

# Science Strategy of NAOJ : Galaxy Formation and Cosmic Evolution

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On behalf of Science Roadmap Committee of NAOJ

# Current Trend in Galaxy Formation Research : Ultimate Goal

## 世界的な銀河形成進化研究の動向：目的

- ▶ To reveal the full picture of galaxy formation happening within the cosmic large scale structure, including central supermassive black holes, through understanding the origins, evolution, and present-day physical structure of galaxies. To understand the cosmic reionization, which is thought to have been driven by galaxy formation. (銀河の起源、進化、現在の物理構造の理解を通じて、中心に存在する超巨大ブラックホールを含めて宇宙の大規模構造の中で起こる銀河形成の全容を明らかにする。銀河形成が起因だと考えられる宇宙再電離を理解する)

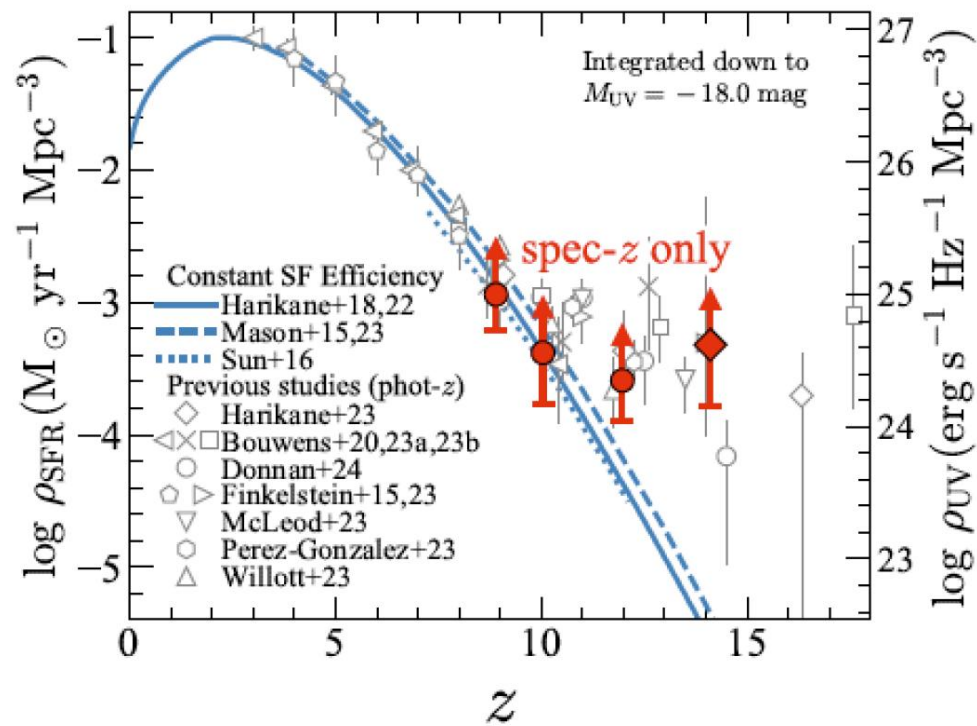
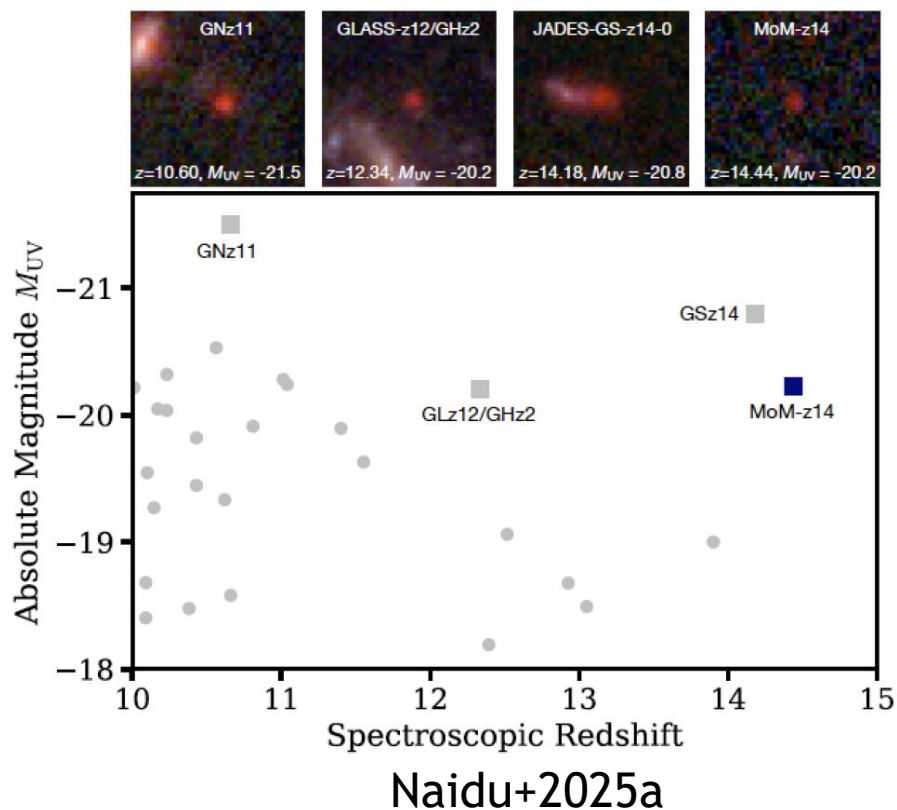
# Current Trend in Galaxy Formation Research : Immediate goals

## 世界的な銀河形成進化研究の動向:目標

- ▶ Unraveling the History of Galaxy Formation : Detect the first stars and first galaxies and uncover their properties, and understand the dynamical and chemical evolution from primordial galaxies to present-day galaxies (初代星・初代銀河を検出し、その性質を明らかにする。初代銀河から現在の銀河までの力学・化学進化を理解する)
- ▶ Unraveling the Origins of Supermassive Black Holes : Reveal the formation process of the seeds of the super massive black holes, and unveil how they formed and co-evolved with their host galaxies (超巨大ブラックホールの種は何によってつくられ、どのように銀河とともに成長したかを明らかにする)
- ▶ Elucidation of the Process and Origin of Cosmic Reionization : Identify the sources of cosmic reionization and elucidate the progress of reionization through the growth of reionization bubbles (宇宙再電離源を明らかにし、電離バブルの成長で宇宙の再電離が進む過程を明らかにする)

# Unraveling the History of Galaxy Formation 銀河形成史の解明

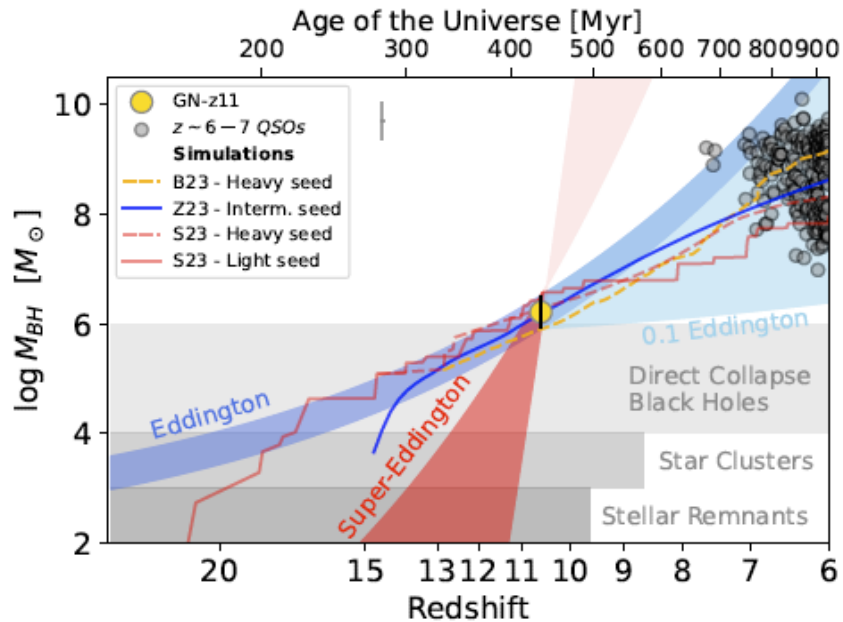
- ▶ Discovery of galaxies in the early universe with **JWST**
  - ▶ Starforming galaxies with different chemical composition
  - ▶ Massive quiescent galaxies at  $z > 5$



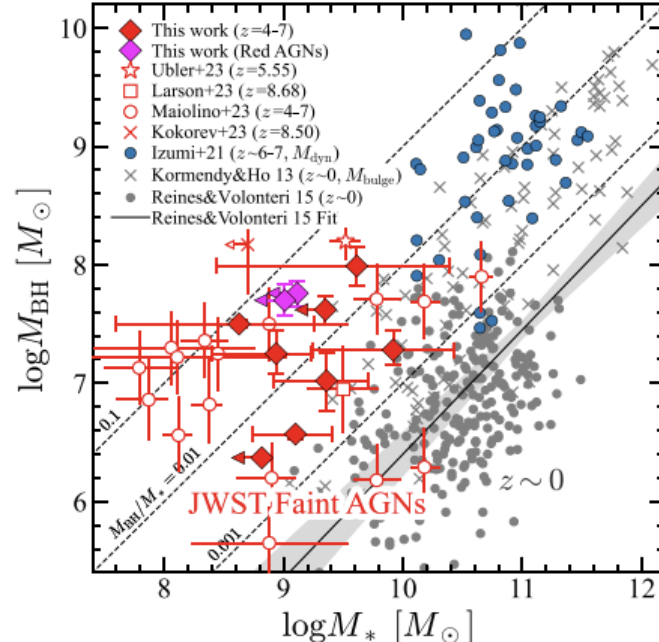
Harikane+2025

# Unraveling the Origins of Supermassive Black Holes 超巨大ブラックホールの起源の解明

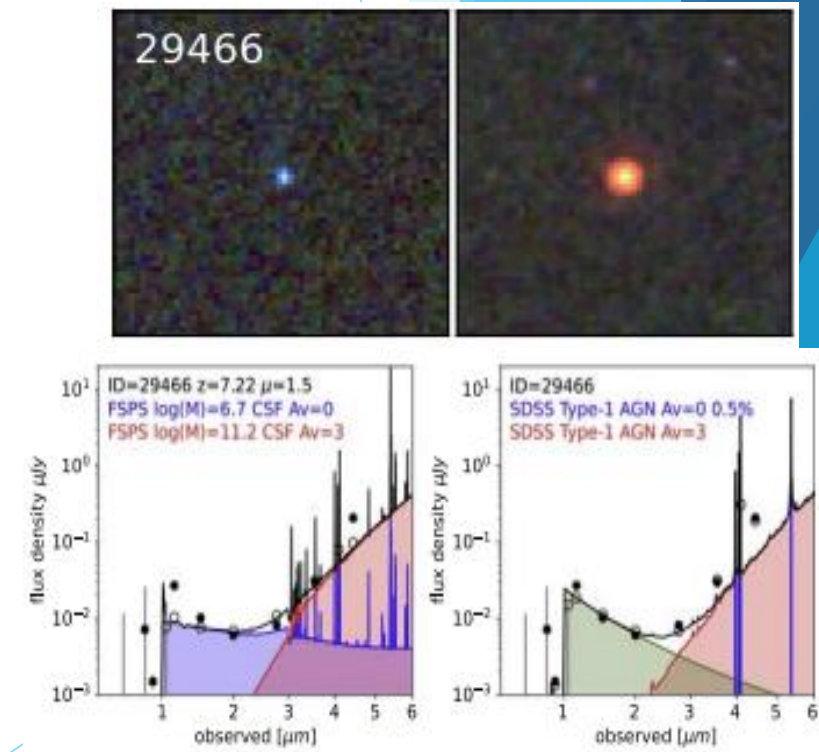
- ▶ Discoveries of new population of AGN in the early universe with **JWST**
  - ▶ Massive SMBHs in the early universe
  - ▶ Overmassive black holes inside dwarf galaxies
  - ▶ Little Red Dots with unique spectral properties



Maiolino+2024



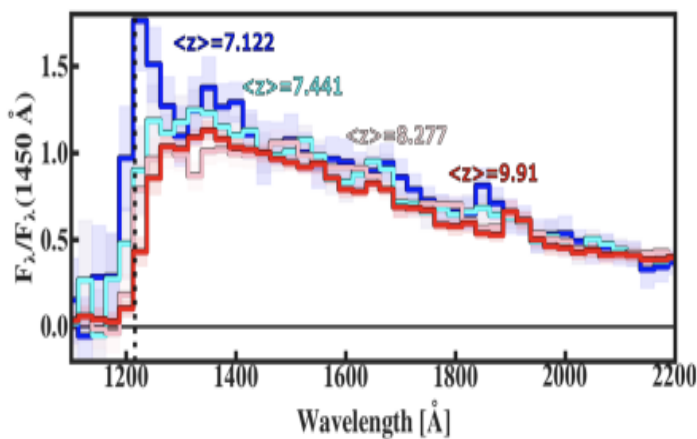
Harikane+2023



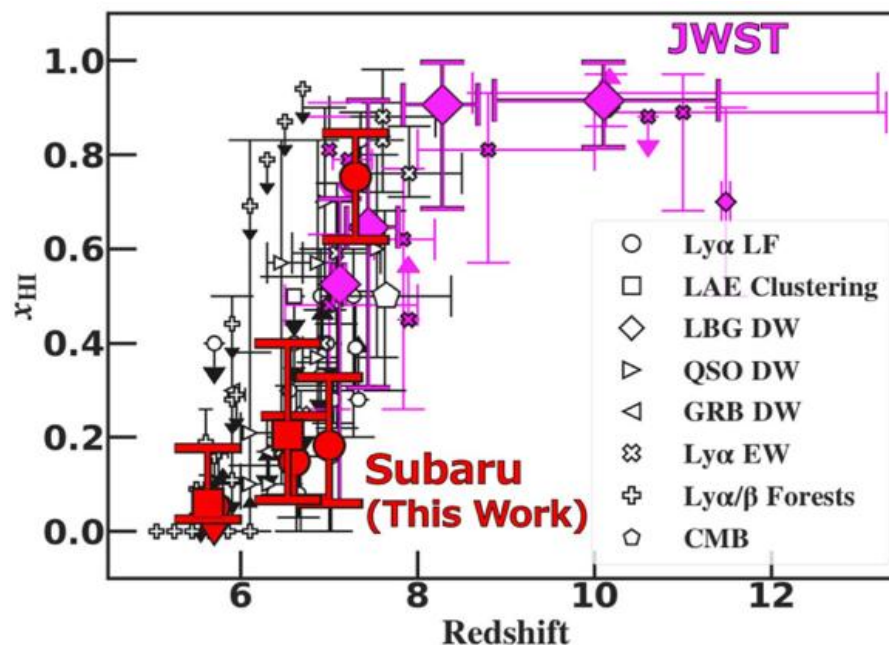
Labbe+2025

# Elucidation of the Process and Origin of Cosmic Reionization 宇宙再電離過程と起源の解明

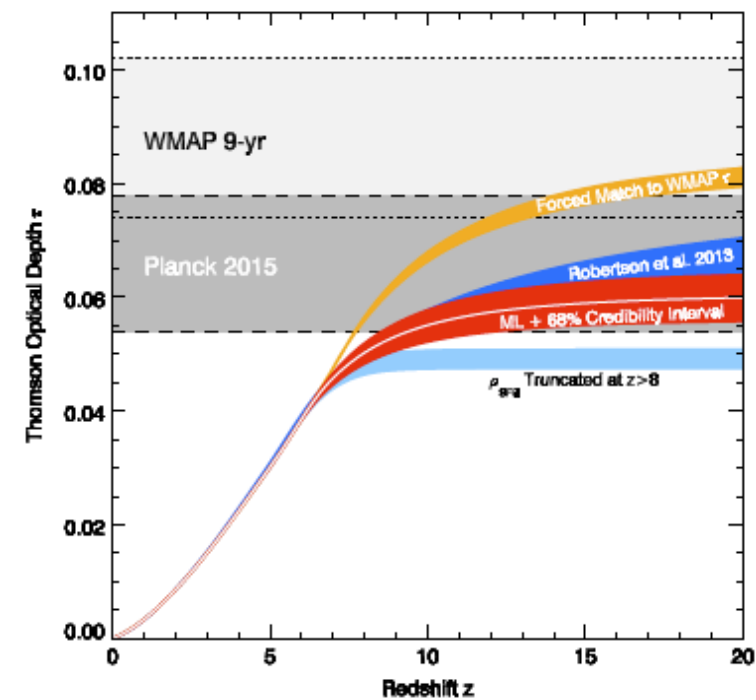
- Constraints on the reionization history of the universe with **JWST**



Umeda+2024



Umeda+2025



Robertson+2015

# Future Research Trend and Science Strategy of NAOJ

## 今後の世界的動向と国立天文台の科学戦略

### Scientific Methods and Goals for “Galaxy Formation and Cosmic Evolution” 「銀河形成と宇宙進化」の手法と科学目標

- ▶ Unraveling the History of Galaxy Formation  
銀河形成史の解明
- ▶ Unraveling the Origins of Supermassive Black Holes  
超巨大ブラックホールの起源の解明
- ▶ Elucidation of the Process and Origin of Cosmic Reionization  
宇宙再電離過程と起源の解明

Phasing in the 5<sup>th</sup> mid-term planning phase (第5期中期計画における段階分け)

[A] Analysis = 分析と成果創出、[C] Construction = 建設、[P] Planning = 計画検討

# Unraveling the History of Galaxy Formation

## 銀河形成史の解明

# Detection and Characterization of the First Stars and First Galaxies

## 初代星・初代銀河の検出と物理的性質の解明 (I)

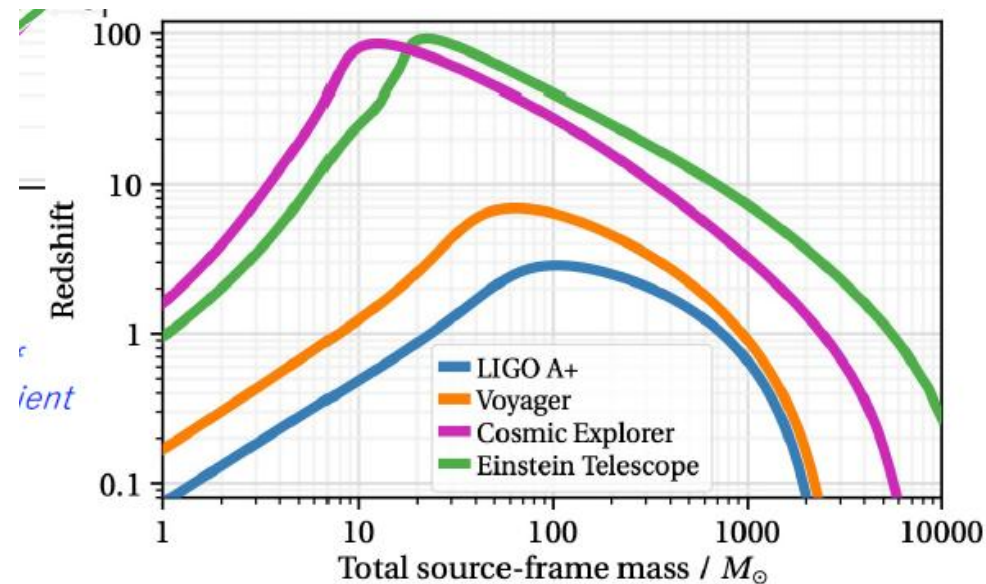
- ▶ Deep and wide field surveys in NIR and MIR (近赤外線・中間赤外線での高感度・広視野探査)
  - [A] JWST, Euclid, Roman, ULTIMATE-Subaru
  - [P] GREX-Plus
- ▶ High-sensitivity and high-spatial resolution spectroscopy in NIR and MIR, high sensitivity sub-mm spectroscopy (近赤外線・中間赤外線での高感度・高空間分解能分光、サブミリ波高感度分光)
  - [A] JWST
  - [C] TMT-IRIS, ALMA2
  - [P] ngVLA, LST/AtLAST

# Detection and Characterization of the First Stars and First Galaxies

## 初代星・初代銀河の検出と物理的性質の解明 (II)

- ▶ Probing the Galactic bulge region with near-infrared astrometry and spectroscopy (近赤外線アストロメトリと分光による銀河系バルジ領域の探査)
  - [A] Roman, ULTIMATE-Subaru
  - [C] JASMINE
  - [P] TMT-HROS, GREX-Plus
- ▶ Constraints on the properties of the first stars with gravitational wave observations (重力波を用いた初代星への制限)
  - [P] Third generation GW detectors (Einstein Telescope)

From white paper [06:3<sup>rd</sup> gen. GW]

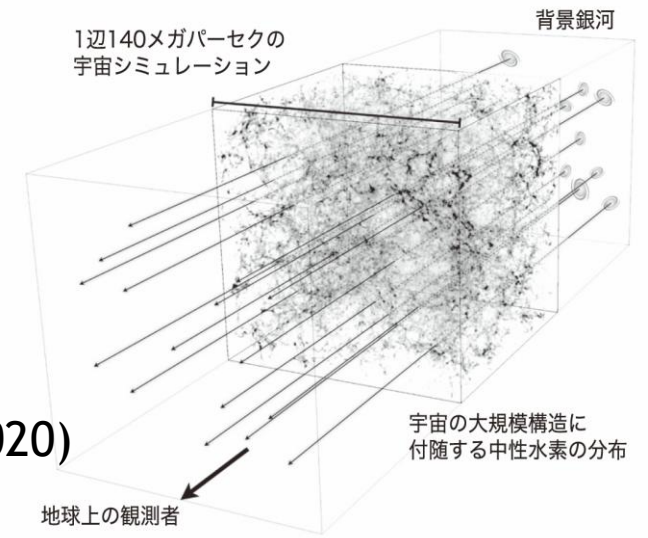


# Understanding the Dynamical and Chemical Evolution toward the Present-day Galaxies (I) 現在の銀河への力学・化学進化過程の理解

- ▶ Probing circumgalactic material via optical and radio absorption-line surveys (可視光および電波での吸収線探査による銀河周辺物質の検出)

[A] Subaru-PFS, ALMA

[C] TMT-WFOS, ALMA2, LAPYUTA (em-line)



From Subaru-TMT science book (2020)

- ▶ Probing large-scale galaxies structure and galaxy evolution in the structure via large-scale spectroscopic surveys (大規模分光探査による銀河大規模構造の検出と銀河進化の解明)
  - [A] Subaru-PFS, ULTIMATE-Subaru
- ▶ Wide-field radio spectroscopic surveys of gas emission lines for early-universe to trace large-scale structure in the early universe (電波広視野分光によるガス輝線による宇宙初期の大規模構造探査)
  - [A] SKA1-LOW
  - [P] LST/AtLAST, ATT30, ngVLA

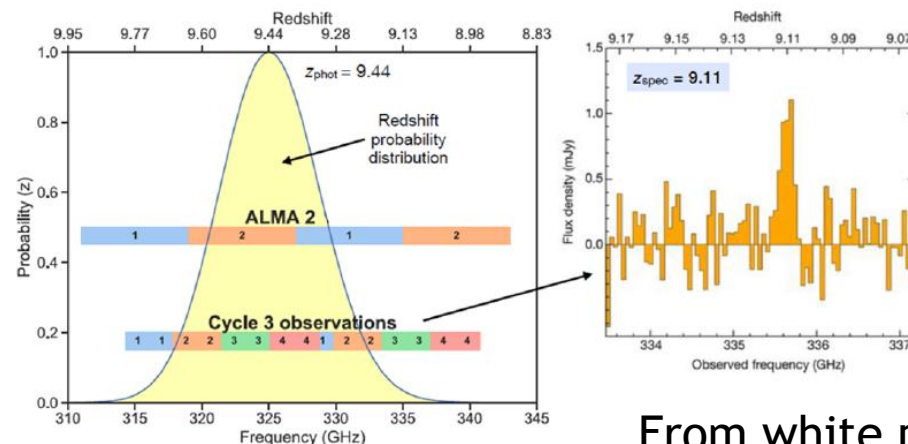
# Understanding the Dynamical and Chemical Evolution toward the Present-day Galaxies (II) 現在の銀河への力学・化学進化過程の理解

- ▶ Unveiling the dust-obscured formation process of massive galaxies through wide-band sub-mm spectroscopy (サブミリ波広帯域分光によるダストに隠された大質量銀河形成過程の解明)

[A] ALMA, ASTE-TIFUUN

[C] ALMA2

[P] LST/AtLAST, ATT30, ngVLA



From white paper [21: ALMA2]

- ▶ Probing the massive dust-obscured galaxies using rest-frame far-infrared continuum surveys (静止系遠赤外線によるダストに隠された大質量銀河の探査)

[A] ALMA

[C] ALMA2

[P] LST/AtLAST, ATT30, ngVLA

- ▶ Revealing the evolution of dynamical and chemical structure of galaxies through infrared integral field spectroscopy (赤外線面分光観測による銀河の力学・化学構造の進化の解明)

[C] TMT-IRIS

# Unraveling the Origins of Supermassive Black Holes

## 超巨大ブラックホールの起源の解明

# Unveiling the Seeds of Supermassive Black Holes 超巨大ブラックホールの種の解明

- ▶ Wide-field deep near-infrared surveys and spectroscopic follow-up observations (近赤外線での高感度広視野探査と分光追求観測)
  - [A] Roman
  - [C] TMT-IRIS

# Revealing the Obscured Growth of Supermassive Black Holes 隠された超巨大ブラックホールの成長過程の解明

- ▶ Wide-field deep mid-infrared surveys and spectroscopic follow-up observations (中間赤外線での高感度広視野探査と分光追求観測)
  - [A] JWST
  - [P] PRIMA
- ▶ High-resolution spectroscopic and imaging observations in millimeter and sub-mm (ミリ波サブミリ波での高解像度分光撮像観測)
  - [A] ALMA
  - [C] ALMA2

# Elucidating the Growth of Supermassive Black Holes through Mergers

## 合体による超巨大ブラックホール成長過程の解明

- ▶ Statistics of supermassive black hole mergers revealed by gravitational wave observations (重力波による超大質量ブラックホール合体現象の統計)

[P] LISA

# Elucidation of the Source and Process of Cosmic Reionization

## 宇宙再電離過程と起源の解明

# Identification of the Source of the Cosmic Reionization 再電離源の特定

- ▶ Understanding the escape of ionizing photons through rest-frame UV observations (静止系紫外線観測による電離光子脱出過程の解明)

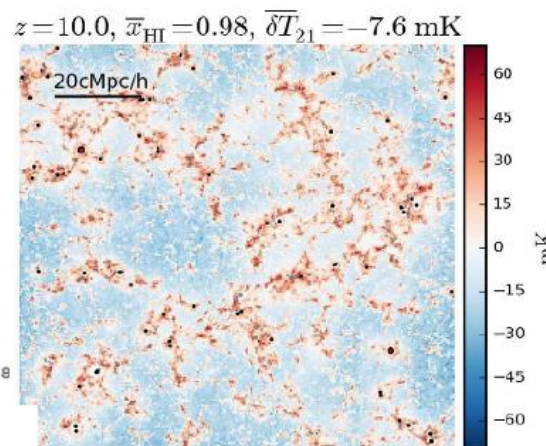
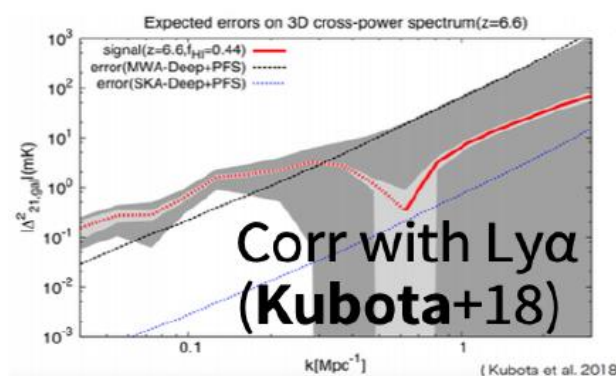
[C] TMT-WFOS, LAPYUTA

[P] HWO

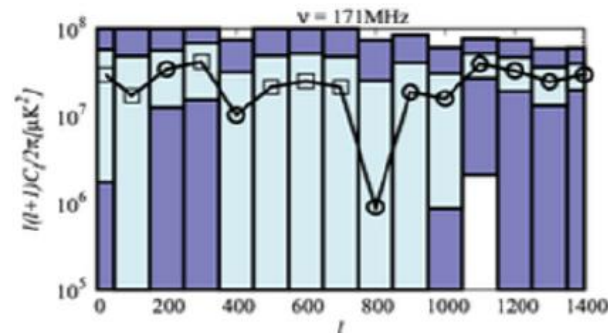
# Direct Detection of the Ionization Bubble 電離バブルの検出

- ▶ 21cm observations of neutral hydrogen during the reionization epoch and cross-correlation analysis with galaxy populations(再電離期の中性水素21 線観測および銀河種族との相関解析)

[A] SKA1-LOW - Subaru-HSC / PFS



Corr with [OIII]  
(Moriwaki+19)



Corr w CMB  
(Yoshiura+19)

From white paper [01:SKA]

# Science Strategy of NAOJ : Summary

## 国立天文台の科学戦略：まとめ

- ▶ [A] Large breakthroughs from the wide-field large-scale survey facility starting science observations (科学運用を開始する広視野・大規模探査の装置により生み出される大きなブレイクスルー):
  - ▶ Roman space telescope, Subaru-ULTIMATE
  - ▶ SKA1-LOW (in combination with samples from large scale surveys with Subaru)
- ▶ [C] Constriction of the future facilities to follow-up objects discovered in the wide-field surveys (大規模探査により発見される天体の追求観測のための次世代装置の建設):
  - ▶ TMT, ALMA2
  - ▶ JASMINE (astrometric follow-up)
- ▶ [P] Planning future facilities to make the next breakthroughs (次のブレイクスルーを生み出す将来装置の検討):
  - ▶ GREX-Plus, PRIMA
  - ▶ LST/AtLAST, ATT30, ngVLA
  - ▶ HWO
  - ▶ Next generation GW facilities