. High-redshift Universe

Masayuki Akiyama
Yuichi Harikane
Takuya Hashimoto
Akio Inoue
Satoshi Kikuta
Tadayuki Kodama
Kotaro Kohno
Yusei Koyama
Mariko Kubo
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*
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
Takuji Yamashita
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
Nozomu Tominaga
Michitoshi Yoshida

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

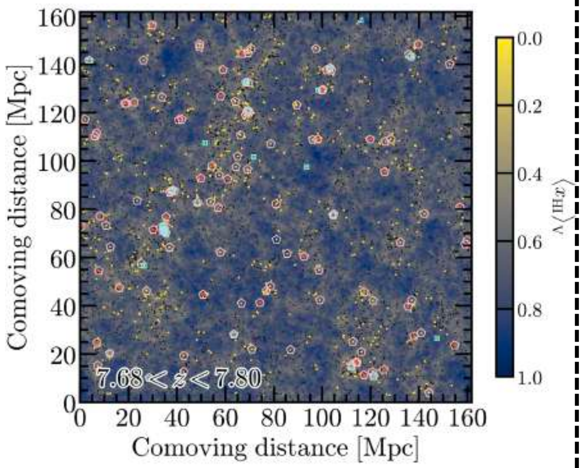
Unveiling the life of galaxies across cosmic time and environment from elementary scale

見たことのない宇宙を、この手に

1) Birth of Galaxies

Deep & Wide NB

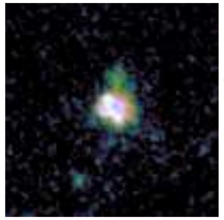
Unprecedentedly deep and wide NB imaging to search Lyα emitters in the epoch of cosmic reionization (at z>>7)

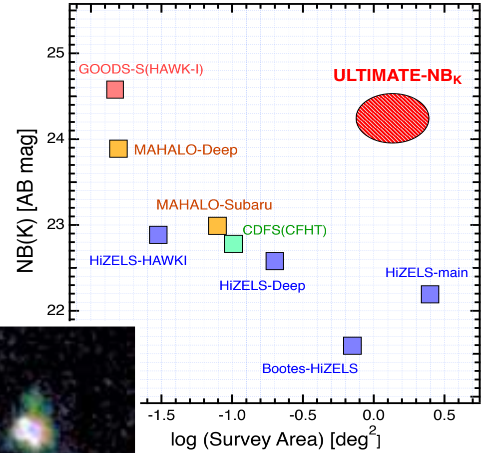


2) Growth of Galaxies

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.

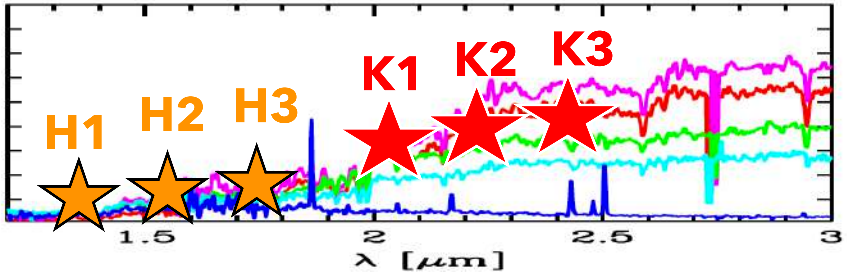




3) Death of Galaxies

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

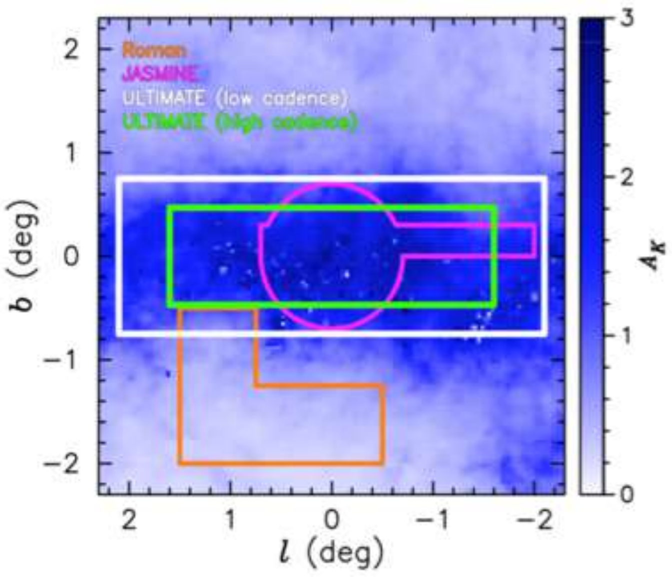
Understanding the evolution of stars, blackholes, and planets near and far

激動する宇宙を、究める

1) Galactic Center

Sharp & Wide JHK + NB

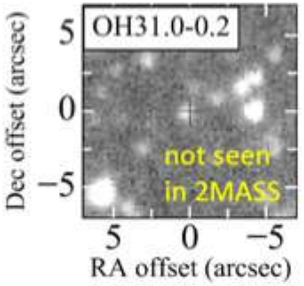
- High/low cadence survey toward the Galactic Center with ULTIMATE, to reveal hidden objects (blackholes and free-floating planets) in the Galactic Center with microlensing and astrometric approach.
- Synergy with JASMINE, Roman.

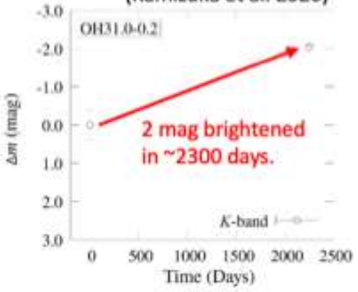


2) Galactic Plane

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



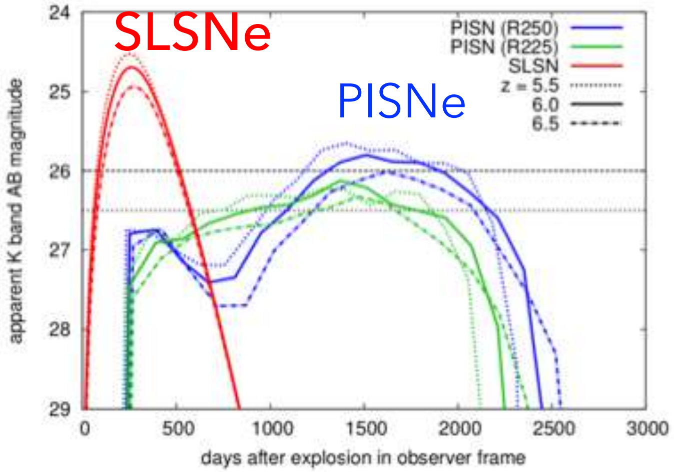


(Kamizuka et al. 2020)

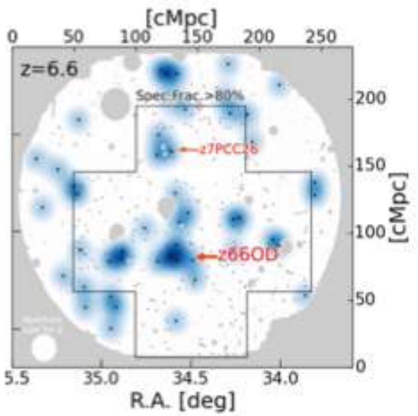
3) High-z Supernovae

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.

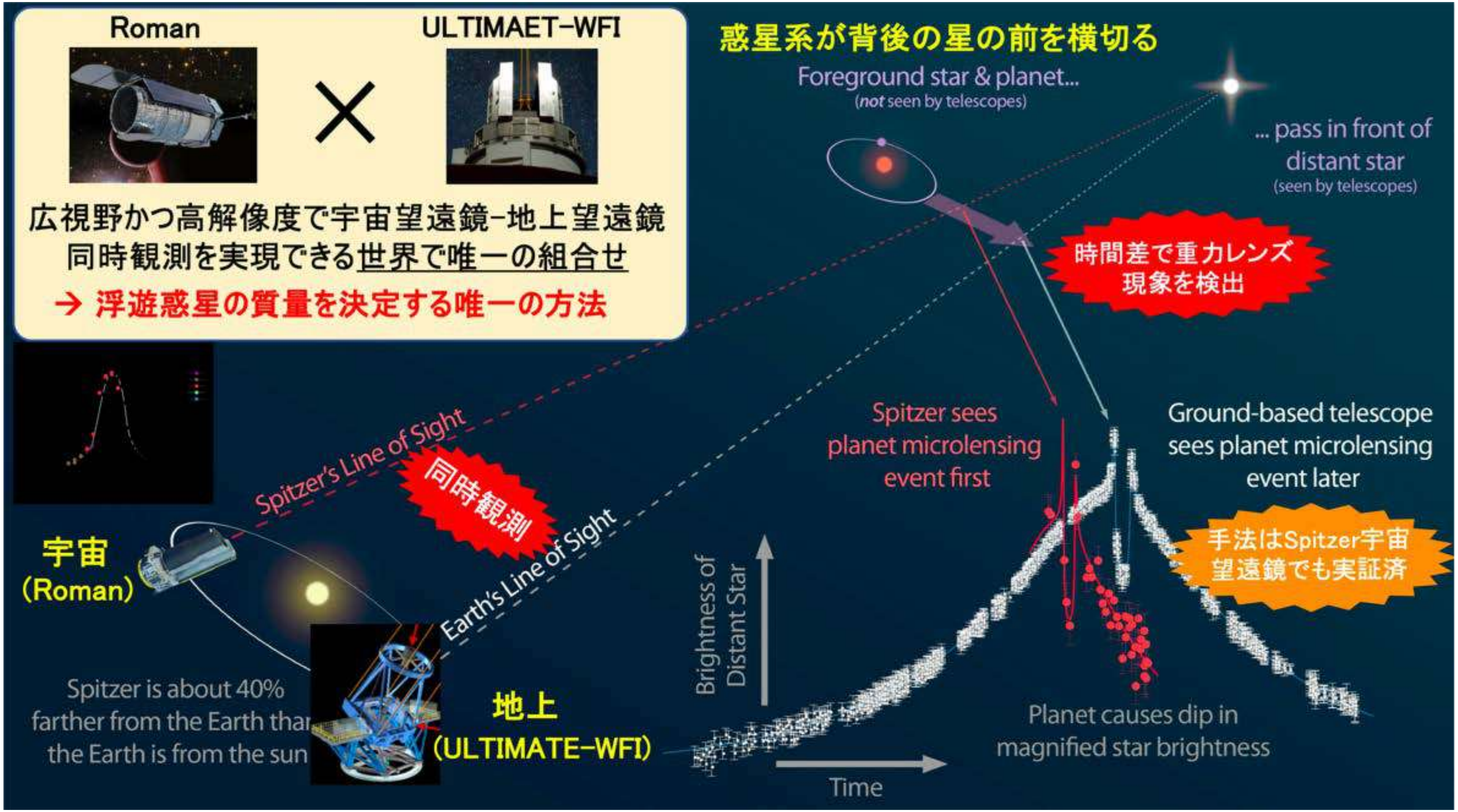


Moriya+2019



Harikane+2019

ULTIMATE(地上)とRoman(宇宙) 同時観測で広がるサイエンス



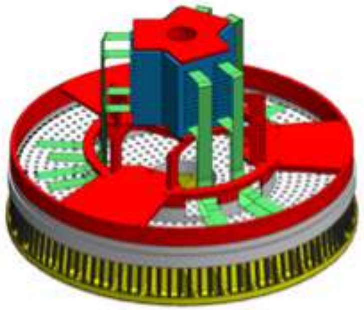
GLAO subsystem overview and status

2022年11月にGLAOの
Preliminary Design Review
(PDR) を予定

Adaptive Secondary Mirror (ASM)

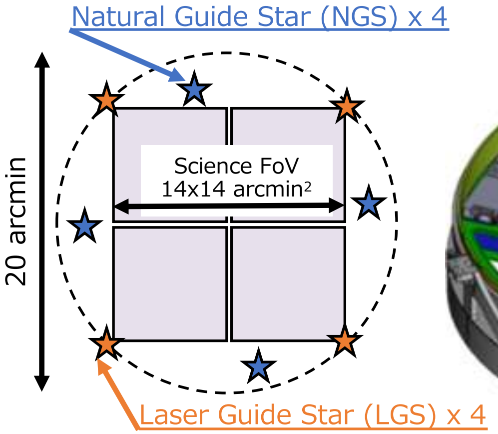
- Φ=1260mm deformable mirror with 924 actuators
- Adopt the well-developed technology from AdOptica/Italy.
- Final design completed in FY2021
- Start fabrication in FY2022

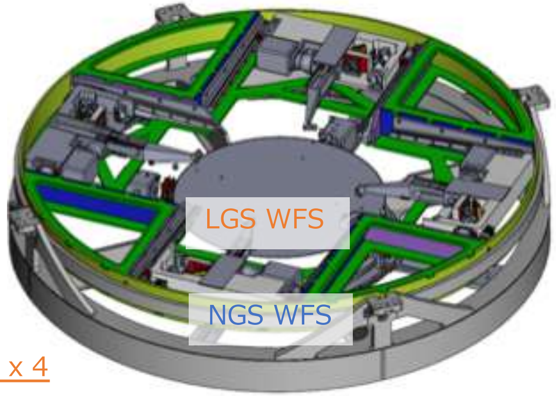
- ASM will be installed in the existing Infrared Secondary Mirror mount



Wavefront Sensors (WFS)

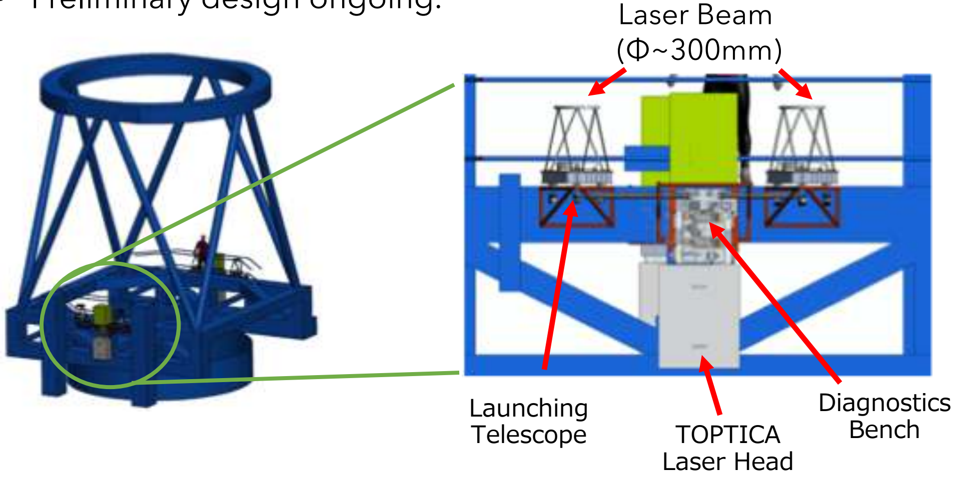
- Equip with the 4 LGS WFSs to measure the turbulence at the ground layer and another 4 NGS WFSs to measure the low-order error that cannot be measured with the LGS.
- Preliminary Design completed in FY2021.





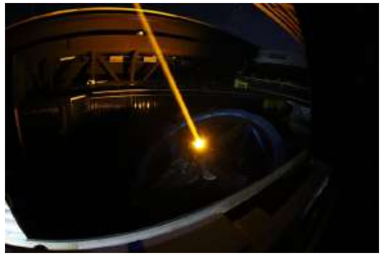
Laser Guide Star Facility (LGSF)

- 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.

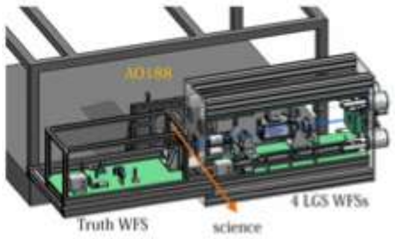


Key Technology Prototyping

- **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



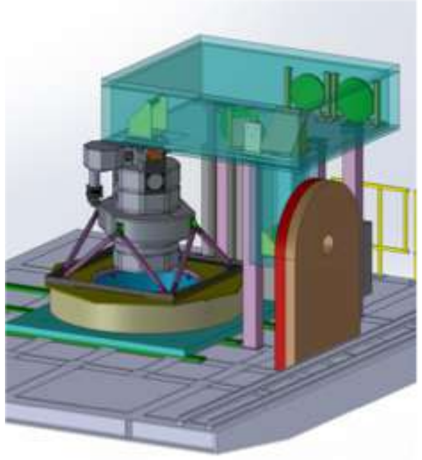
LTAO WFS (ULTIMATE-START)

ULTIMATE 観測装置プラン

外部資金による開発が前提

① MOIRCS

- NsIRへ移設
- FoV: 4′ x 7′
- 0.12″ /pix
- λ: 0.9-2.5um
- Imaging + **MOS** spectroscopy



ファーストライト装置として期待

② WFI

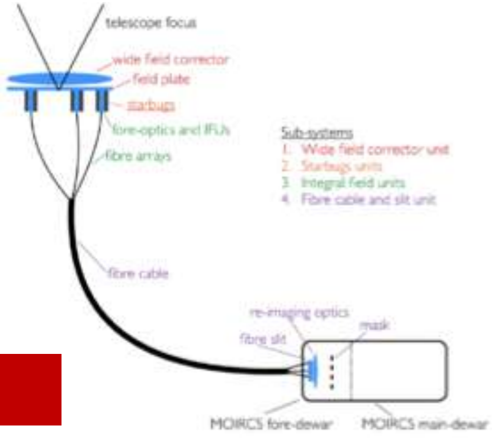
大型科研費申請中

- Cs
- FoV: **14′ x 14′**
- 0.1″/pix
- λ: 0.9-2.5um
- NB/MB/BB imaging
- K~26mag (AB, 5σ, 5h)

ULTIMATEの主力装置, 300夜クラスのSSPを想定

③ Fiber-bundle multi-obj IFU

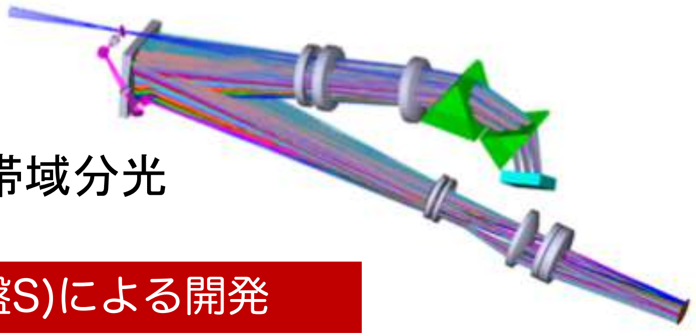
- Cs (w/ MOIRCS/PFS)
- FoV: 14′ x 14′
- **IFU** FoV: 1.2″x1.2″
- λ: 0.9-1.8um
- Multiplicity: 8-13



オーストラリアより提案

④ NINJA spectrograph

- NsIR
- 1天体集中
- 最高感度
- R~3000-4000
- λ: 可視〜近赤外広帯域分光



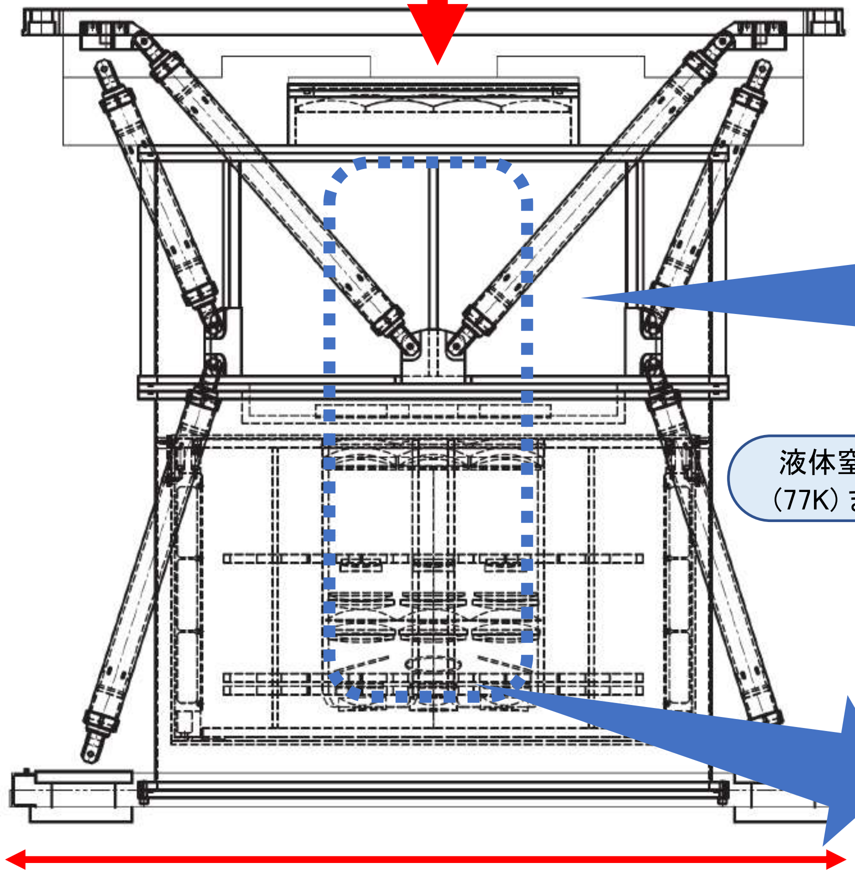
LTAO装置, 科研費(基盤S)による開発

ULTIMATE-WFI (Wide-Field Imager)

ULTIMATEの主力装置, GLAOの視野全面(~200平方分角)をカバーする

真空冷却容器

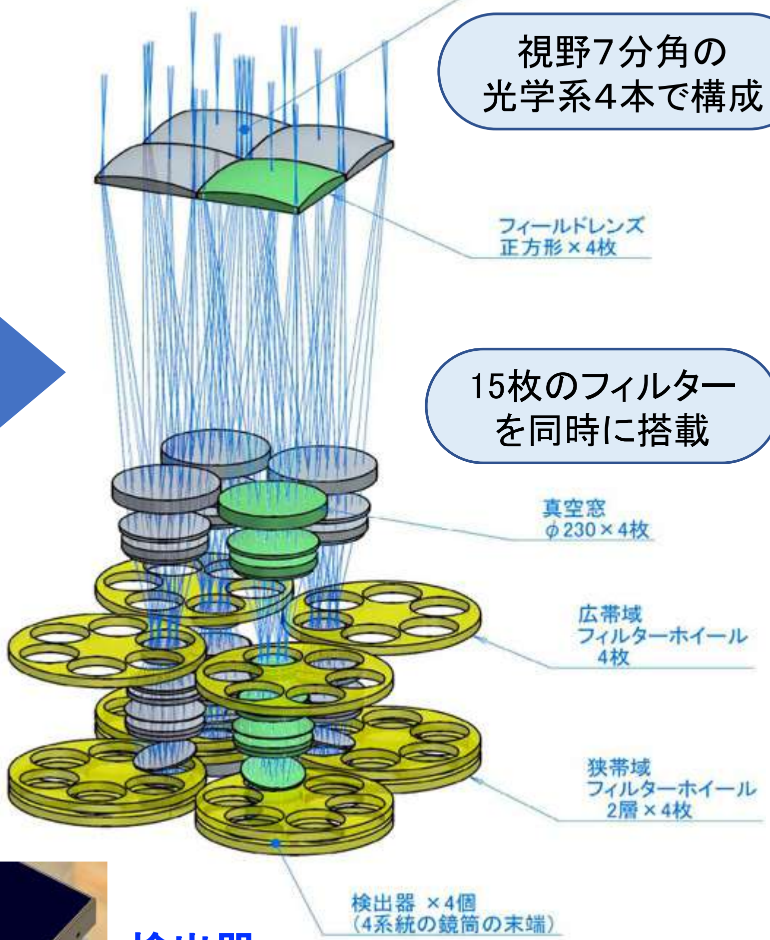
望遠鏡からの光



液体窒素温度 (77K) まで冷却

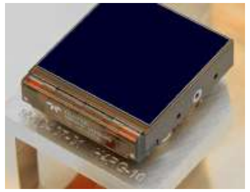
総重量3トン (2m x 2m x 2m)

光学系



視野7分角の光学系4本で構成

15枚のフィルターを同時に搭載



検出器

焦点面を4枚の4Kx4KHgCdTe検出器(HAWAII-4RG)でカバー, pixel scale = 0.11”/pix

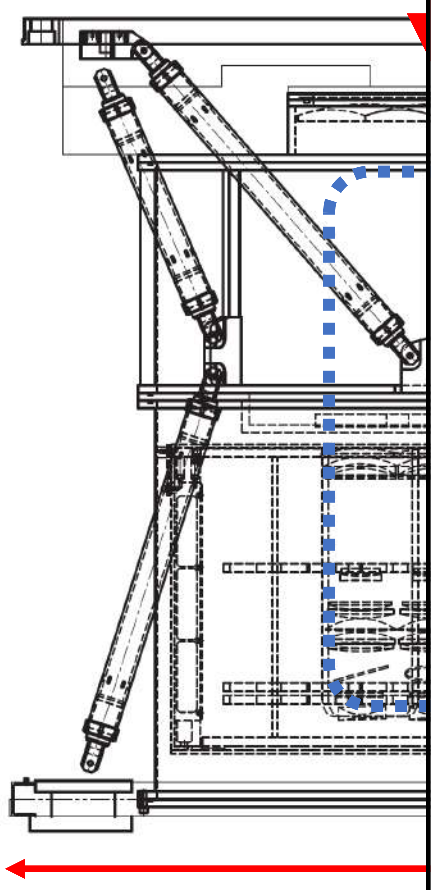
2021年6月に概念設計審査を実施

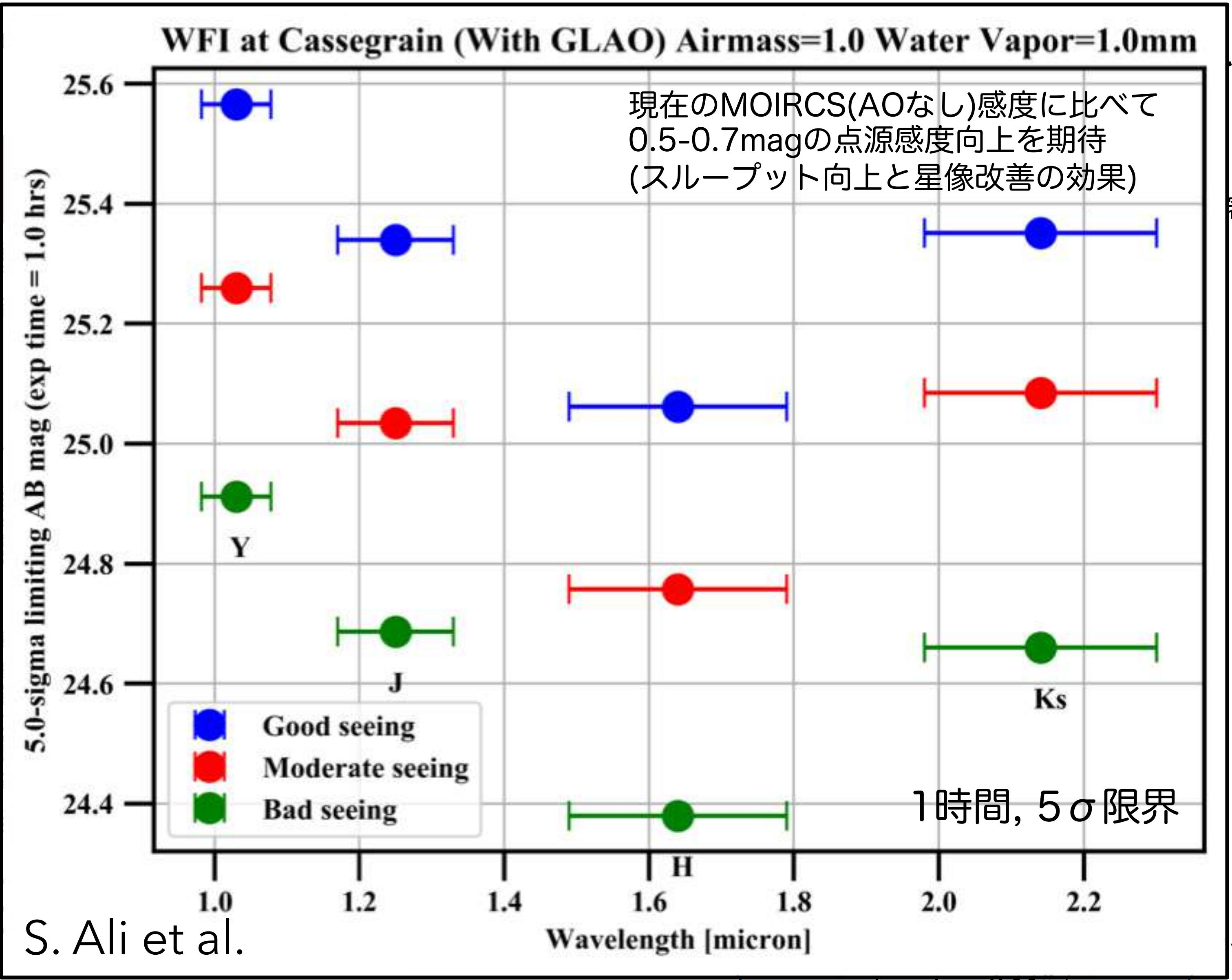
審査員(アルファベット順)

- **Rene Doyon** (U. Montreal/Canada)
- **Takashi Ichikawa** (Tohoku Univ./Japan)
- **Jessica Lu** (UC Barkley/USA)
- **Tetsuya Nagata** (Kyoto Univ./Japan)
- **Hideko Nomura** (NAOJ/Japan)
- **Youichi Ohyama** (**chair**, ASIAA/Taiwan)
- **James Rhoads** (NASA/USA)
- **Lee Spitler** (Macquarie/Australia)

ULTIMATE-WFI (Wide-Field Imager)

ULTIMATEの主力装





2021年6月に
概念設計審査を実施

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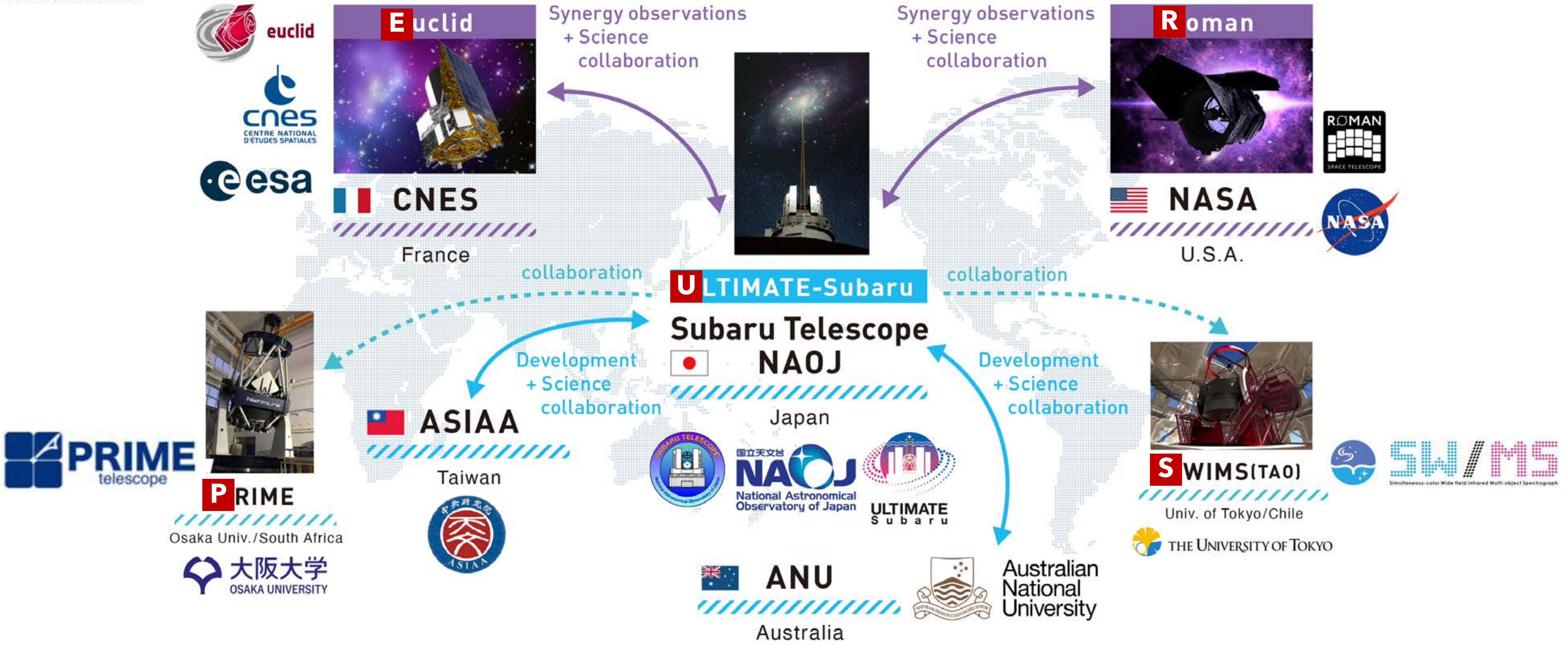
- **Youichi Ohyama** (**chair**, ASIAA/Taiwan)
- **James Rhoads** (NASA/USA)
- **Lee Spitler** (Macquarie/Australia)

SUPER IRNET

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)

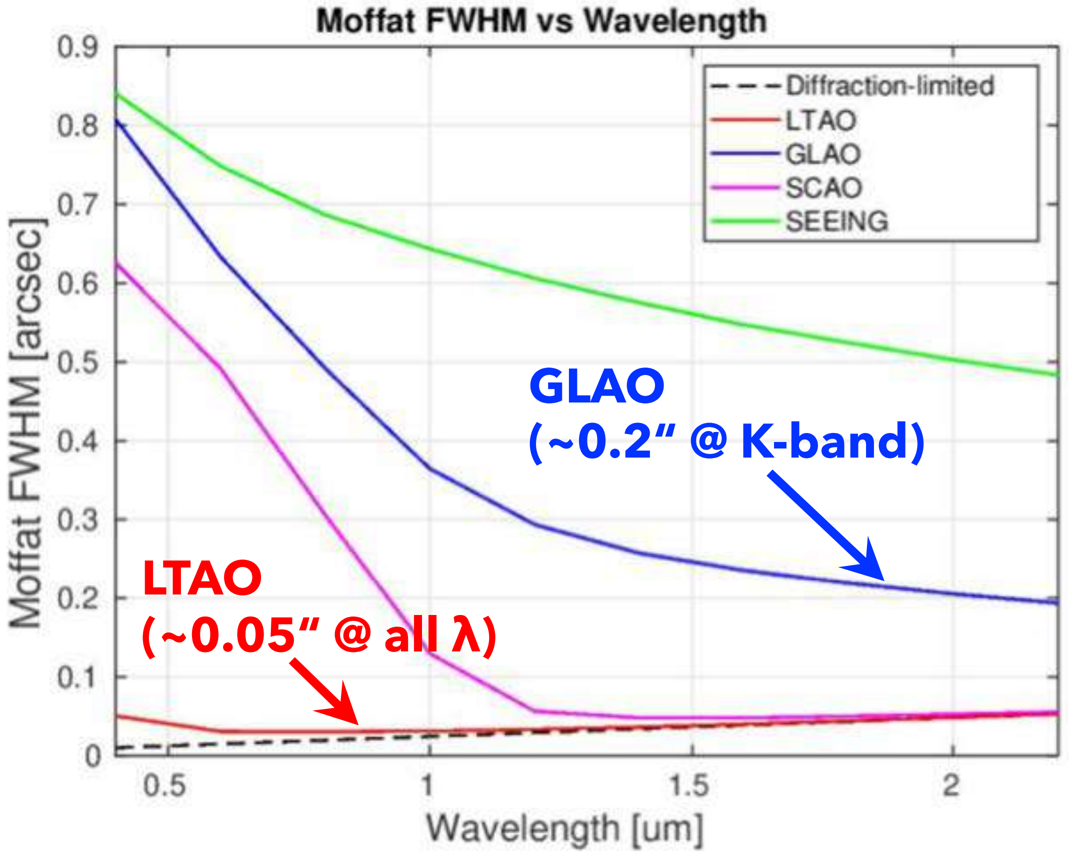
「地上・宇宙望遠鏡の連携による近赤外線広視野深宇宙探査時代の国際研究拠点形成」

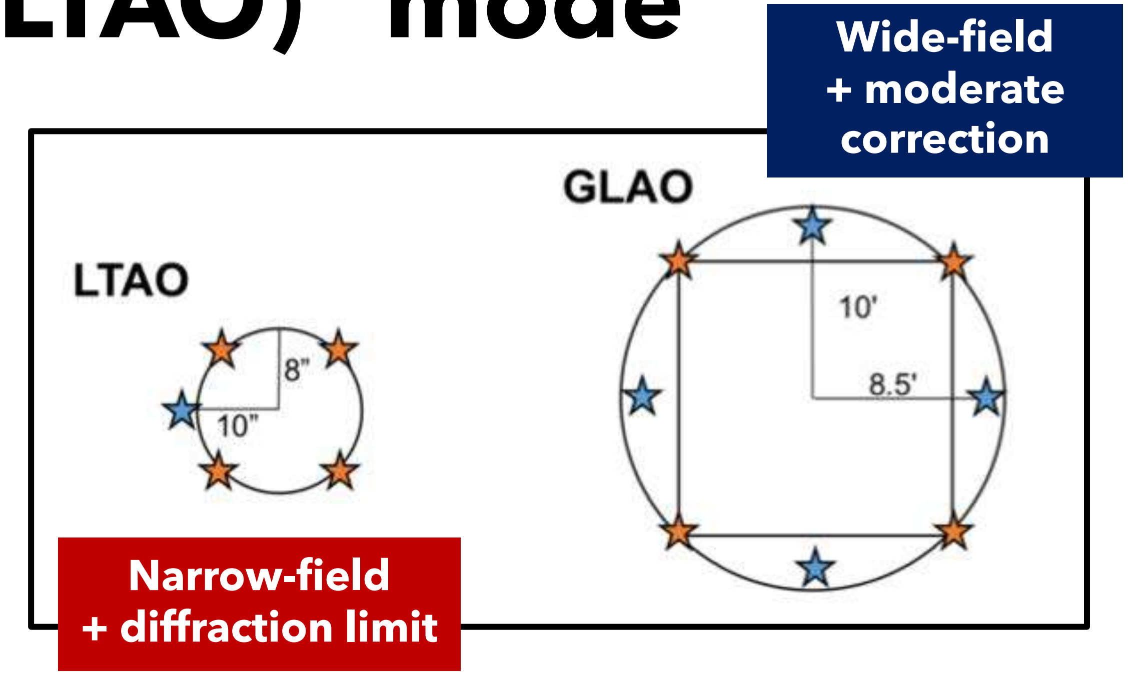
- 2021～2022年度にかけてオンラインセミナーを６回開催
- 2022年度内に**<u>対面でのワークショップ</u>**も計画中

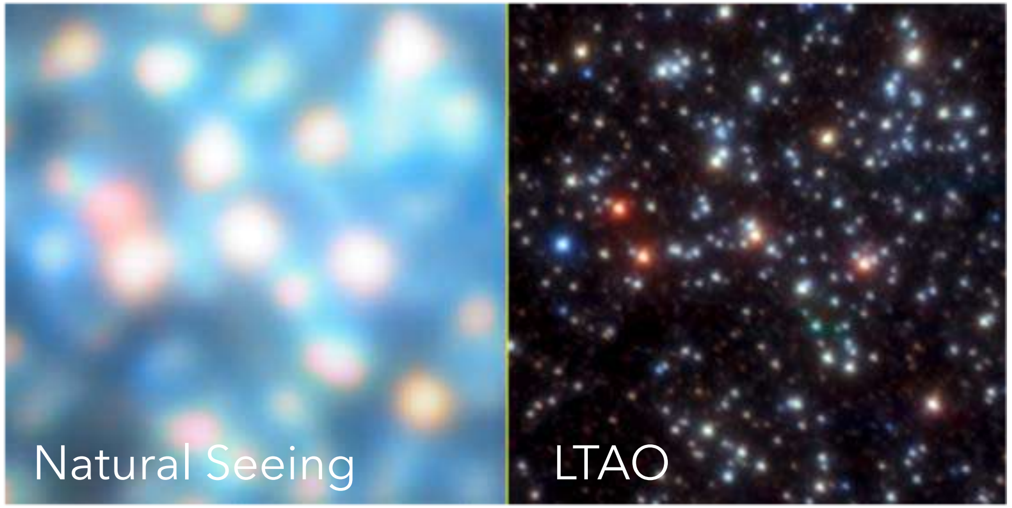


ULTIMATE "narrow-field (LTAO)" mode

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



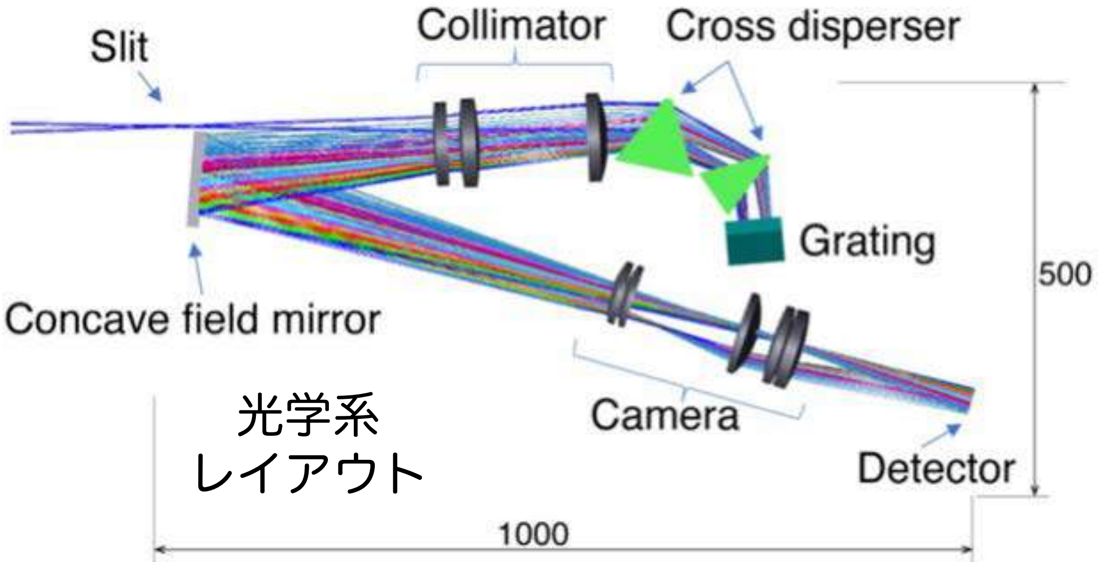




NINJA Near-INfrared and optical Joint Spectrograph with Adaptive optics

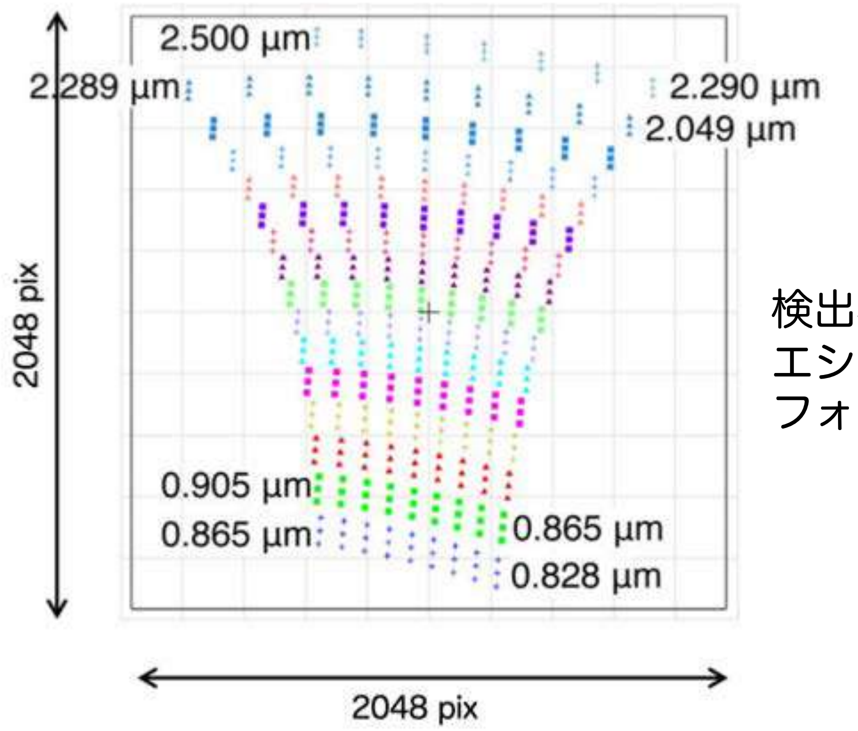
Tokoku et al. (2022), 2022年度秋季年会V204a(東谷)/V205a(守屋)

- 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 (2025年度運用開始を目標)



光学系
レイアウト

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



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, 守屋尭, 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, 穂満星冴, 安田彩乃 (東京大学)

まとめ

- ULTIMATE = すばる２時代の明夜を担う次世代補償光学 x 赤外線観測装置
- 2017年度より”ULTIMATE-START”始動 [科研費]
- 2019年度より国立天文台Aプロジェクト (すばるGLAOプロジェクト)
- 2021年度より本格的な予算措置スタート (+ SUPER-IRNETスタート, NINJA始動[科研費])
- 2022年度より「すばる２」始動, 可変副鏡の製作開始
- 観測装置開発は外部資金獲得が前提 → 外部資金獲得と国際協力に向けた努力を継続中

広視野モード (GLAO)

- FWHM~0.2” @ K-band
- 20-arcmin FoV (in diameter)
- GLAO+WFI = ULTIMATEの主軸
- 多彩なフィルター群を用いた近赤外線深宇宙探査で宇宙望遠鏡と連携＆TMTへの独自ターゲット提供

研究員公募 (予定)

- 可変副鏡の較正システム担当 (国立天文台三鷹勤務)
- 主に機械光学系の設計・製作、および完成したシステムを使った可変副鏡の較正作業などを担当
- 問合せ先: 大屋真 (国立天文台先端技術センター)

狭視野モード (LTAO)

- ULTIMATEが提供するもう一つの観測機能
- FWHM~0.05” @ 可視〜近赤外
- FoV: a few to ~10-arcsec