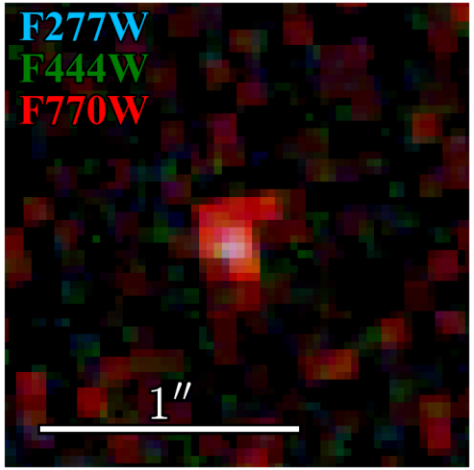
JWST による初代 Little Red Dots 探査

Tanaka et al. (2025), arXiv2508.00057, *ApJ* accepted



Takumi Tanaka (Kavli IPMU)

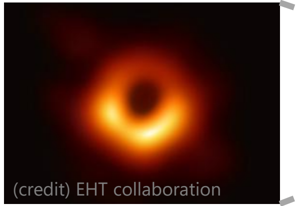
Hollis Akins (UT Austin), **Yuichi Harikane** (U.Tokyo),
Caitlin Casey (UC Santa Barbara), **Kohei Inayoshi** (KIAA),
Jayhan Kartaltepe (RIST), **John Silverman** (Kavli IPMU),
Kazuhiro Shimasaku (U.Tokyo), **Feige Wang** (U. Michigan),
Koki Kakiichi (Cosmic Dawn Center), **Jianwei Lyu** (U. Arizona),
and on behalf of the **COSMOS-Web, EMBER, and COSMOS-3D team**

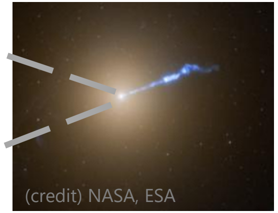
December 01, 2025 @AOSSA, Fukui
First Star & First Galaxy WS 2025

What's the origin of SMBHs?

In the local Universe

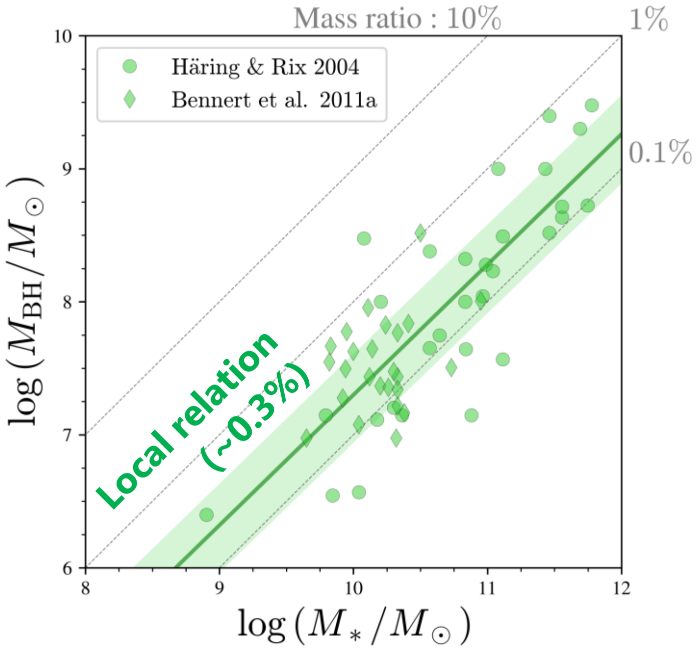
- Supermassive Black Holes (SMBHs) at the center of galaxies





Mass : $\gtrsim 10^6 M_\odot$ $\sim 10^{10-11} M_\odot$

Size : $\gtrsim 10^6$ km $\sim 10^{16-17}$ km



Tight mass relation:
mass ratio is ~constant!

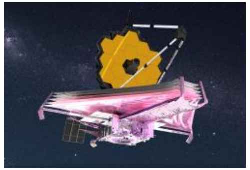
(e.g. Magorrian et al. 1998; Kormendy&Ho 2013)

~Key queations~

How SMBHs formed?

JWST revolutionized high-z AGN study

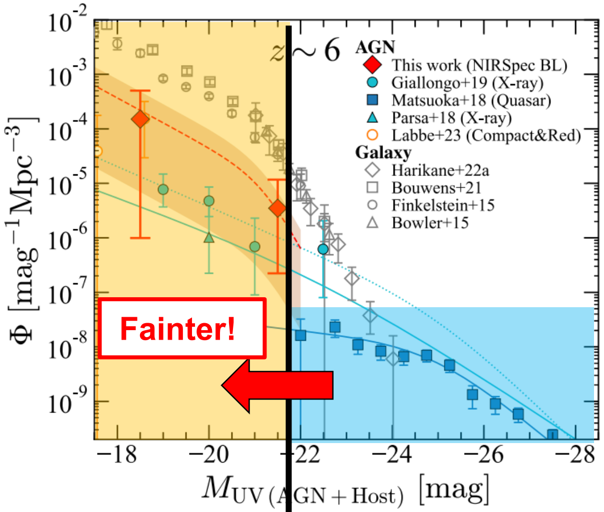
- **Before JWST**
  - Rest-UV observations at high-z (optical-NIR)
  - Limited to **Luminous quasars**



(c) NASA GSFC/CIL/Adriana Manrique Gutierrez

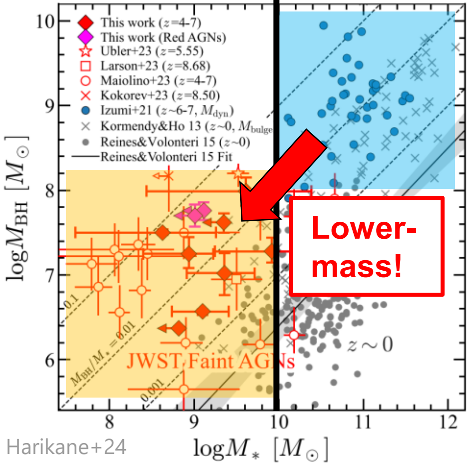
- **After JWST**
  - Deeper observation at rest-optical (NIR-MIR)
  - We can find **Low-luminosity AGNs (low-mass BHs)**

    → **More primitive SMBHs!**



Low-luminosity AGNs by JWST

Previous luminous unobscured quasars



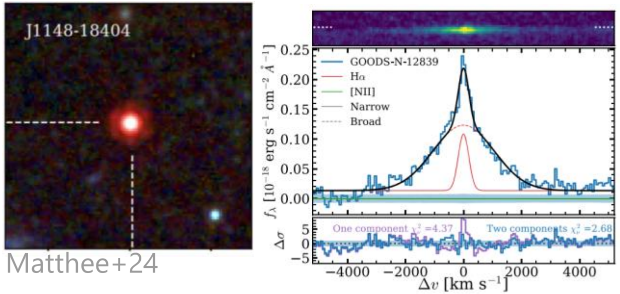
Harikane+24

"Little Red Dots" (LRDs)

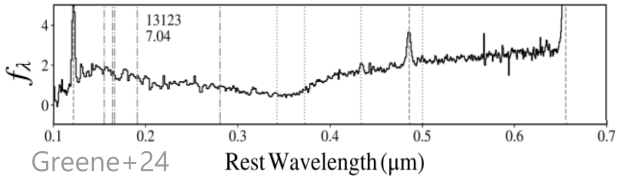
- **JWST-discovered new population**
  - Compact morphology (~PSF)
  - V-shape SED (trough in Balmer break)
  - Broad emission lines (FWHM>1000 km/s)
    → type-I AGNs?

- **Very abundant at z~5-8**
  → much more than previously found quasars

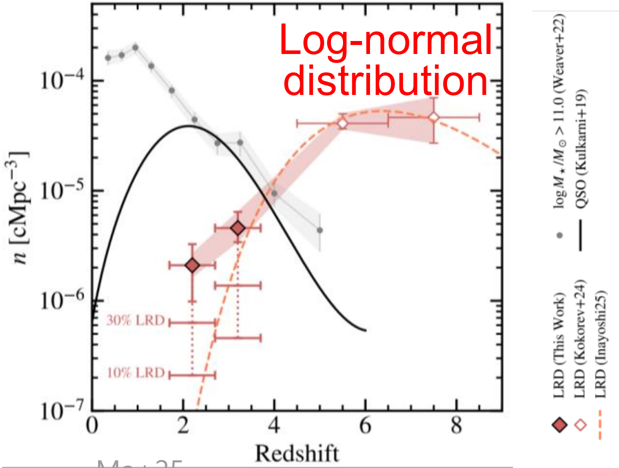
(e.g., Matthee et al. 2024; Greene et al. 2024; Akins et al. 2024, …)



Matthee+24



Greene+24

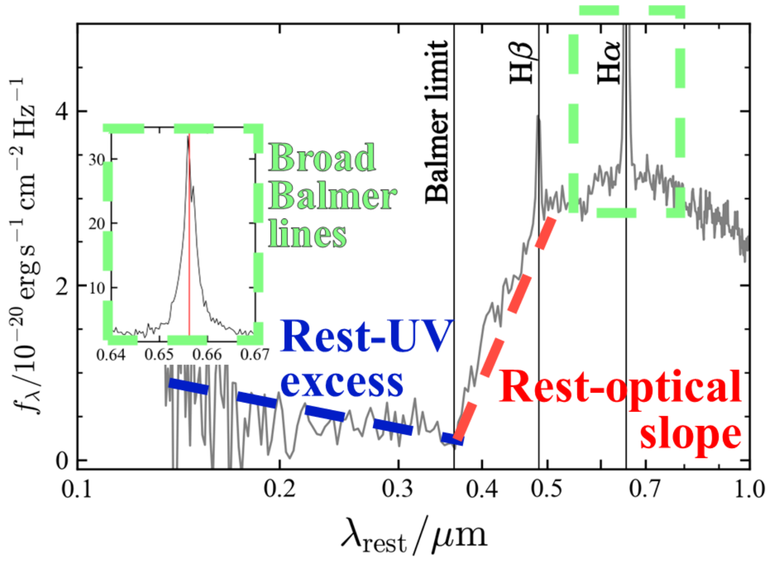


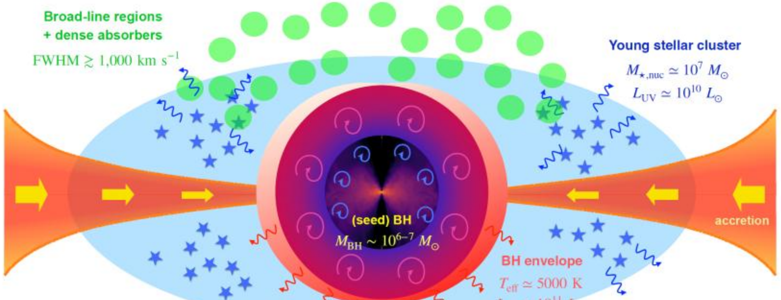
Ma+25

Takumi Tanaka (Kavli IPMU, takumi.tanaka@ipmu.jp)

Recent interpretation of LRDs

- **Recent interpretation:** (Inayoshi+25)
  - Primitive BH + dense gas envelope (T~5000 K)
    → rest-optical = Wien Tail
  - Young stellar population → rest-UV
  - **Bridging seed BHs and typical non-LRD SMBHs?**





Inayoshi+25

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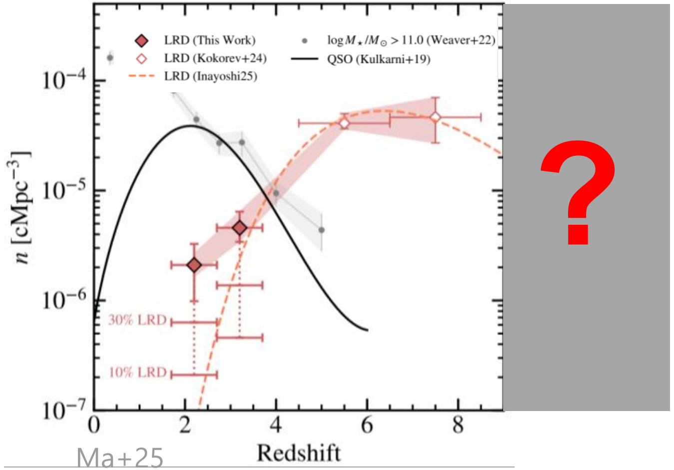
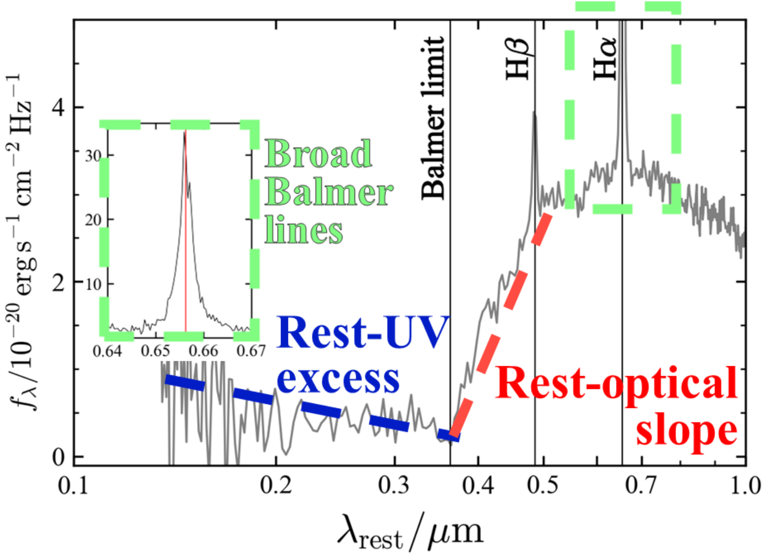
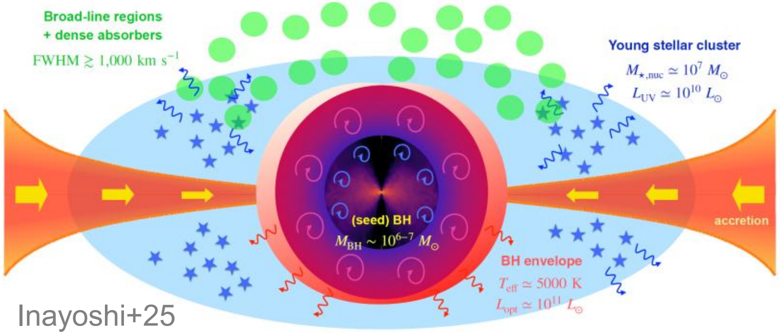
Search for LRDs in the early Universe can shed the light on seeding scenario!



Ma+25



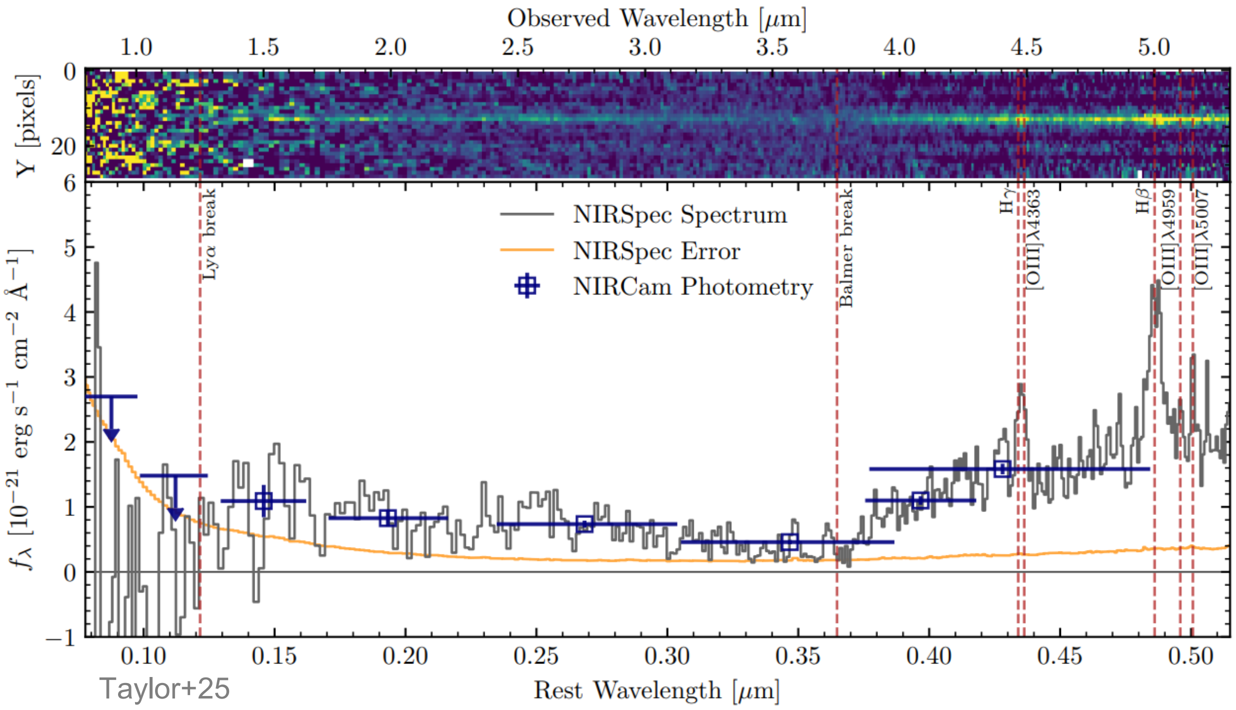


Inayoshi+25

Takumi Tanaka (Kavli IPMU, takumi.tanaka@ipmu.jp)

Redshift record for LRDs

- CAPERS-LRD-z9 @ z=9.3 (Taylor+25)
  - If go to higher-z, the V-shape SED trough shifts to $\lambda_{\rm obs} \gtrsim 4\ \mu\rm m$



Taylor+25

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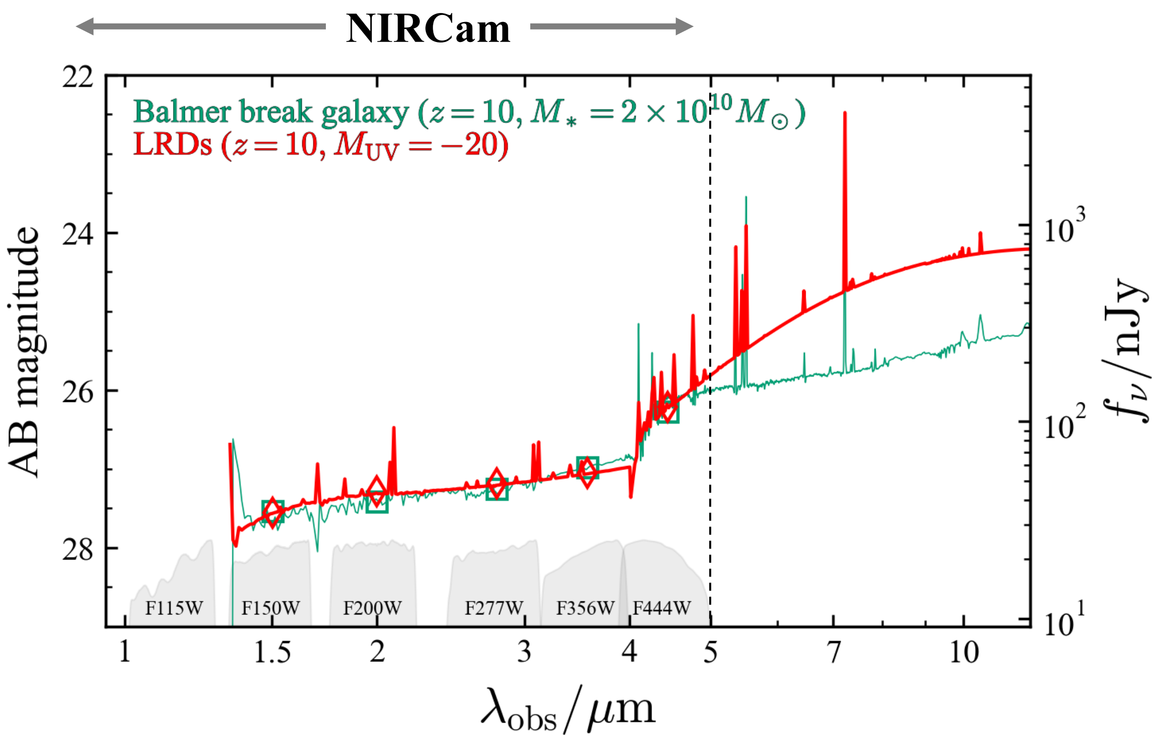
The need for MIR information

- Only with JWST/NIRCam, we can't distinguish z~10 LRDs from z~10 galaxies



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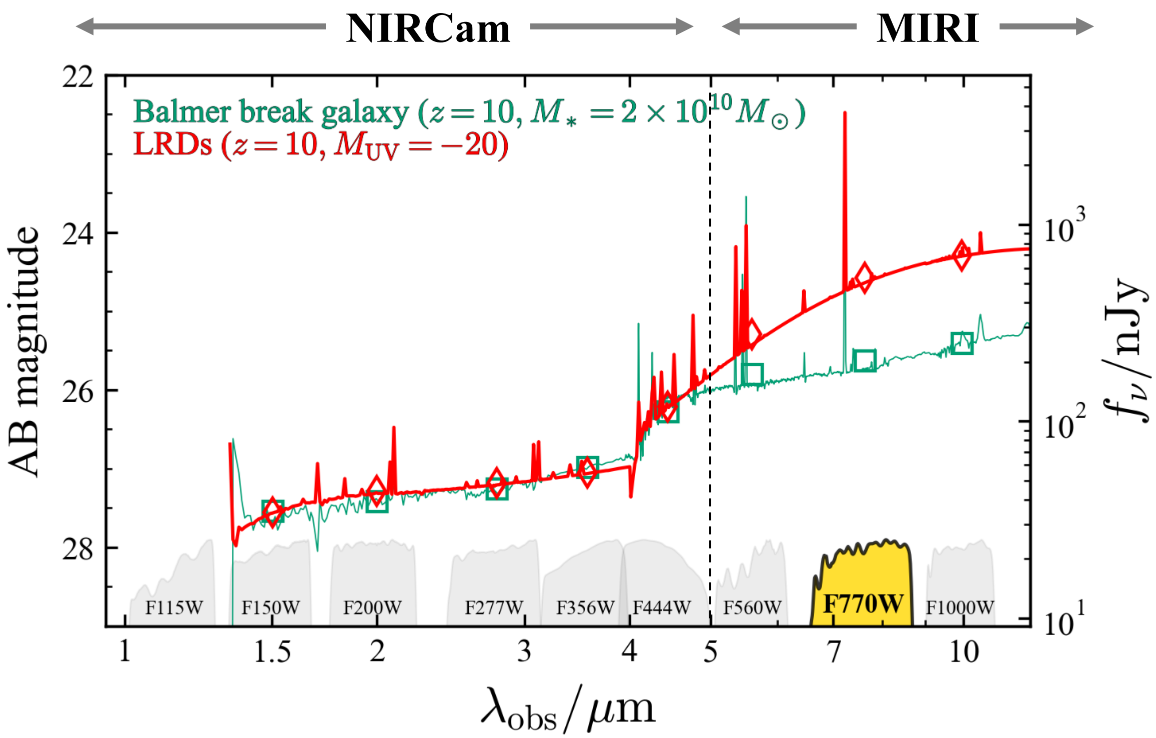

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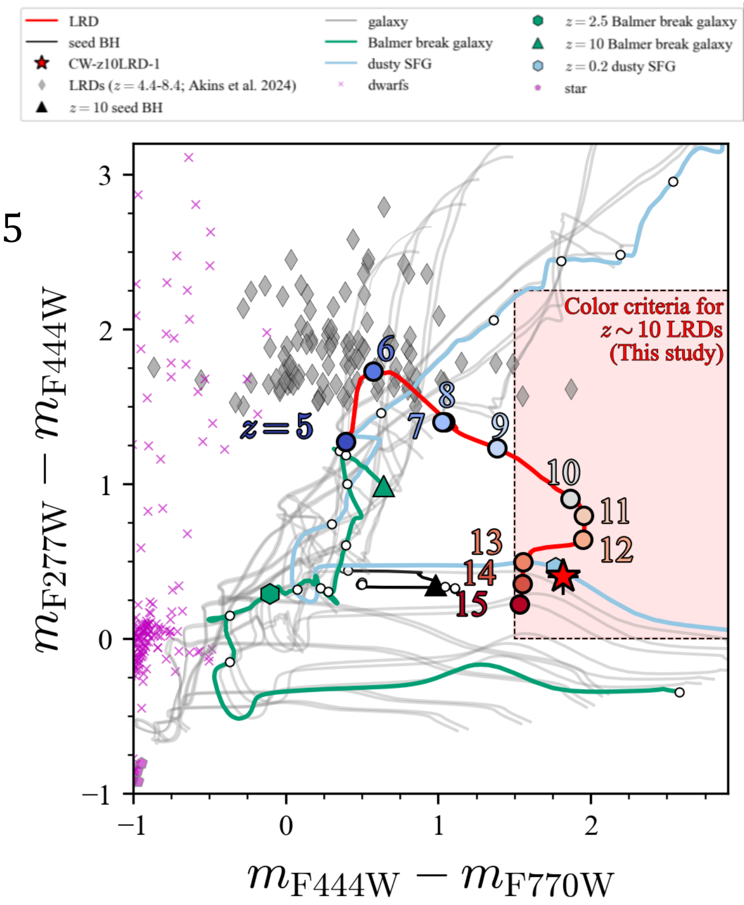
Color selection with COSMOS-Web

- COSMOS-Web
  - The largest NIRCam+MIRI coverage (0.18 $\deg^2$)
  - >3σ detection in F150W-F770W for $M_{\rm UV} < -19.5$

- Selection
  - Start from COSMOS2025
  - F115W dropout (S/N cut)
  - Color cut
  - Compactness cut
  - Visual inspection



Tanaka+25

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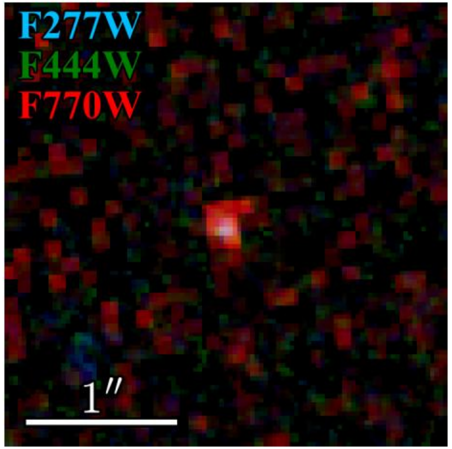
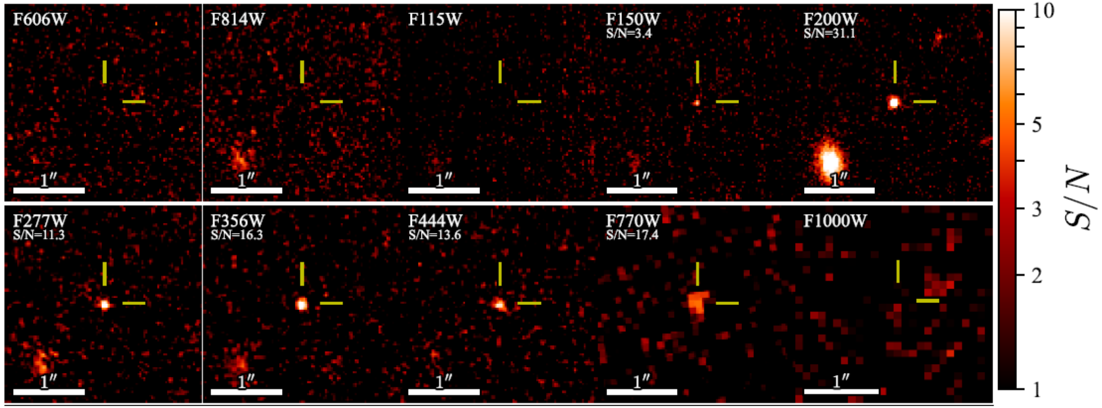
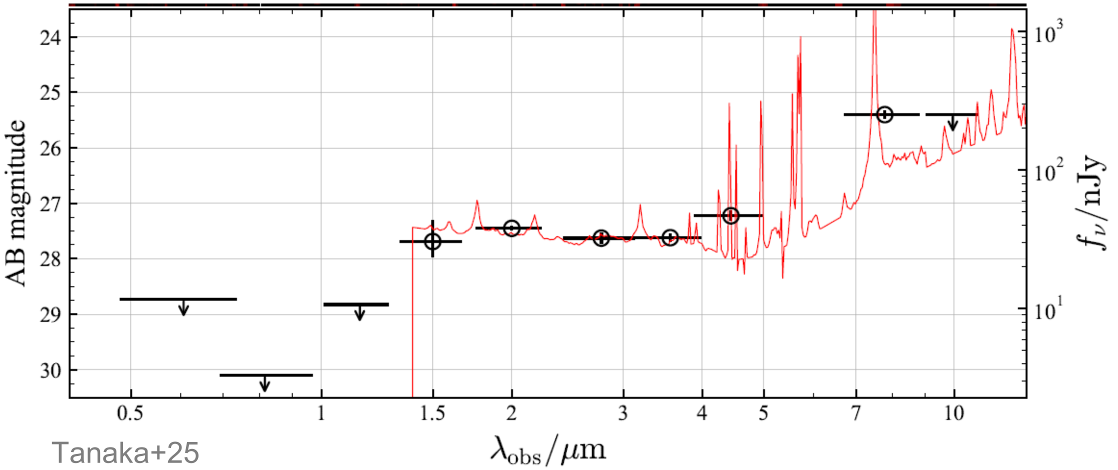
One solid candidate: CW-z10LRD-1



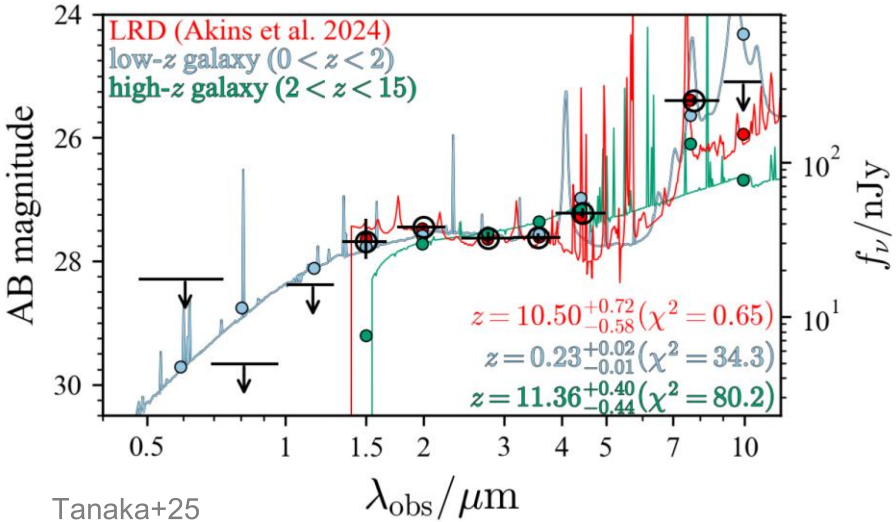




Tanaka+25

SED analysis

- **photometric redshift ~10.5**
  - the farthest LRD ever seen?
  - Spec follow-up is needed!
    - Spec-z
    - BH mass



Tanaka+25

- Possibility of contamination?
  - **z~10 non-LRD galaxy**
    - Strong Ha contribution? → too strong (Ha EW=8000A needed)
    - Strong Balmer break? → too strong for stellar-origin
  - **z~0.2 galaxy (with PAHs)**
    - inconsistent with non-detections in F814W, F115W, and F1000W

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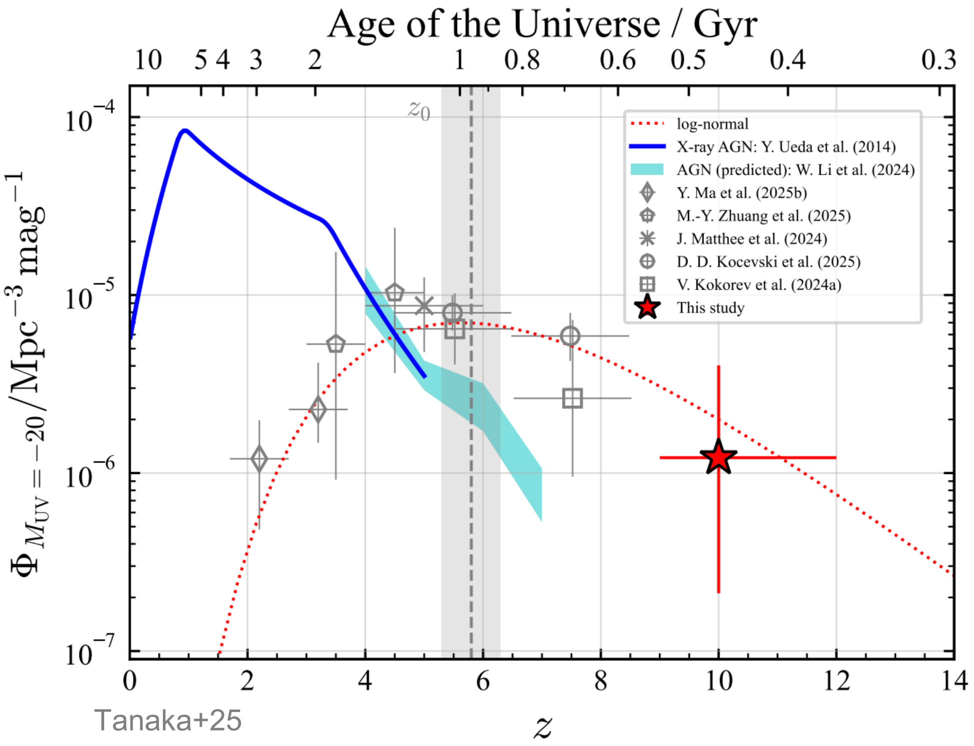
First constraint on the number density

- Well fitted with log-normal distribution (Inayoshi25)
- But still large uncertainty…



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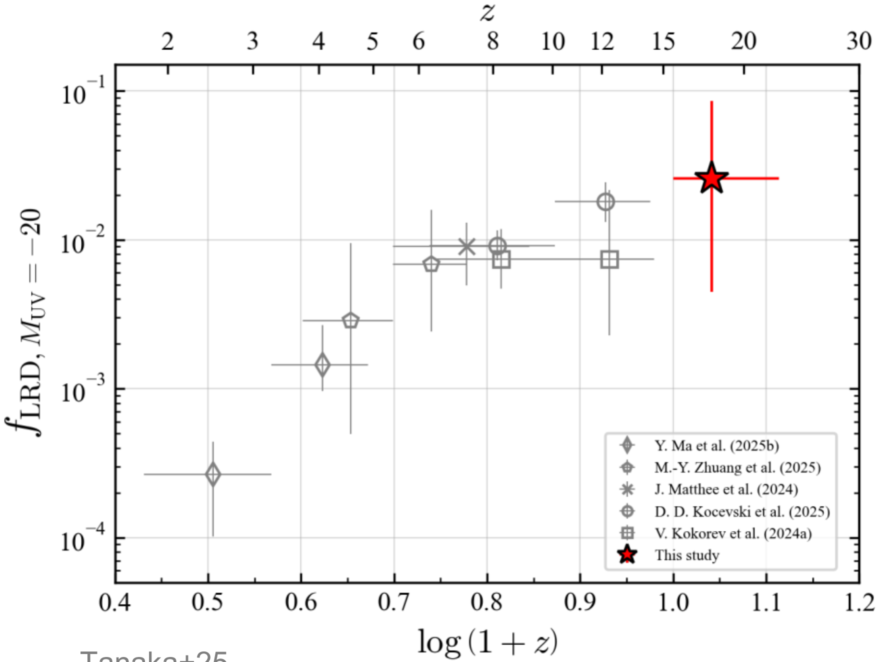
LRD fraction

- LRD fraction
  - Fraction of LRDs to the overall galaxies

$$f_{\mathrm{LRD},M_{\mathrm{UV}}=-20}(z) = \frac{\Phi_{\mathrm{LRD},M_{\mathrm{UV}}=-20}(z)}{\Phi_{\mathrm{galaxy},M_{\mathrm{UV}}=-20}(z)}$$

  - Increase toward higher-z
    even after the peak of Φ_{LRD} (z~6)



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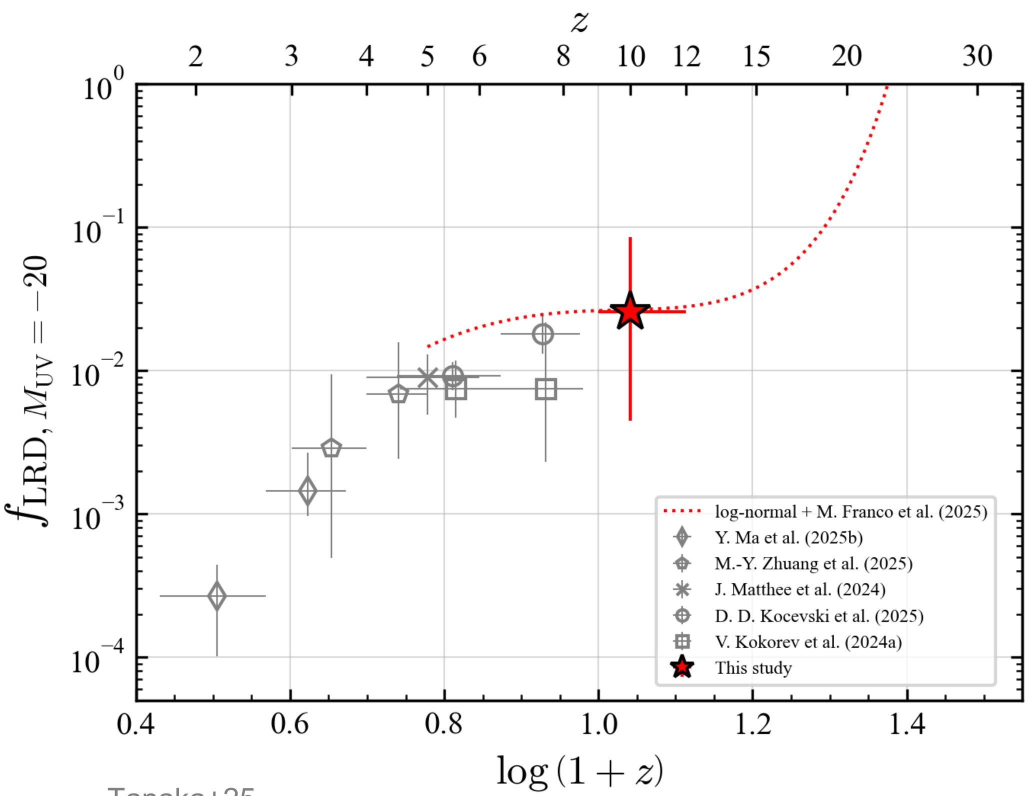
Interpretation of LRD fraction

- Empirical modeling
  - Log-normal + galaxy LF evolution
  - $f_{\rm LRD} = 1$ at z~20-30 (!?)

- Theoretical modeling
  - Pacucci&Loeb (2025)
    LRD: low-spin DM halo
  - $f_{\rm LRD} \propto (\tau_{\rm Salpeter}/t_{\rm Univ})$ model



Tanaka+25

BH mass

- Fit SED with
  - UV: stellar component
  - Optical: black body + Balmer absorptions (Inayoshi+25)

- $L_{\mathrm{optical}} \sim 3 \times 10^{44}\ \mathrm{erg\ s^{-1}}$

- $M_{\mathrm{BH}} \sim 2 \times 10^{6} M_{\odot}$ when assuming $\lambda_{\mathrm{Edd}} \sim 1$

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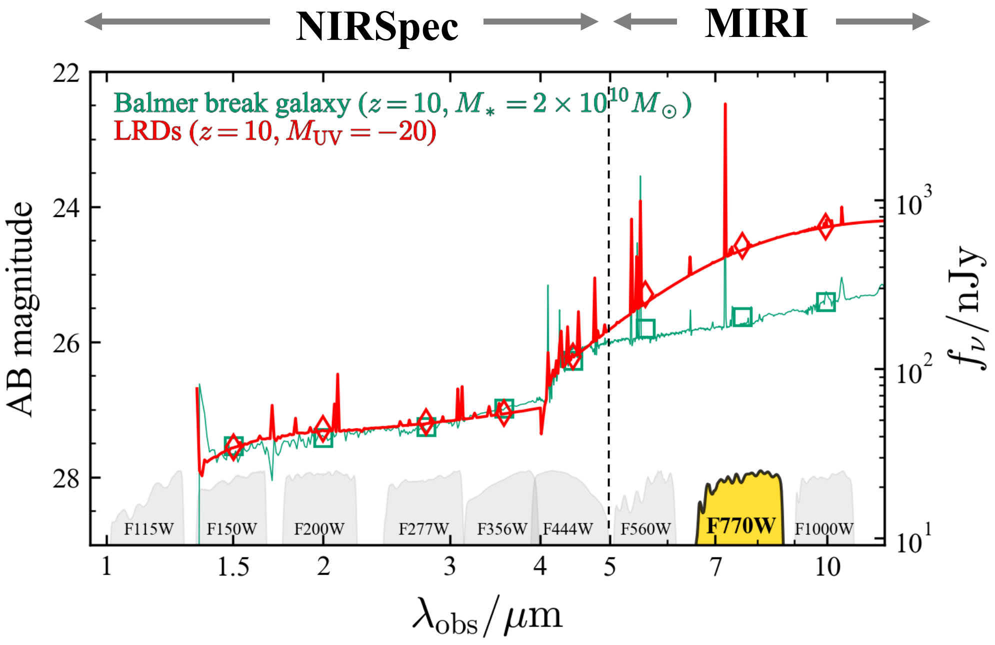
Prospects

- Further follow-up with MIRI/spectroscopy
  - Constrain the optical SED
  - Balmer lines: Hβ + Hα
- Comparison with theory
  - Making predictions based on Inayoshi+25's framework



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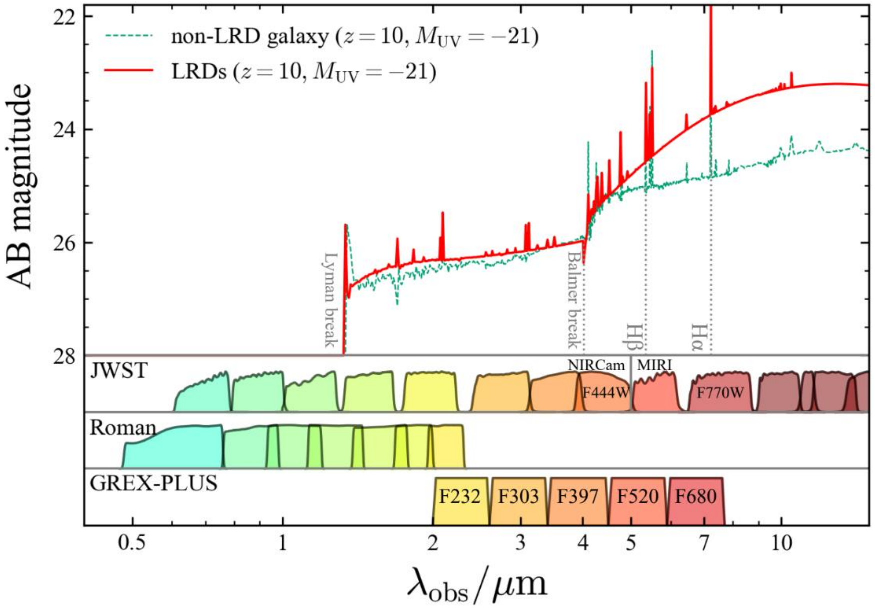
How to increase the sample size?

- How to increase the sample size?
    - Larger joint NIRCam-MIRI survey
    - MIRI follow-up of dropout candidates
    - GREX-PLUS (2030s-?)



GREX-PLUS Science Team+ (in prep.)

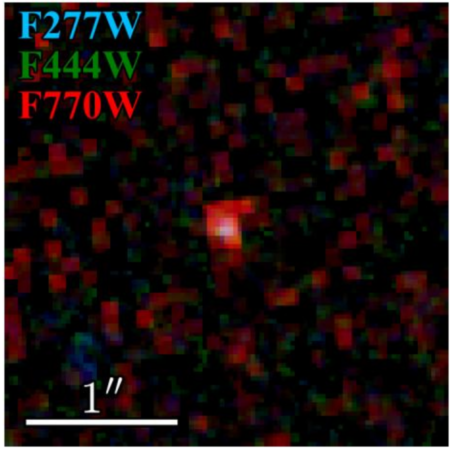
Tanaka+ (in prep.)

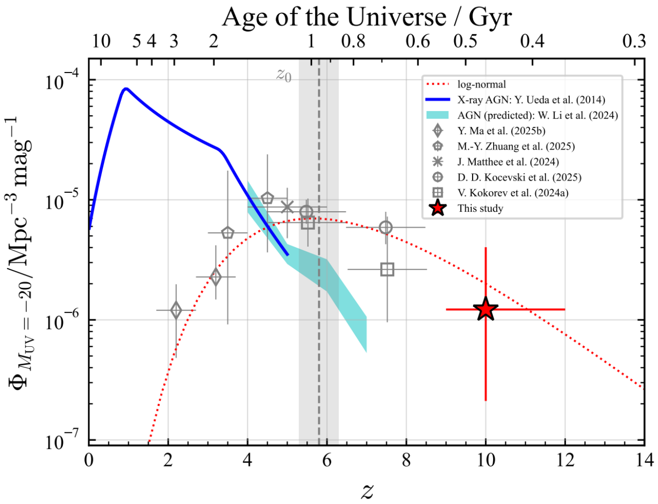
Summary

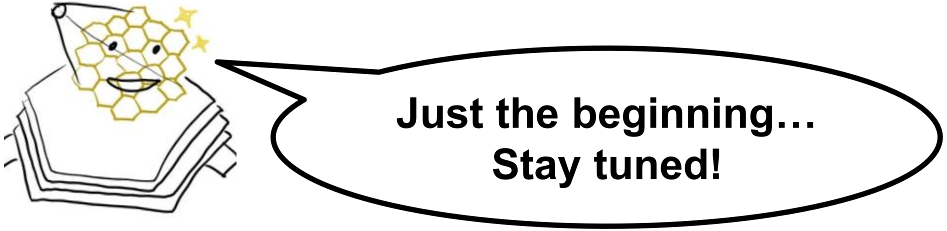
- Joint NIRCam + MIRI color selection of z~10 LRD
  → discovered $z_{\mathrm{spec}} = 10.36$ LRD (the most distant!)

- First number density constraint of z~10 LRDs
  LRD fraction increase toward higher-z ?

- Future exploration with further MIR survey
  - Higher redshift
  - larger sample
  - Wider luminosity bins







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