High-redshift Quasar Studies in the TMT era

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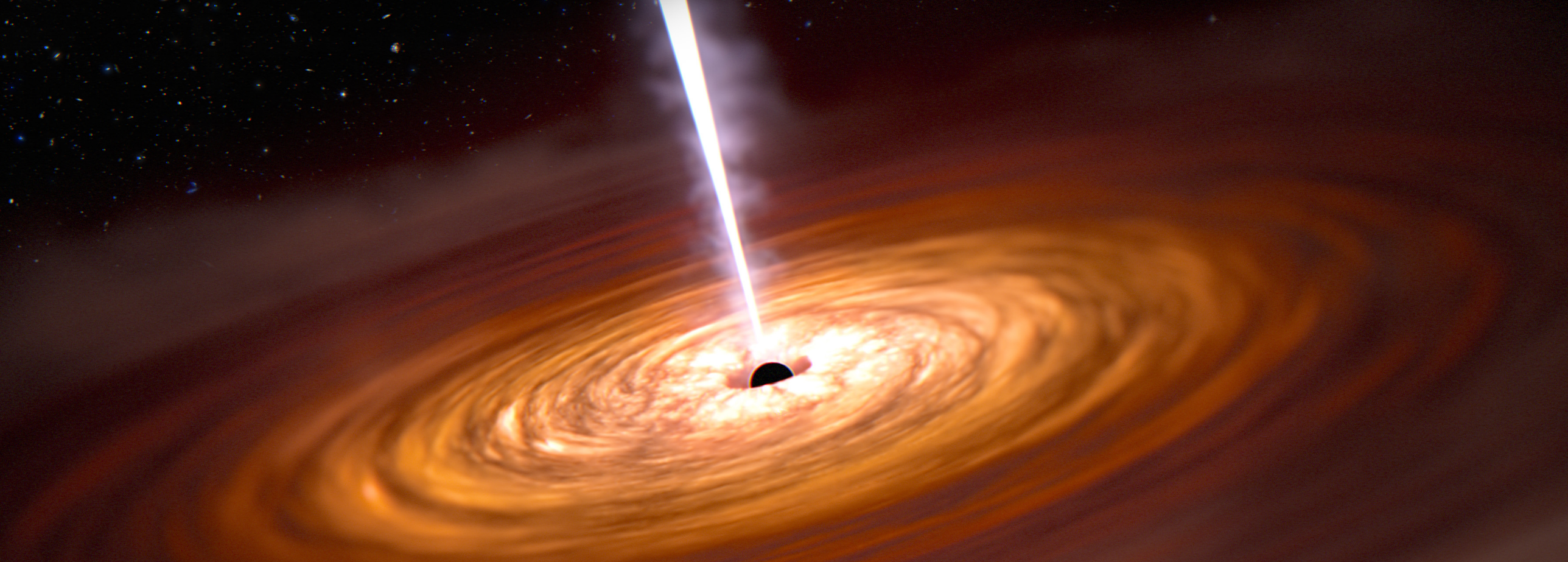
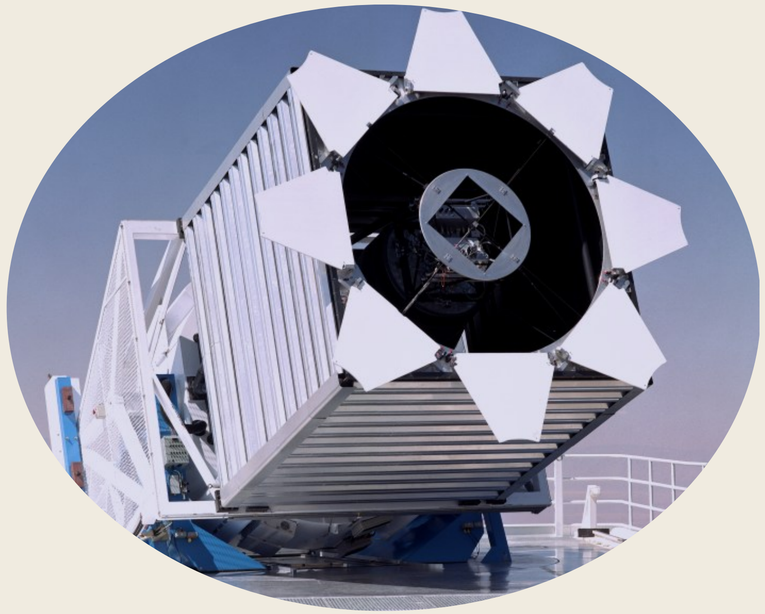


Supermassive Black Hole

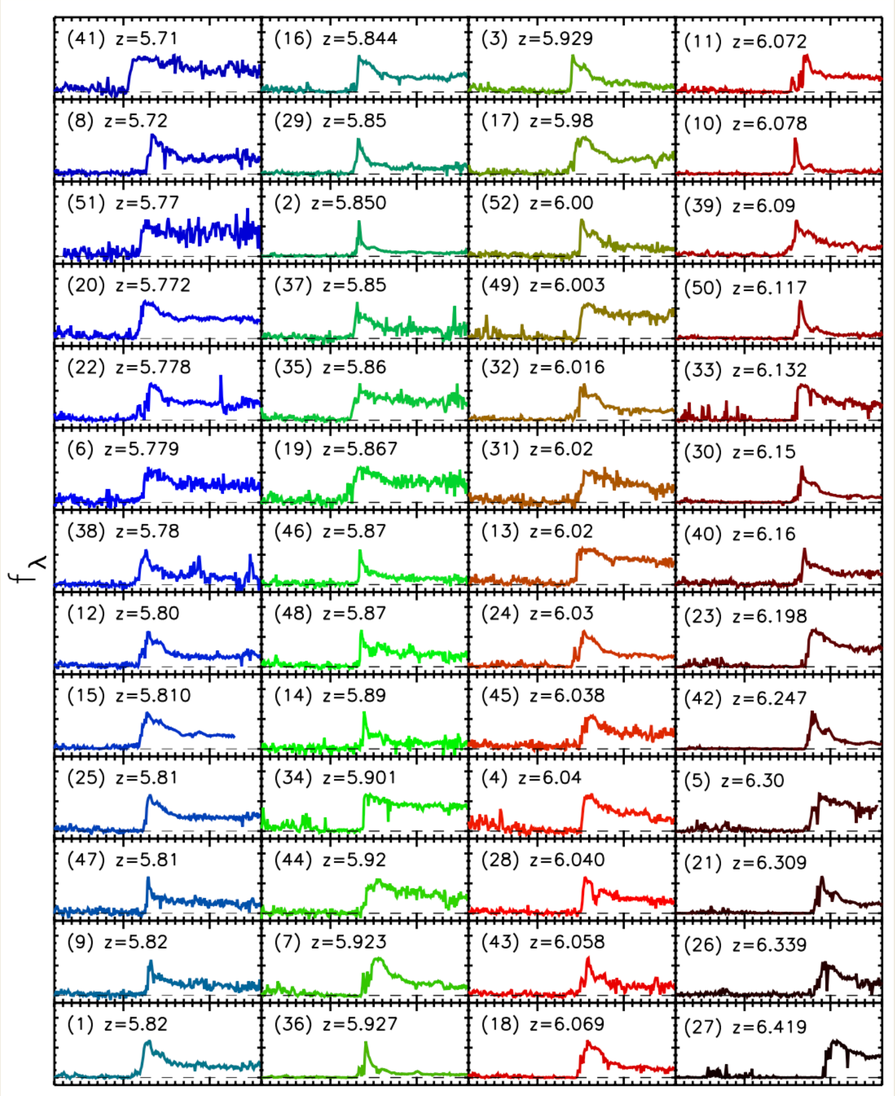
- Residing at the galaxy center
- Mass: $\log M_{BH} / M_{sun} = 5 - 10$
- Observable when mass accretes onto BH (AGN/quasar)
- 10^9 M_{sun} BH observed within 1 Gyr of the Universe

Credit: NASA, ESA, CSA, Joseph Olmsted (STScI)

AGN discovery (2000s-)



ground-based wide-field surveys
(SDSS, Pan-Starrs1)

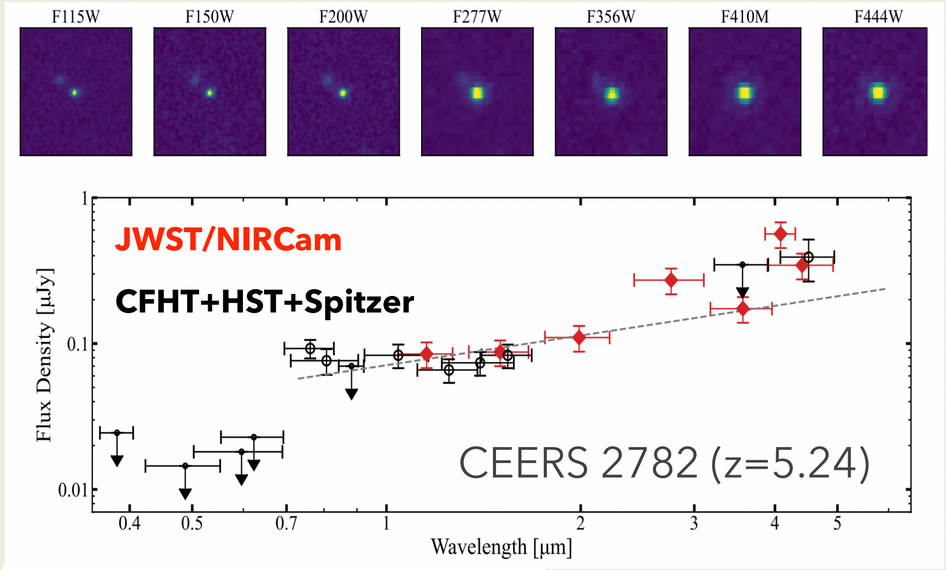


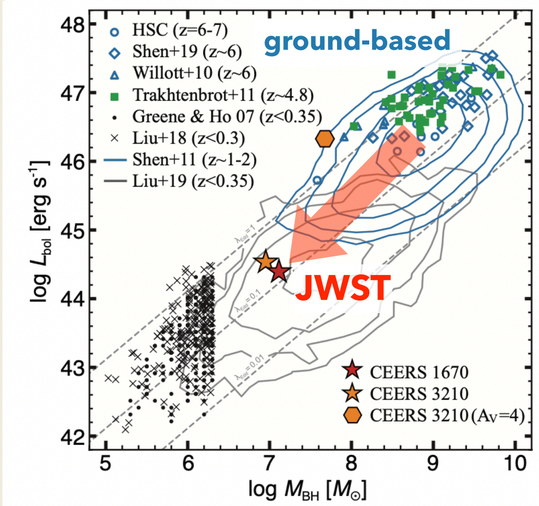
UV-luminous unobscured quasars
(log L_{bol} [erg s^{-1}] = 47, log M_{BH} / M_{sun} > 9)

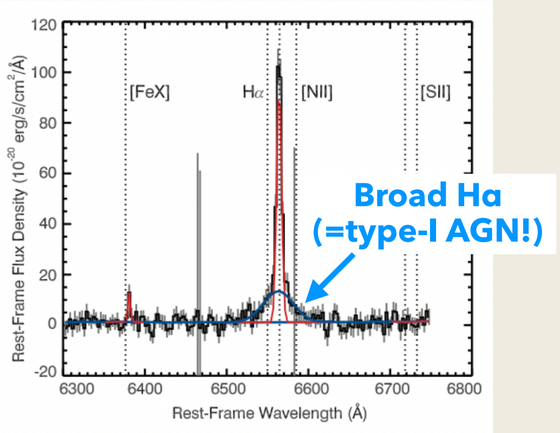
Jiang+16

AGN discovery (2020s)

space-based surveys
(JWST)



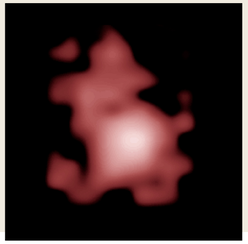




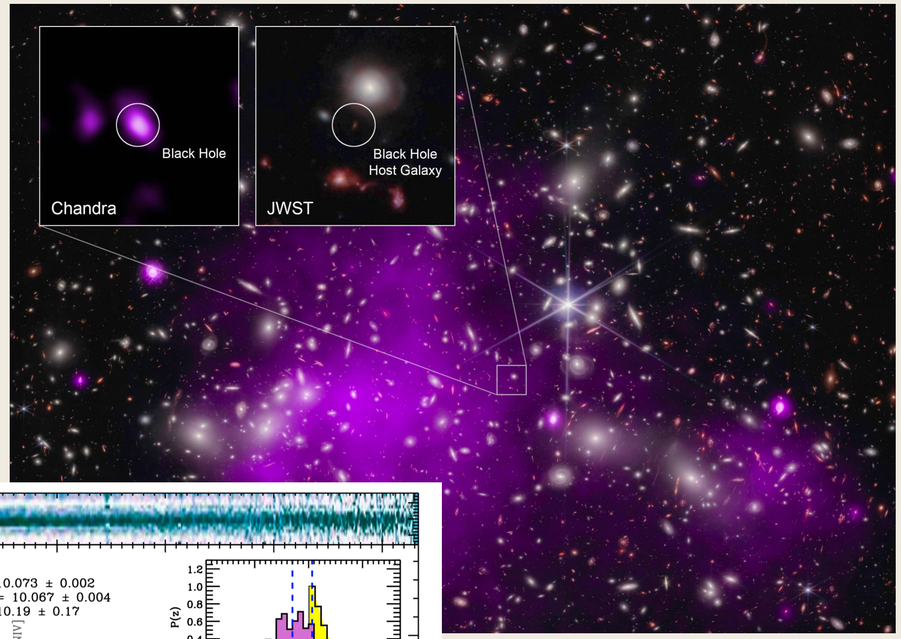
Optical-selected unobscured+obscured AGN
($\log L_{bol}$ [erg s^{-1}] = 44 - 45, $\log M_{BH} / M_{sun}$ = 6-7)

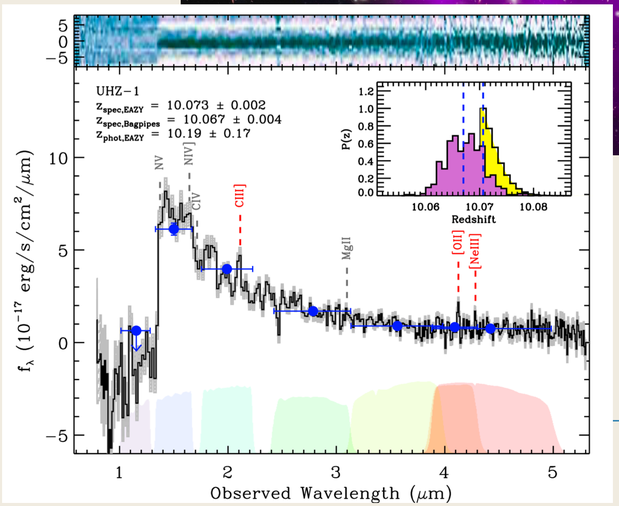
Onoue+23; Kocevski, MO+23

z>10 Galaxies Hosting AGN

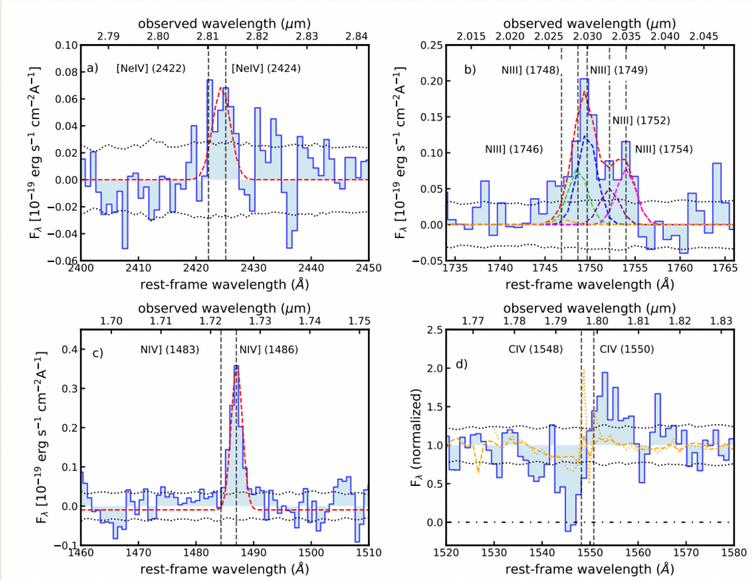


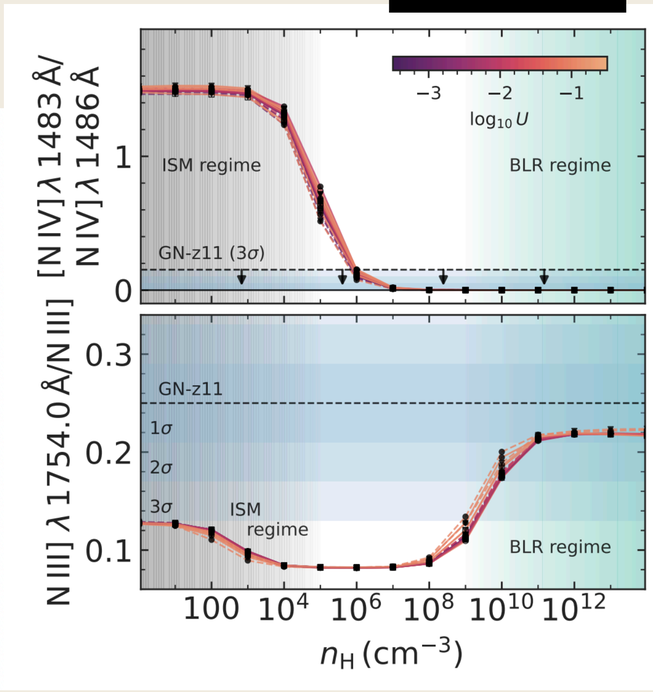
- z=10.1 X-ray AGN (Goulding+23; Bogdan+24)



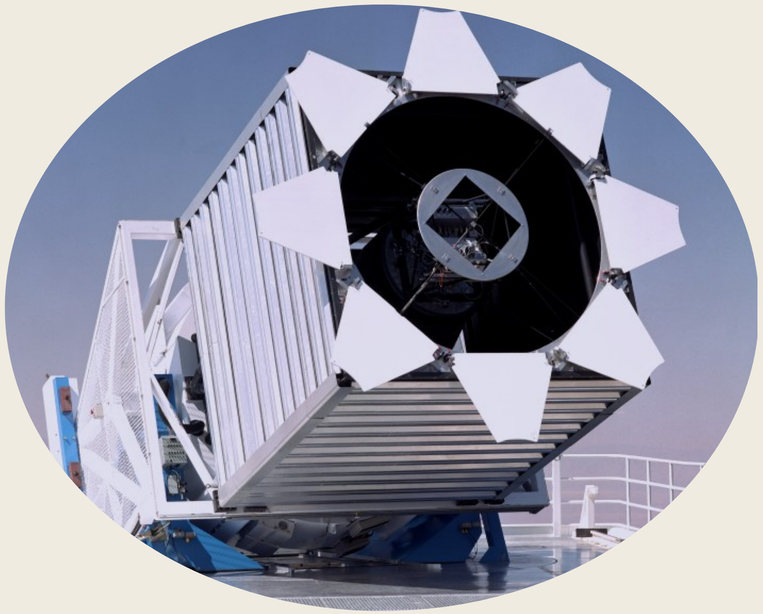


- GN-z11 (z=10.6; Maiolino+24)



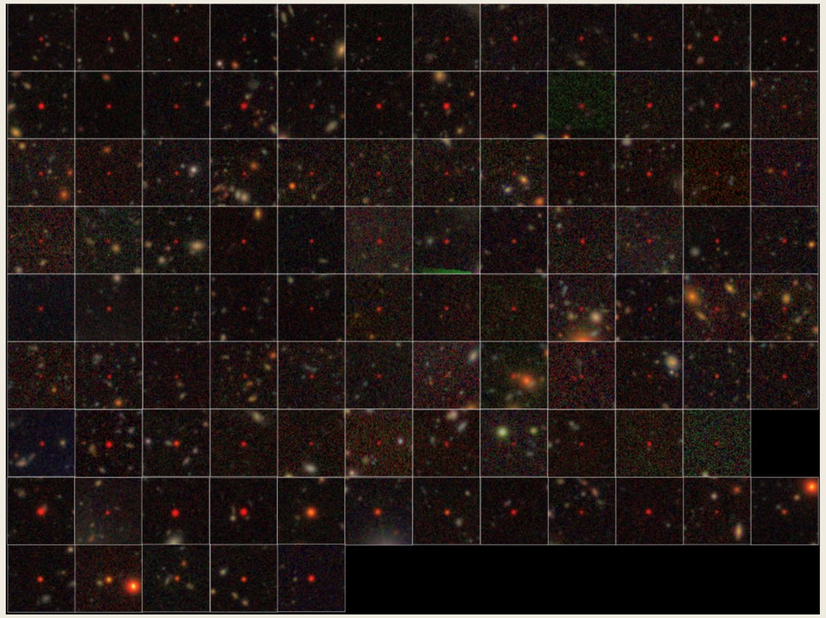


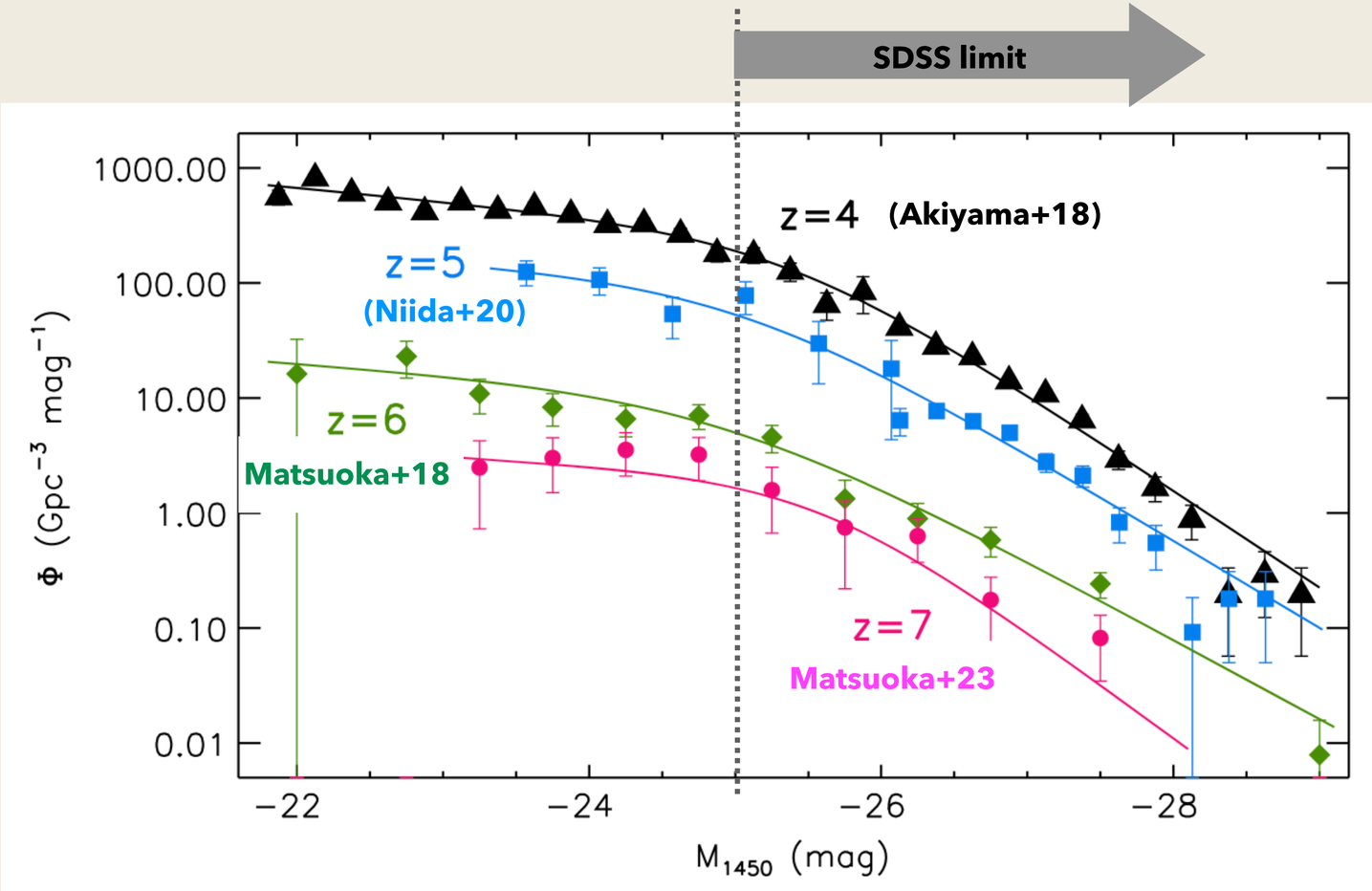
Subaru's role?



→ **Intermediate-luminosity quasars**
(more representative BHs than SDSS, more matured than JWST)

HSC-SSP's constraints on z>4 quasar abundance

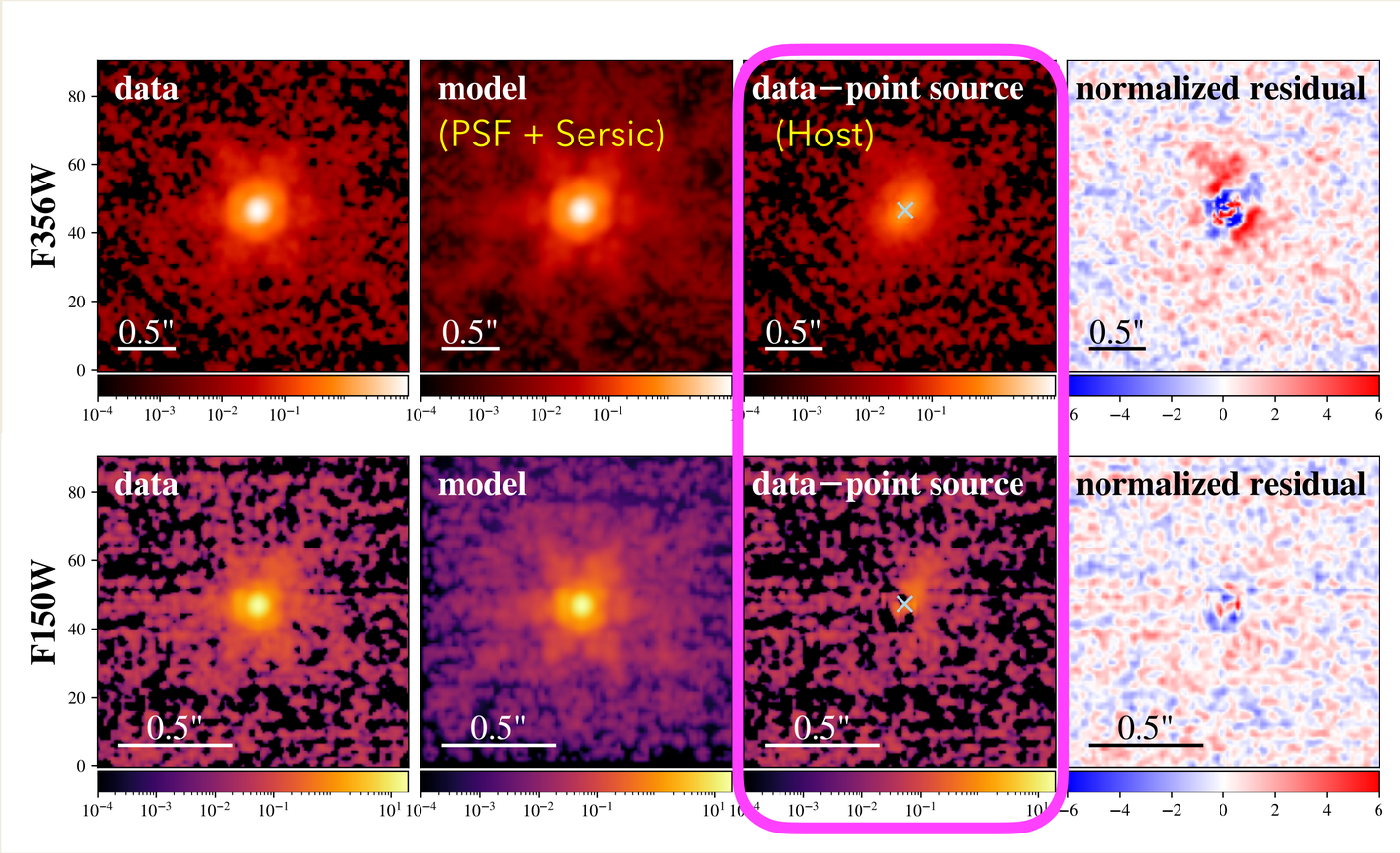


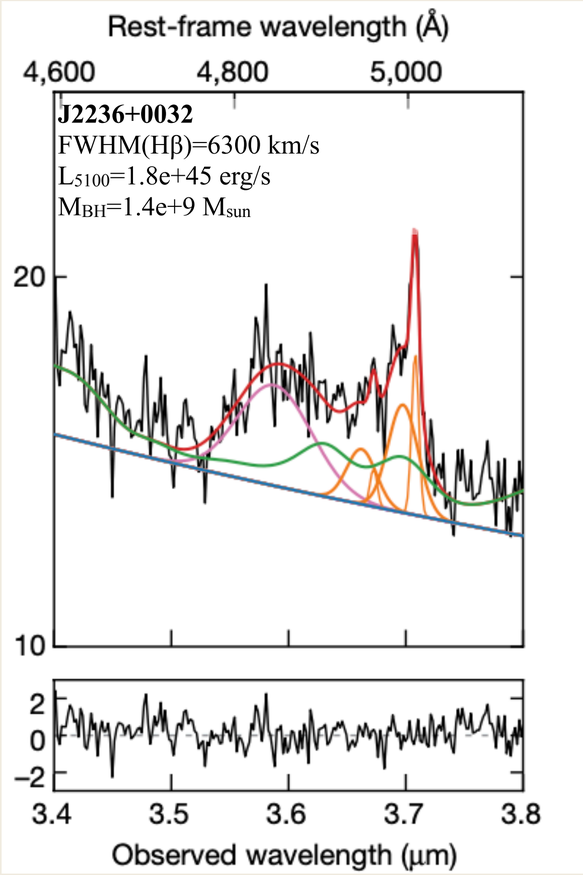


- ✦ z=4-7 Luminosity function constrained down to faint end
- ✦ HSC is dominating the quasar discovery at intermediate-luminosity range (until LSST)

See also MO+19, He+24 for BH mass measurements

JWST follow-up of HSC z=6 quasars

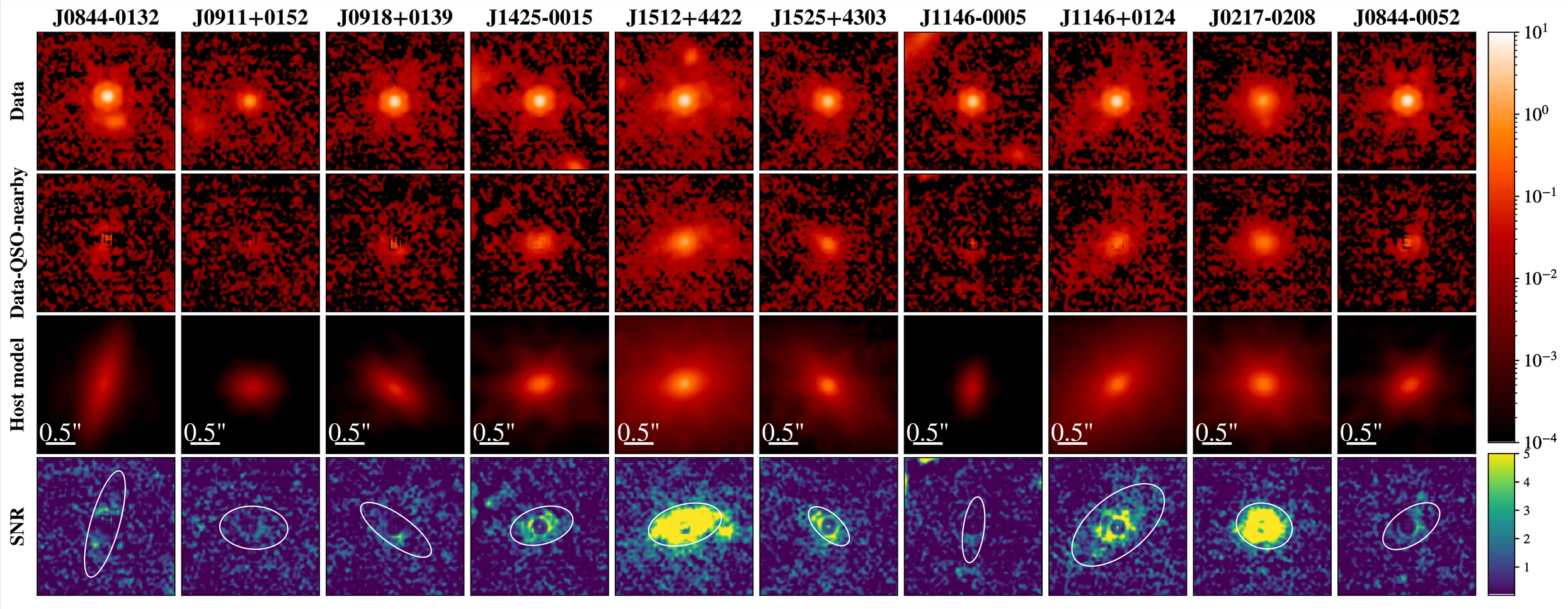




Host stellar emission can be well recovered with JWST (log M_*/M_{sun} ~ 10.5) & secure M_{BH} estimate with Hβ

Ding, MO+23

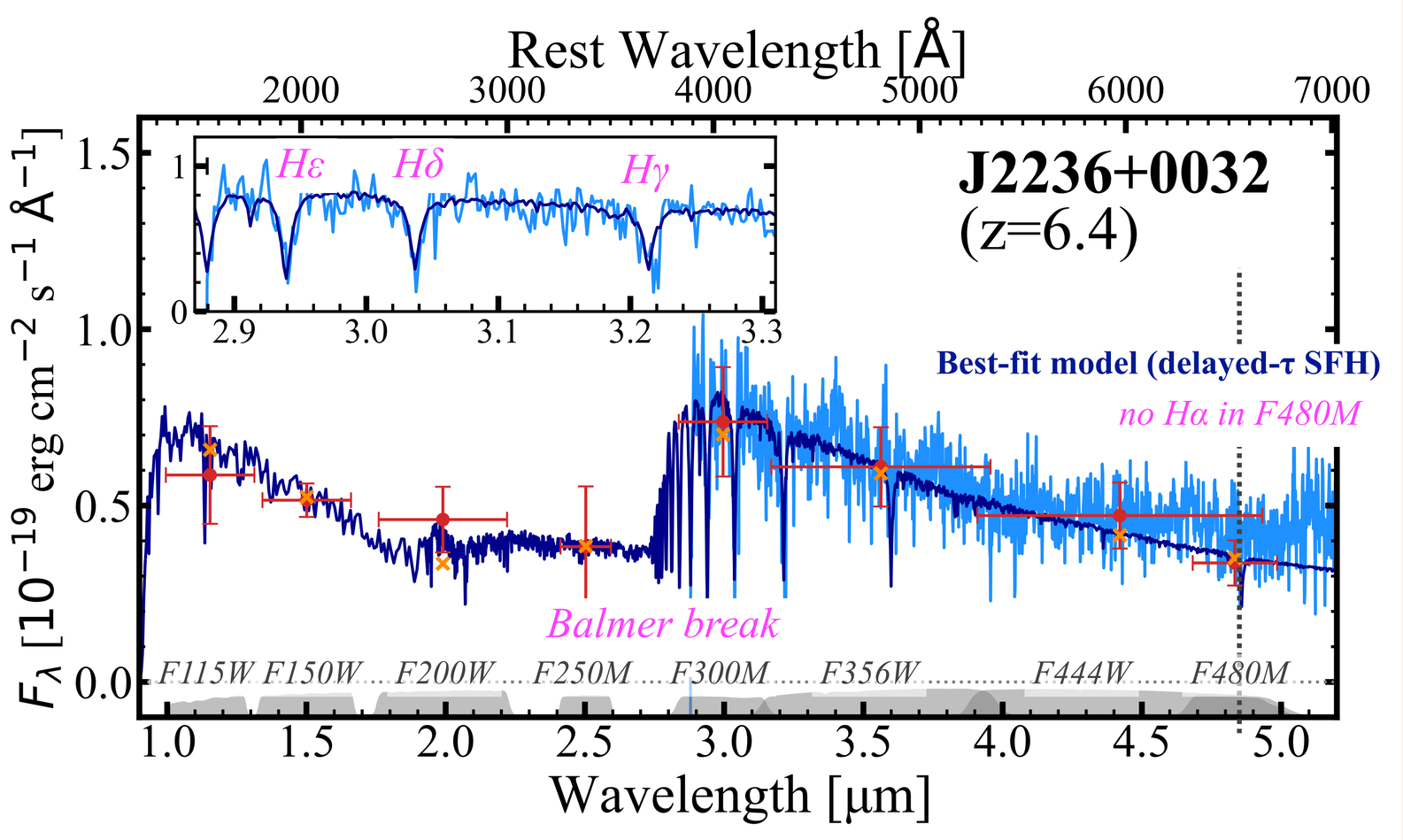
Full Cy1 Sample (F356W)

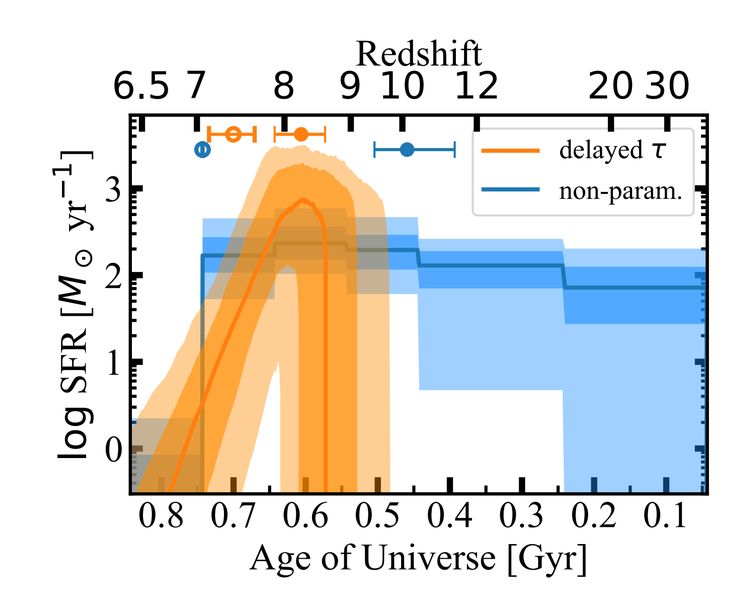


Detection rate: 10 / 12, log M_*/M_{sun}~10.5 (host fraction~10-40%)

Ding, MO et al. in prep.

Quiescent Quasar Host





✦ ***NIRCam imaging + NIRSpec G395M shows***

- clear Balmer break (F250M+F300M)
- no spatially extended Hα (F480M)
- age = 240^{+30}_{-40} Myr (z_{form}=8.2±0.4)
- $sSFR_{100Myr}$ < 0.1 Gyr^{-1}
- σ_* < 180 +/- 50 km s^{-1} (from Balmer lines)

MO, Ding, Silverman et al. (2024)

Limitation in JWST studies

- **Spectroscopic confirmation is limited**
  (M_{UV} >28 mag or log M_{BH}/M_{sun} <6 candidates are too faint for NIRSpec)

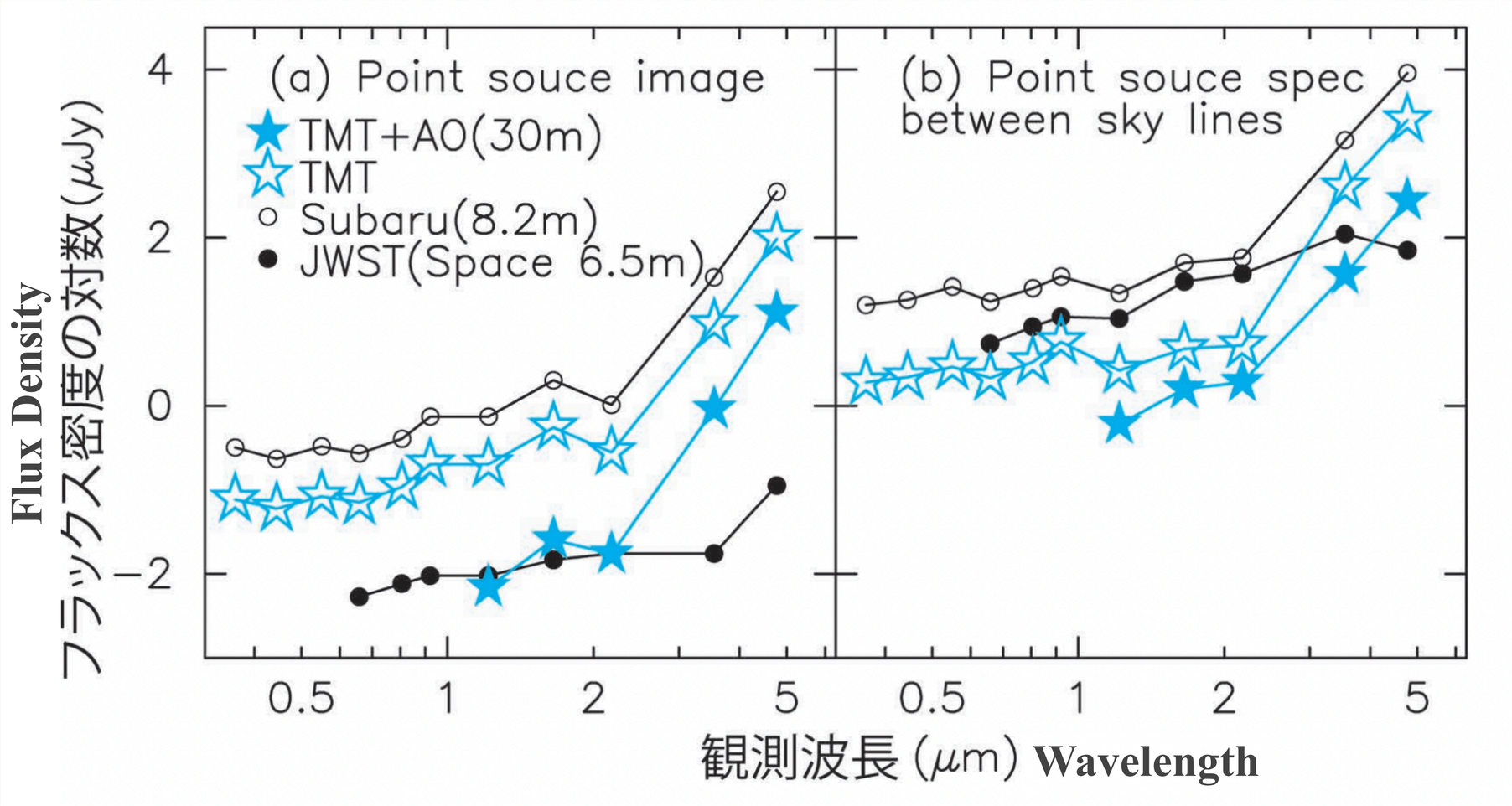
- **Does PSF really represent quasar emission?** There could be possible contribution of *unresolved stellar emission* to PSF (, in which case M_* is underestimated)

- M_{BH} - σ_* relation can be directly compared with the local relation, but
  σ_* measurements for quasar hosts are challenging (success rate for HSC quasars: 2/12)

- **Sample size is limited** (*O*~10 at z~6; *O*~100 at z~2; Tanaka+24)
  - ➡ Need a larger sample to constrain *scatter* of M_* / M_{BH}, but JWST observing time is too expensive
  - ➡ M_{BH} estimate in NIR is also expensive with 8m-class telescopes (>5 hrs / target at M_{UV} > 23)

TOWARD TMT ERA

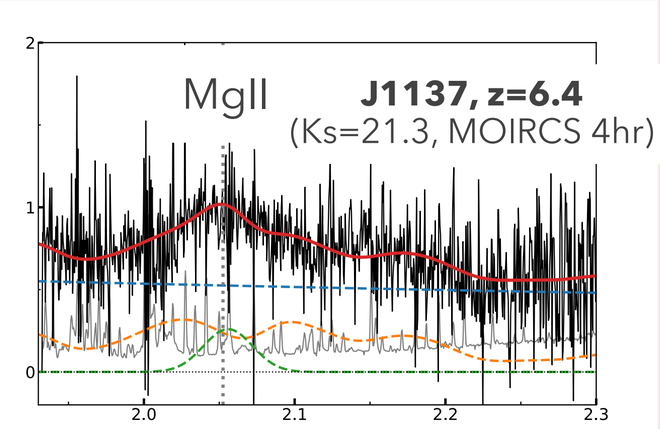
TMT's sensitivity



At 1-2μm, AO-assisted sensitivity is comparable to JWST at 1-2μm
Better in spectroscopy (at wavelengths not affected by OH sky)

Courtesy of Tetsuya Hashimoto（天文月報 2014年 12月）

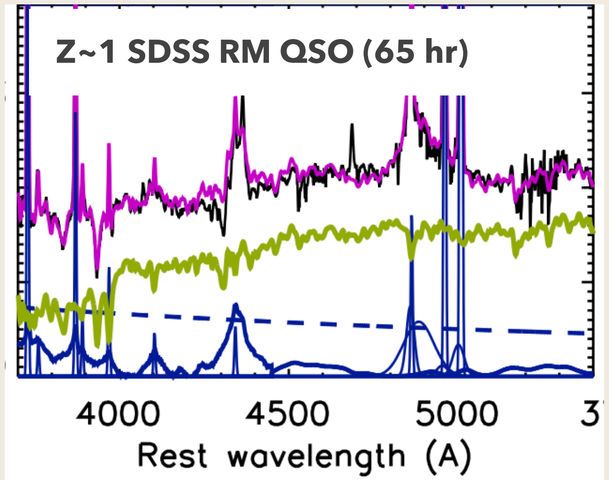
TMT Science cases



✦ **Systematic TMT+AO follow-up of HSC/PFS faint quasars (at z≦4)**

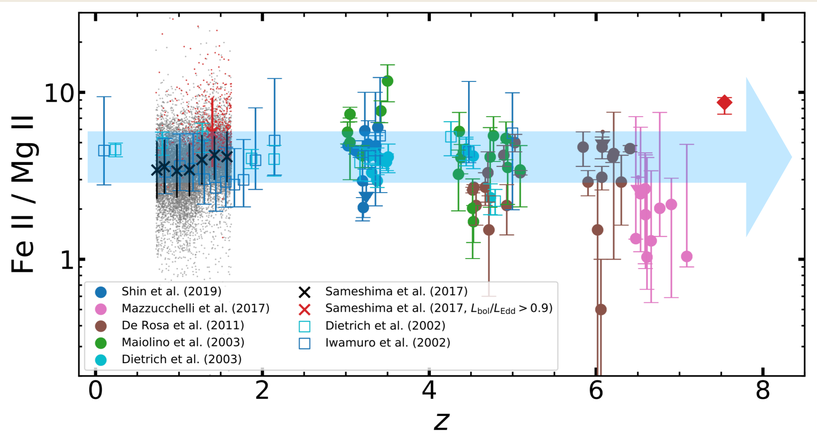
- Host stellar light detection for M_* (to cover λ_{rest} > 4000A)
- M_{BH} estimate through rest UV lines, e.g., MgII 2798, CIV 1400 (especially at >23 mag)
- *Deep NIR spectroscopy to detect host stellar absorption* (M_{BH} - σ_*)

✳ ***A large sample (N>100)*** enables us to constrain the BH demographics in the M_* / σ_* vs M_{BH} plane at high redshift *(BH first and/or galaxy first)*



MO in prep.; Matsuoka+15

TMT Science cases



Other science cases

- ✦ **high-SNR spectral follow-up to characterize weak emissions**
  - Broad-line-region metallicity (e.g., HeII 1640 vs CIV 1400)
  - FeII / MgII (~[Fe / α] on the nuclear scale)
- ✦ **IFU follow up to trace AGN feedback: to be compared with ALMA**
- ✦ **Confirmation of JWST/Euclid/Roman-selected faintest AGN candidates**
  - M_{BH} distribution; seed BH signature (e.g., OI λ1304, CII λ2326; Inayoshi, MO+22)

Nagao+06; Jiang, MO+24

Summary

- **Subaru has played a significant role in high-z quasar observations, bridging the gap between SDSS and JWST discovery space**

- **JWST follow-up observations of HSC quasars have revealed host stellar emission at z=6, thanks to their relatively faint quasar luminosity.** Characterization of M* vs M_{BH} distribution is ongoing.

- **TMT follow-up observations of Subaru(HSC/PFS)-selected quasars will reveal the demographics of high-z SMBHs**, overcoming some limitations in the JWST studies and possibly revealing young seed BHs