# Exploring the early growth history of SMBHs and host galaxies with Subaru and JWST

Masafusa Onoue (KIAA / Kavli IPMU)

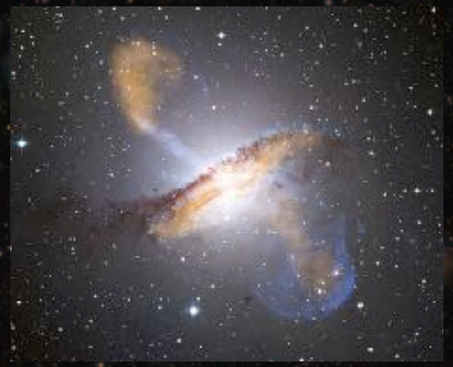
On behalf of JWST Cy1 GO #1967

# High-z quasars - Unique probe of the early Universe

Fundamental questions we aim to answer:

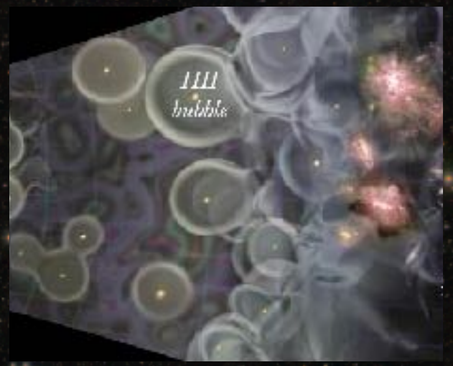
## *Why do supermassive black holes (SMBHs) exist?*

- When were they born?
- What were their seeds?
- How did they grow in the early and late epochs of the cosmic history?



## *How did the host galaxies form and (co-)evolve?*

- When and how did the first stellar-mass assembly happen?
- Did SMBHs impact the host galaxy evolution? If so, how?
- Do they mark the highest density peaks of the DM distribution?




## *When and how was the Universe re-ionized?*

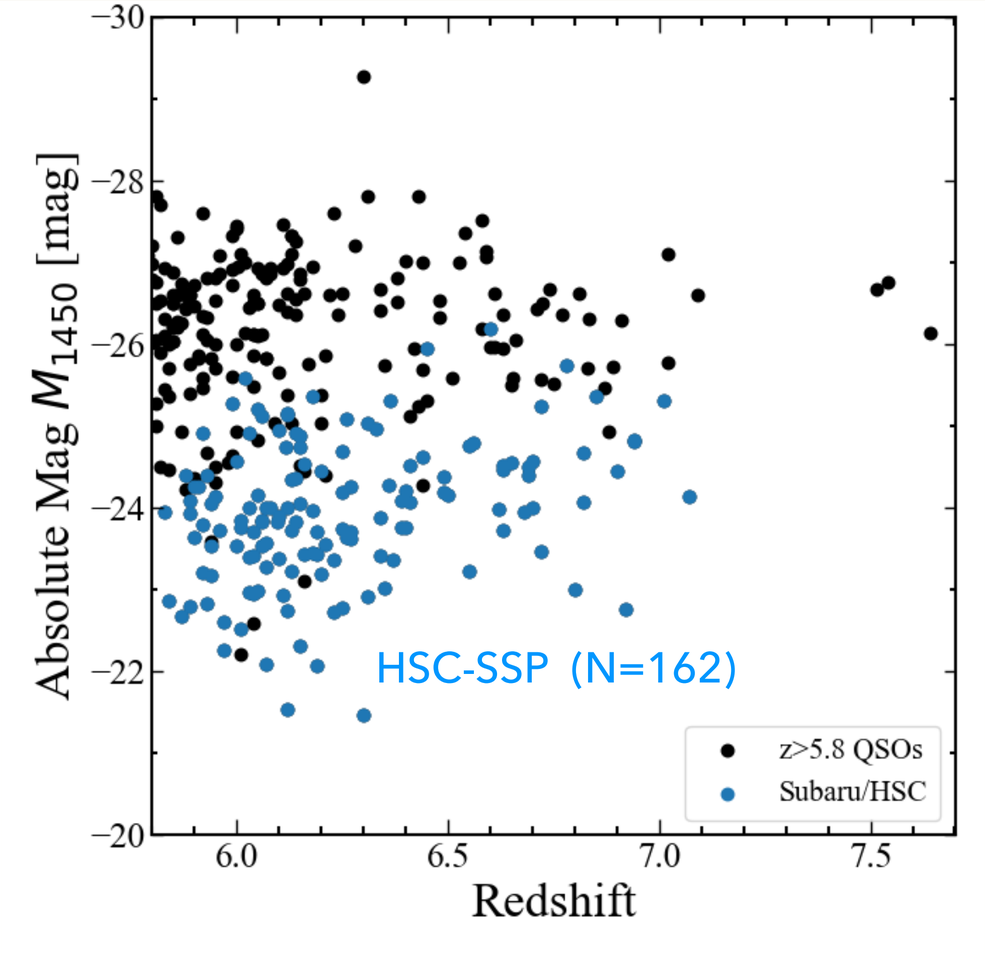
- When did re-ionization start and complete?
- How did it proceed, as a function of space and time?
- What provided the ionizing photons?

and many more!



Courtesy of Y.Matsuoka

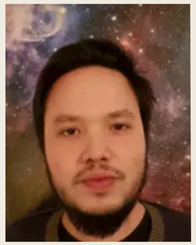
# z>6 QSOs



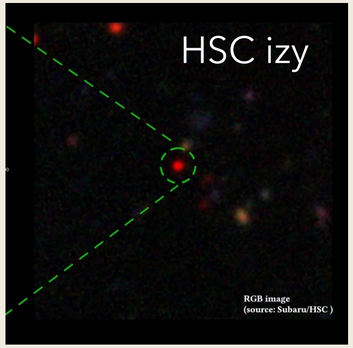

Matsuoka+16-22
* Paper II receives PASJ Excellent Paper Award 2022

**HSC-SSP QSOs dominate the low-luminosity regime**

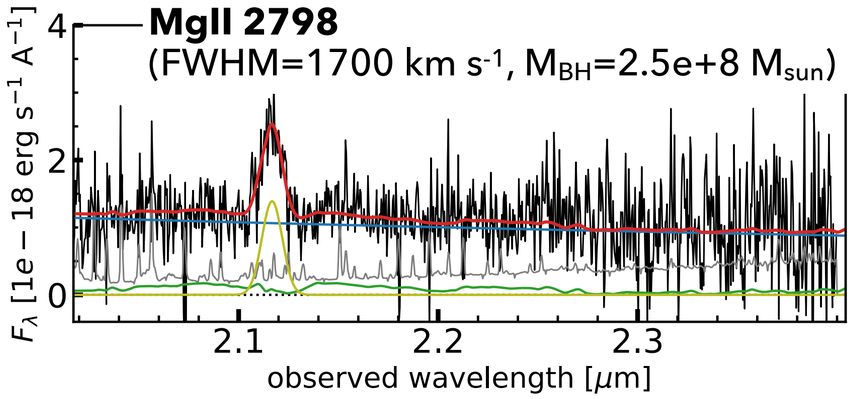
# eROSITA Detection of z=6.56 QSO



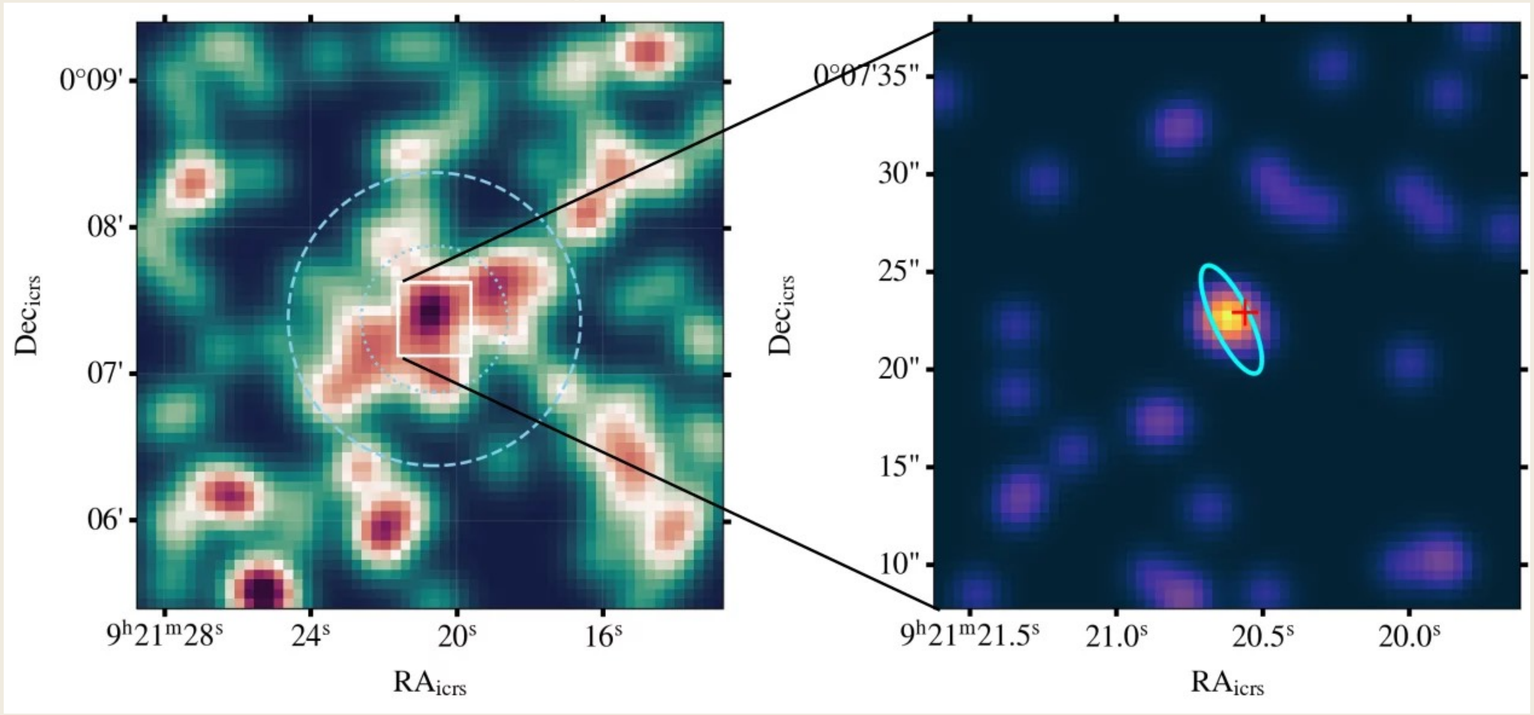

- HSC J0921+0007 ($y_{AB}$=21.2)




- Subaru/MOIRCS ($T_{exp}$=70 min)




- Left: eFEDS 0.2-2.3 keV, Right: Chandra 0.5-7 keV

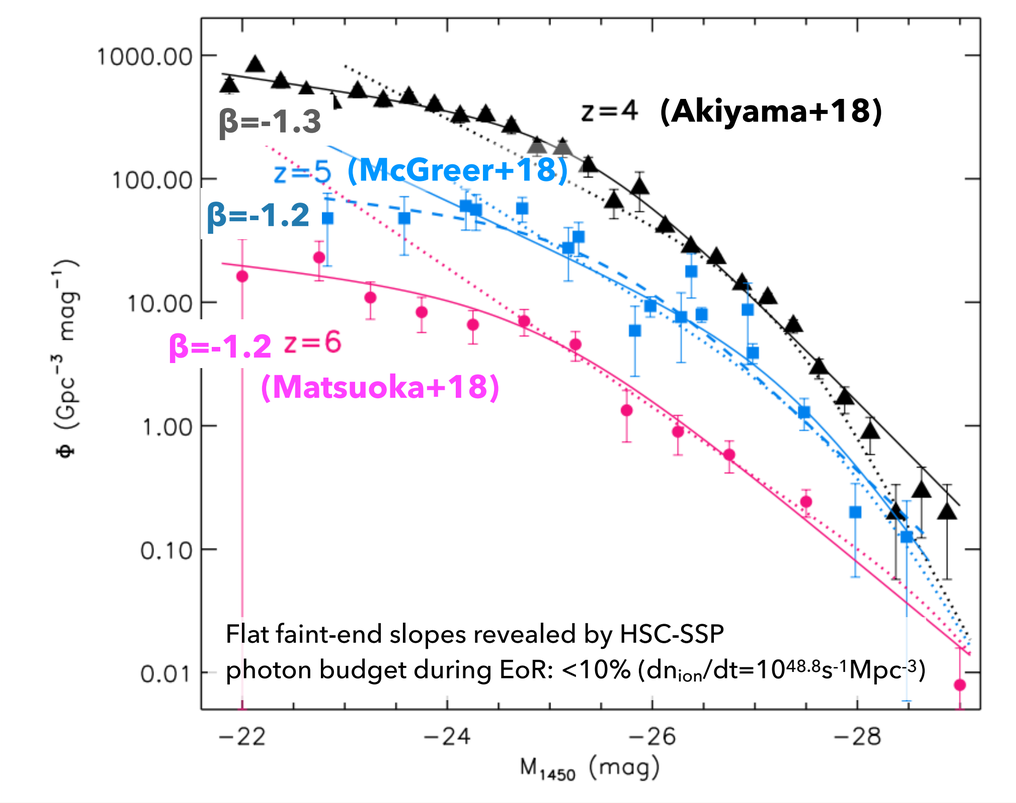



Wolf, Salvato, Nandra, Buchner, MO +22

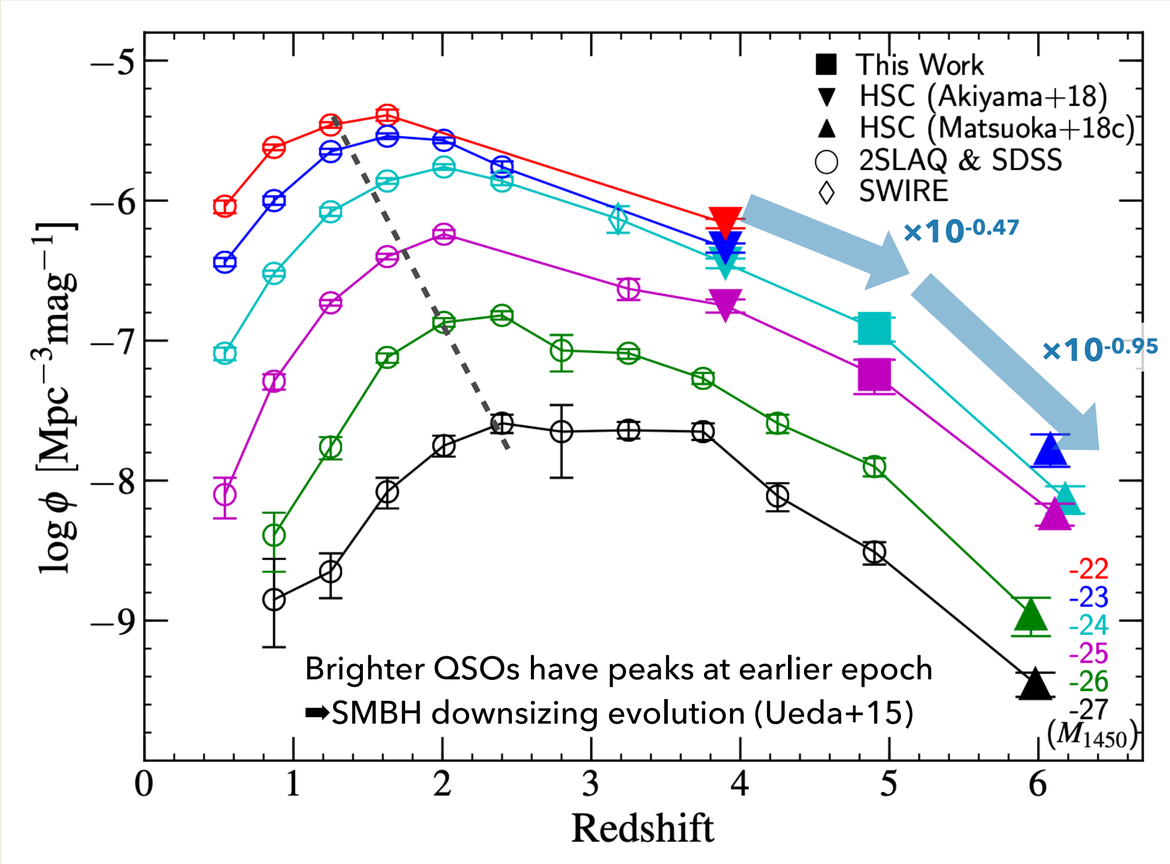
**Blind detection of a distant X-ray-loud QSO** (high-z analog of local NLSy1?)

# z=4-6 Quasar LF from HSC-SSP

- z=4-6 QLF (Matsuoka+18)

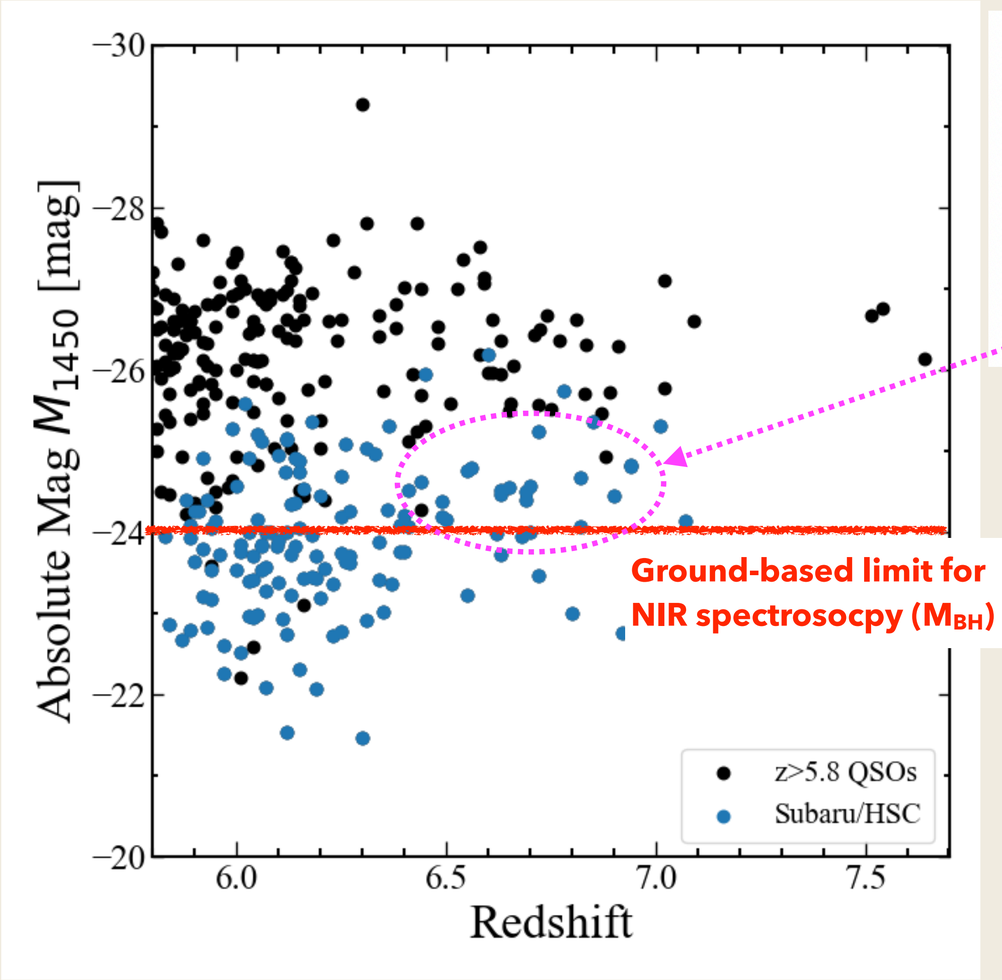


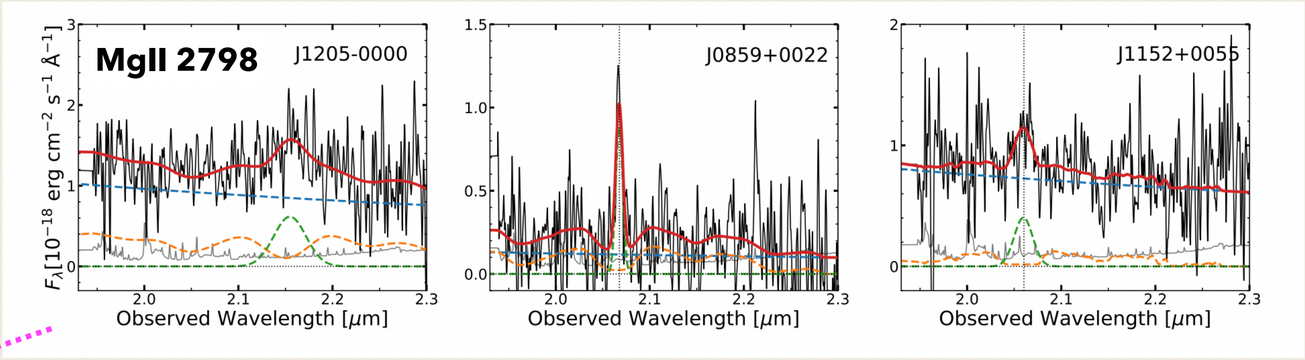

- QLF evolution at z=0-6 (Niida+20)

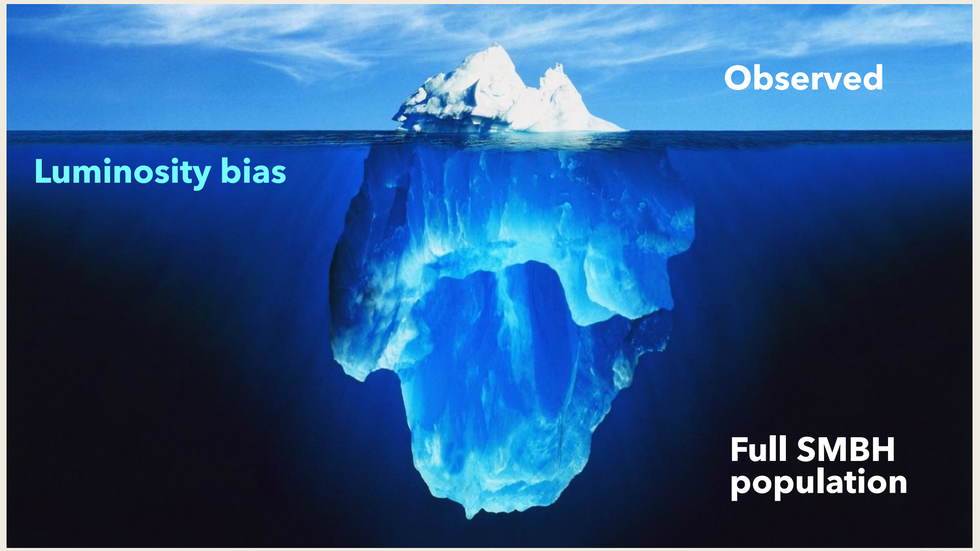



**HSC-SSP is currently the most powerful survey to sample representative quasar populations at high-z**

# Limitation in NIR spec follow-up



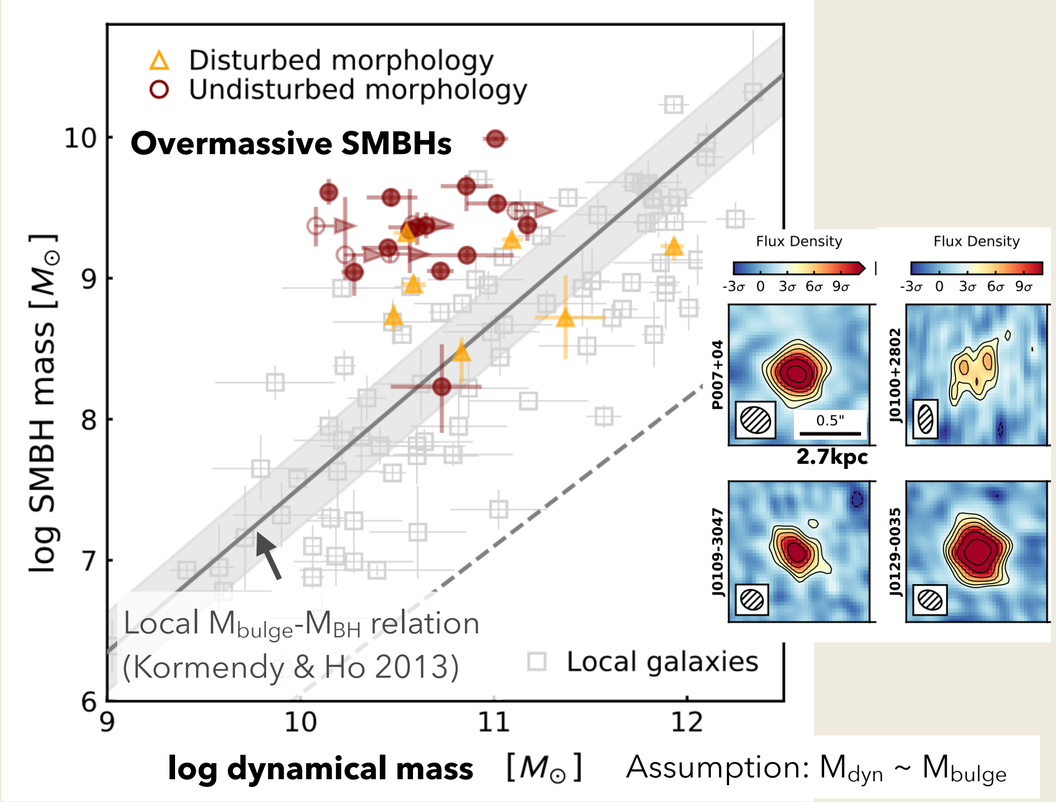




Onoue+19

**Current knowledge biased toward the most luminous (i.e., massive & active) population**

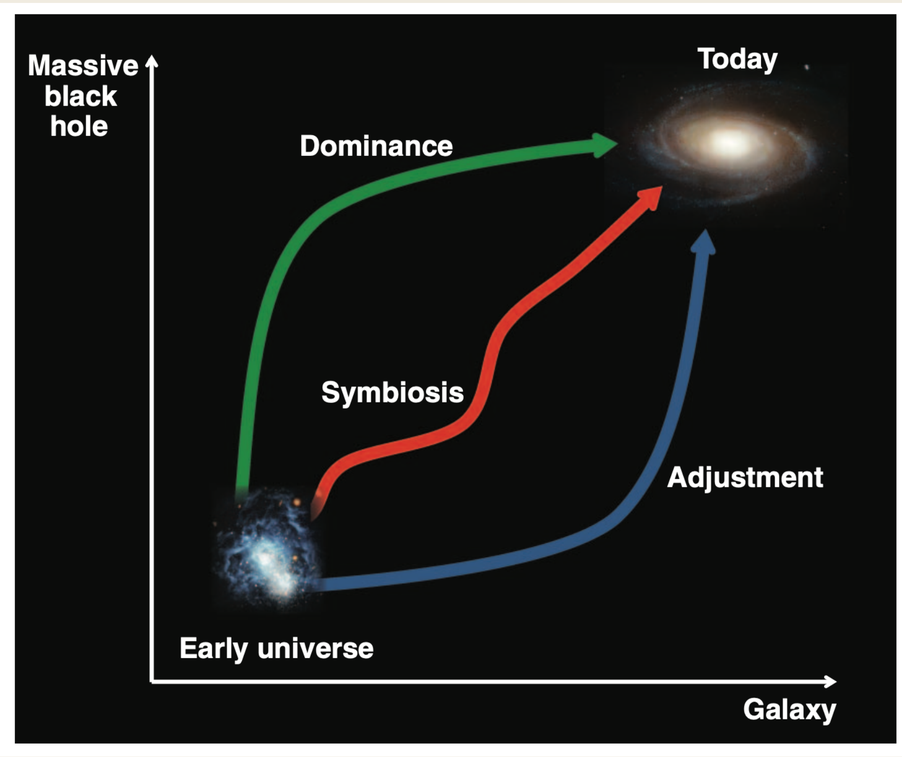
# SMBH vs Host Dynamical Mass

▸ [CII] 158μm-based dynamical mass vs virial SMBH mass at z=6 (Neeleman+21)




See Izumi+18-21 for HSC quasars

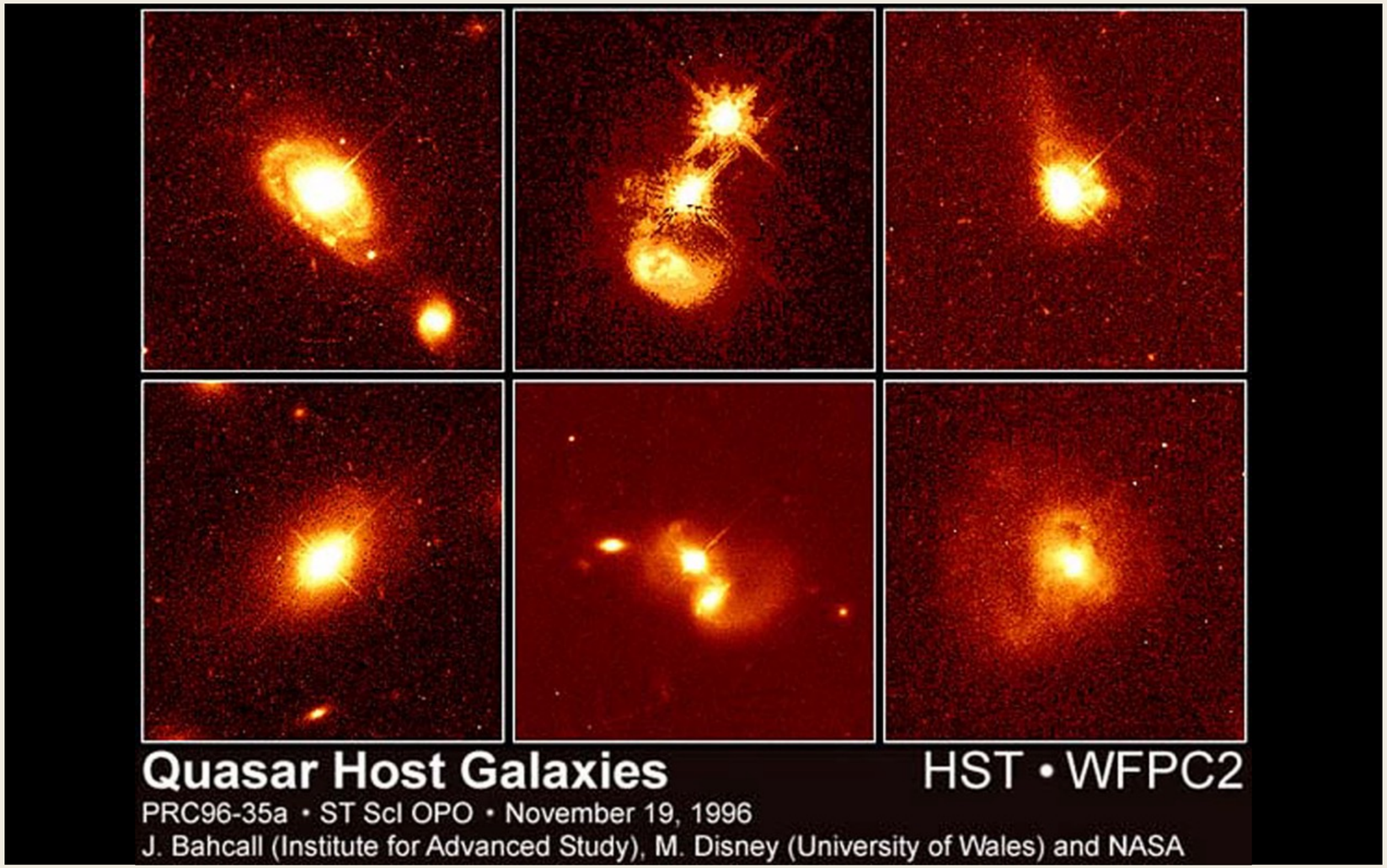
▸ Schematic diagram of SMBH-galaxy co-evolution (Volonteri12)




Volonteri12

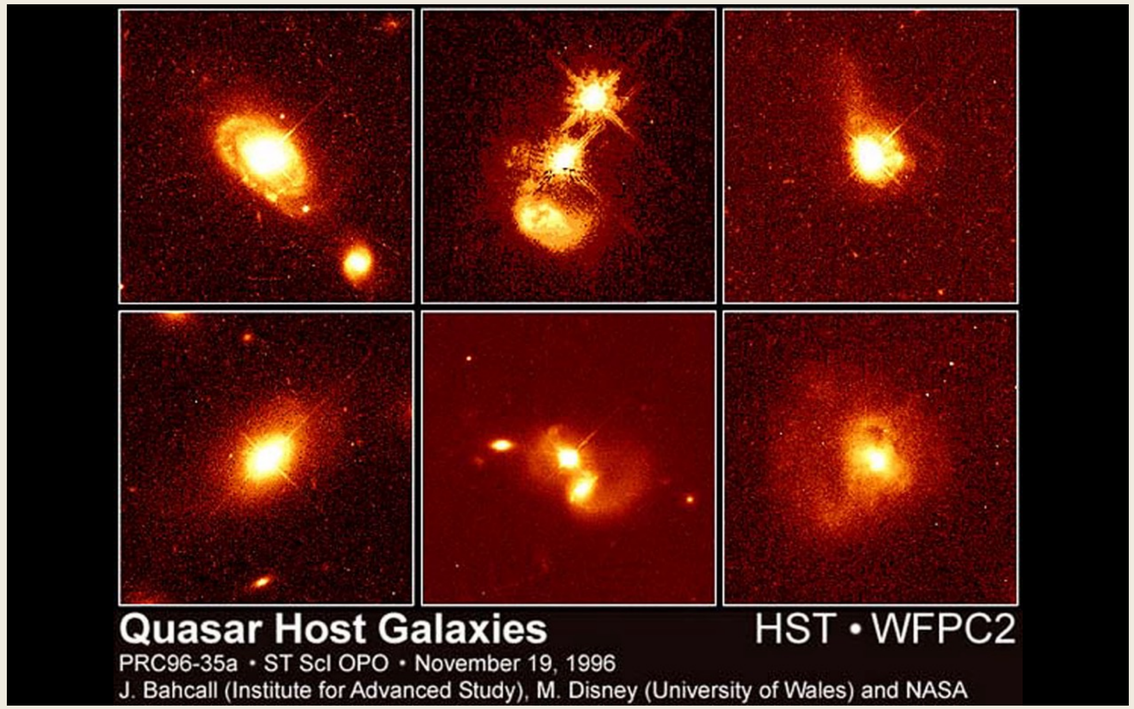
**BH growth first and host growth next? Direct measurements of M* are anticipated**

# HST Images of Quasar Hosts

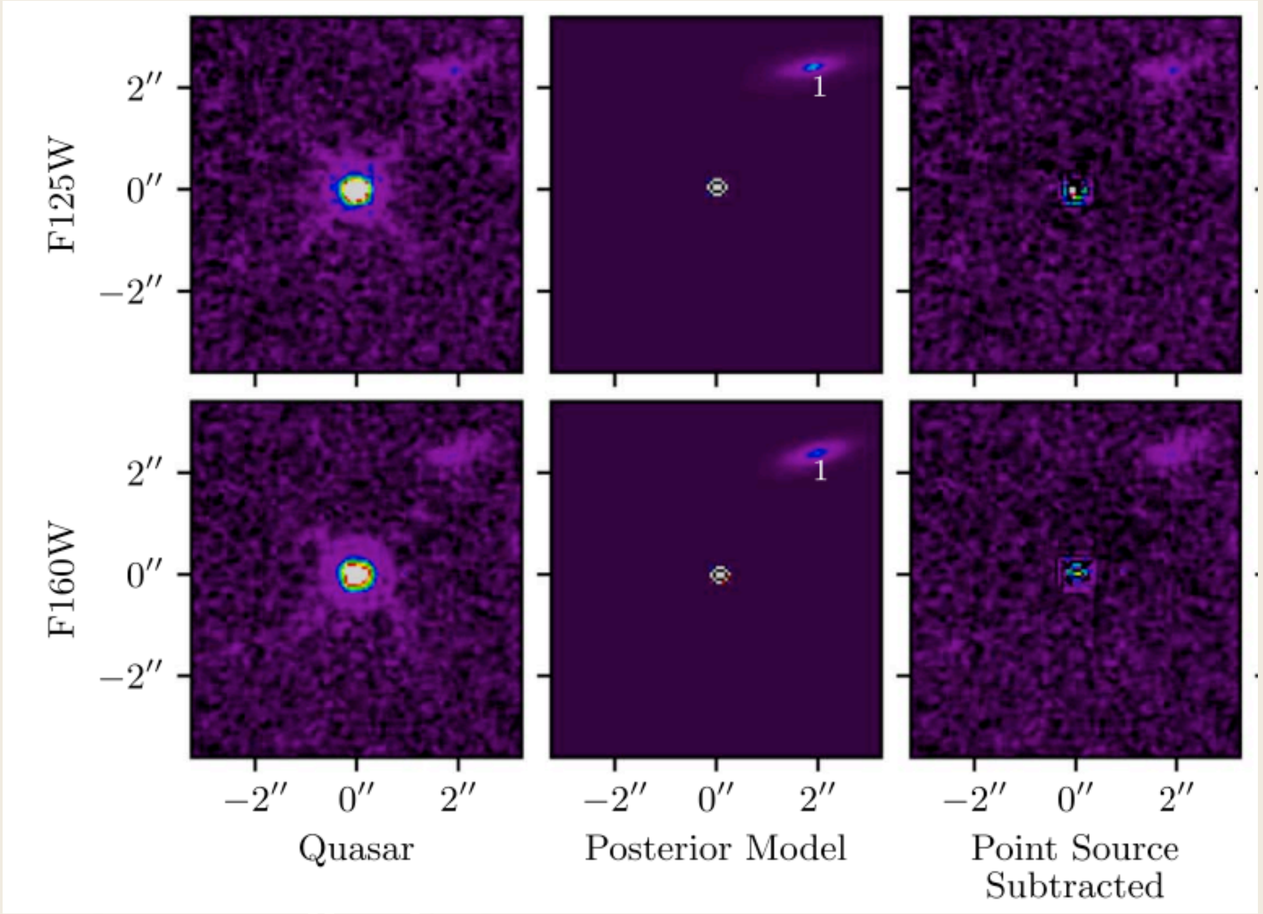


# HST Images of Quasar Hosts

- z=0




- z=6 (CFHQS J0033-0125)



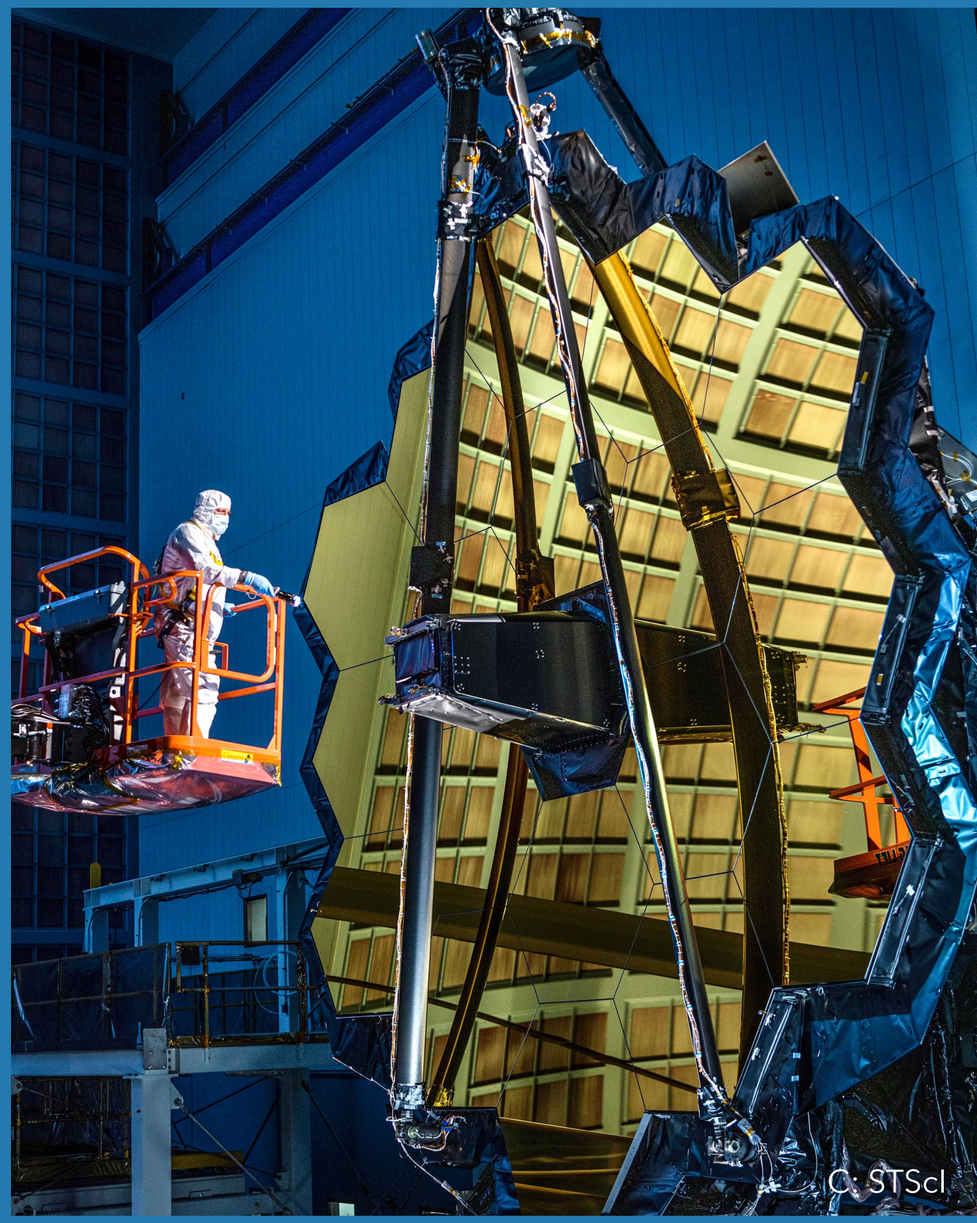

**Challenging to detect host stellar light at z>2**

Marshall+20

# Cy1 JWST GO #1967:

*Full Census of SMBHs and Host Galaxies at z=6*

*PI: M.Onoue (KIAA/IPMU)*
*Co-PIs: X.Ding (IPMU), J.Silverman (IPMU), Y.Matsuoka (Ehime U.), T.Izumi (NAOJ)*
*+ 40 Co-Is*



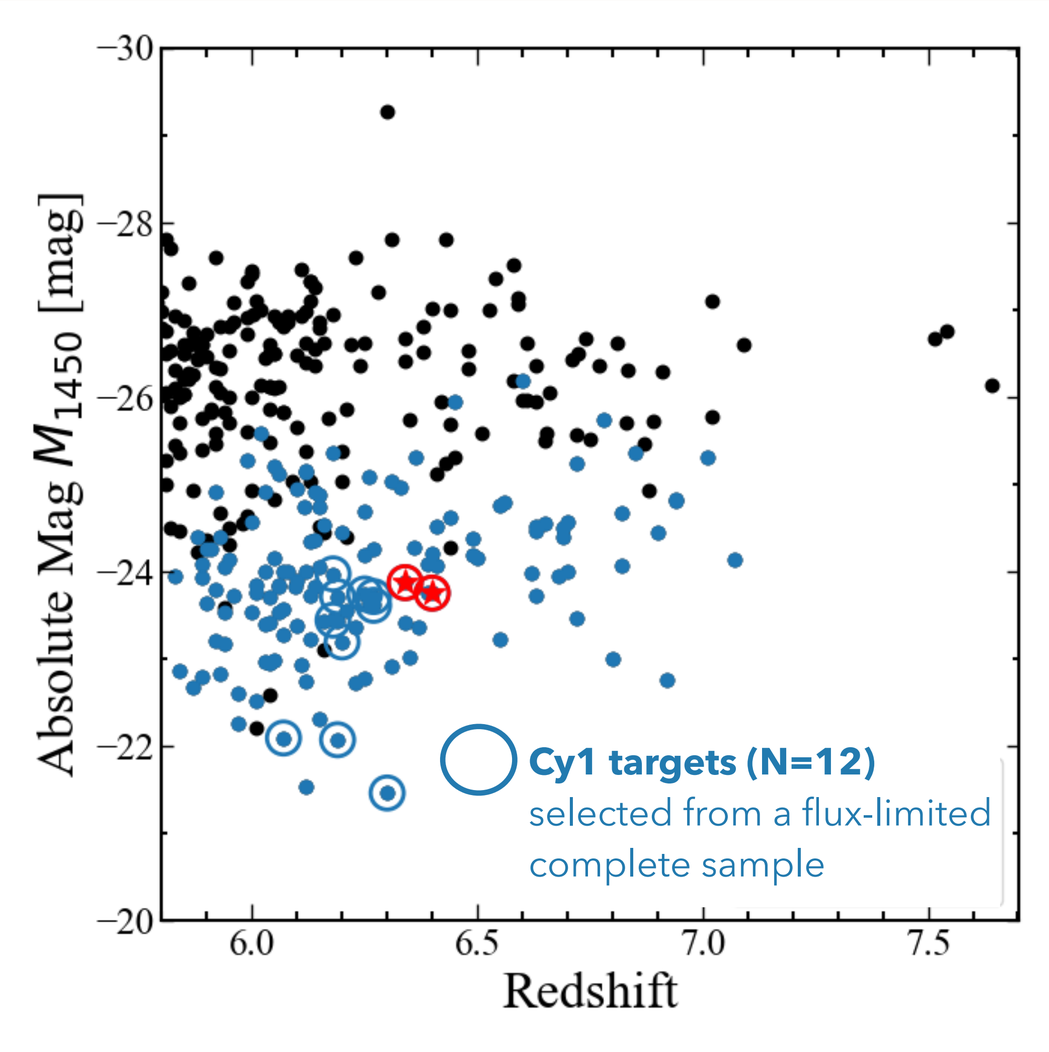

- NIRCam Imaging (FoV: 2.2x2.2 amin$^2$)
  - Filter: F150W + F356W (straddling 4000A break)
- Quasar- Host decomposition -> host stellar light detection
  - **M**$_*$, age, companions, environment, etc.

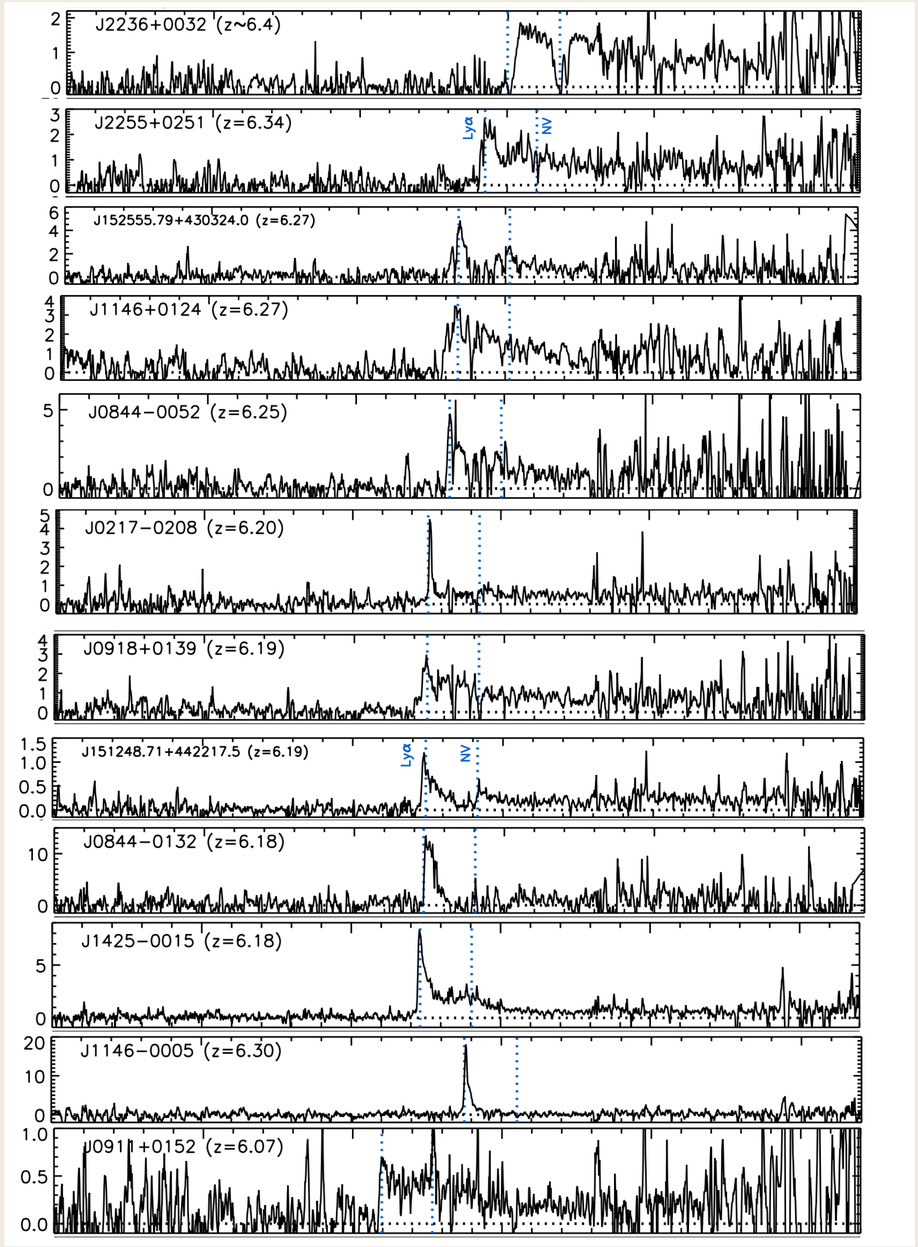
+


- NIRSpec Fixed-Slit spectroscopy
  - Grism: G395M (R=1000), 2.87-5.27μm (rest 4000-7300Å, incl. Balmer lines)
- Rest-optical emission line measurements
  - Hβ-based **M**$_{BH}$, BLR/NLR, [OIII] gas outflow, etc.

- Mean (and scatter of) **M**$_{BH}$ **/ M**$_*$ ratio at z=6 (SMBH first, or galaxy first?)
- BH mass function, Eddington ratio distribution
- Comparison of stellar and dynamical masses (ALMA Cy9 2022.1.01135.S, PI: T.Izumi)

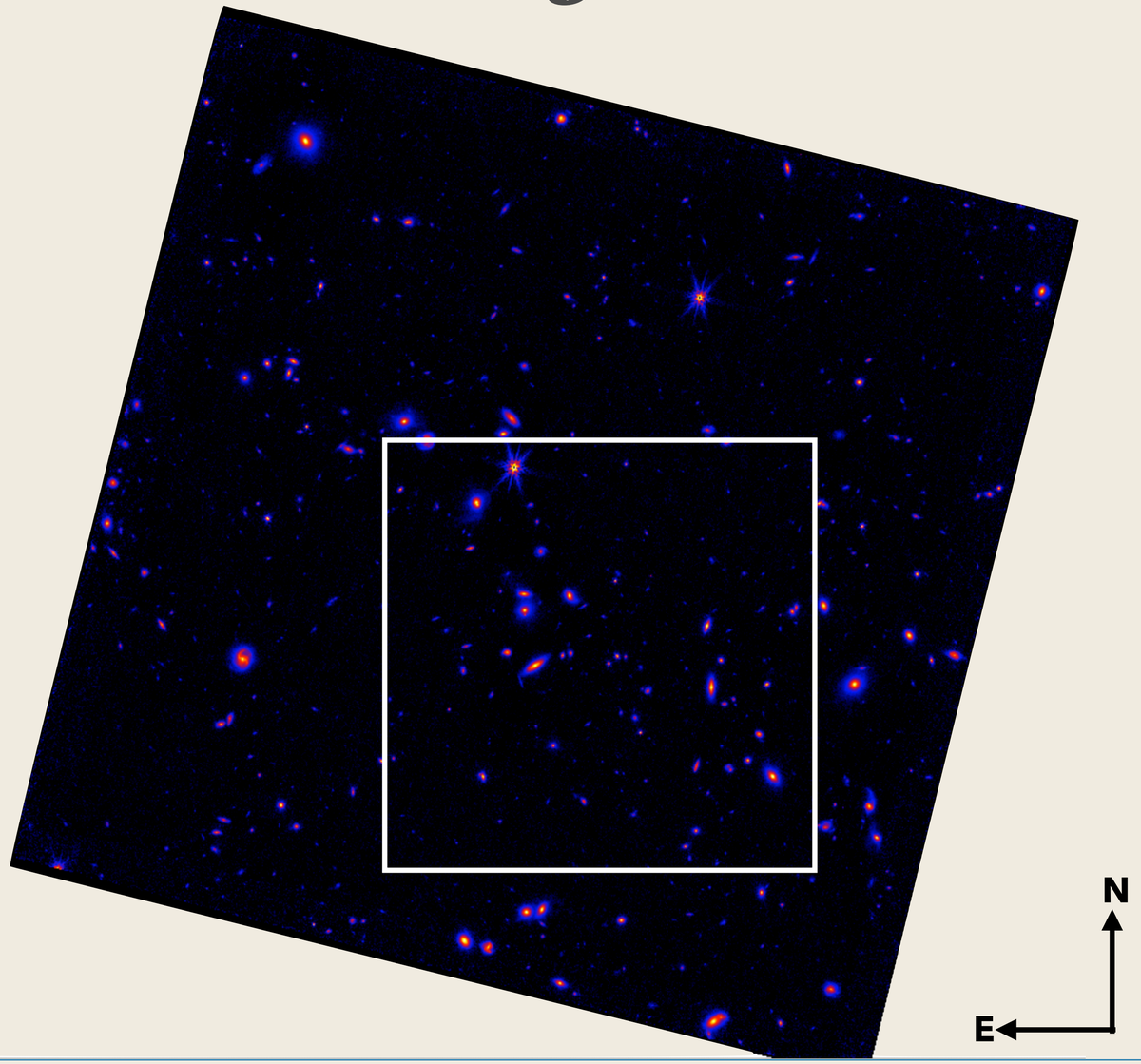
# Targets

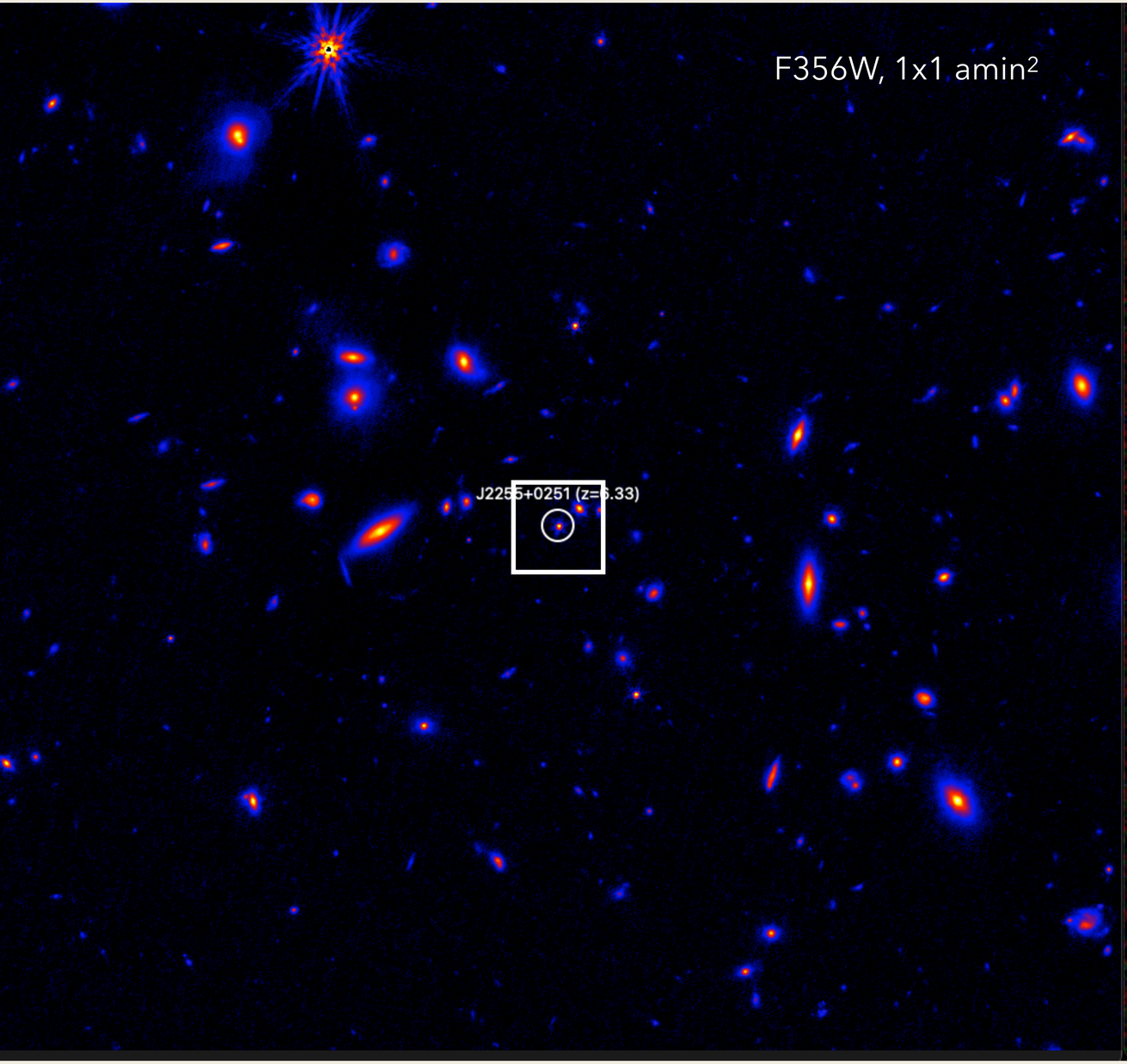

Absolute Mag $M_{1450}$ [mag]
−30
−28
−26
−24
−22
−20
6.0
6.5
7.0
7.5
Redshift
Cy1 targets (N=12)
selected from a flux-limited
complete sample

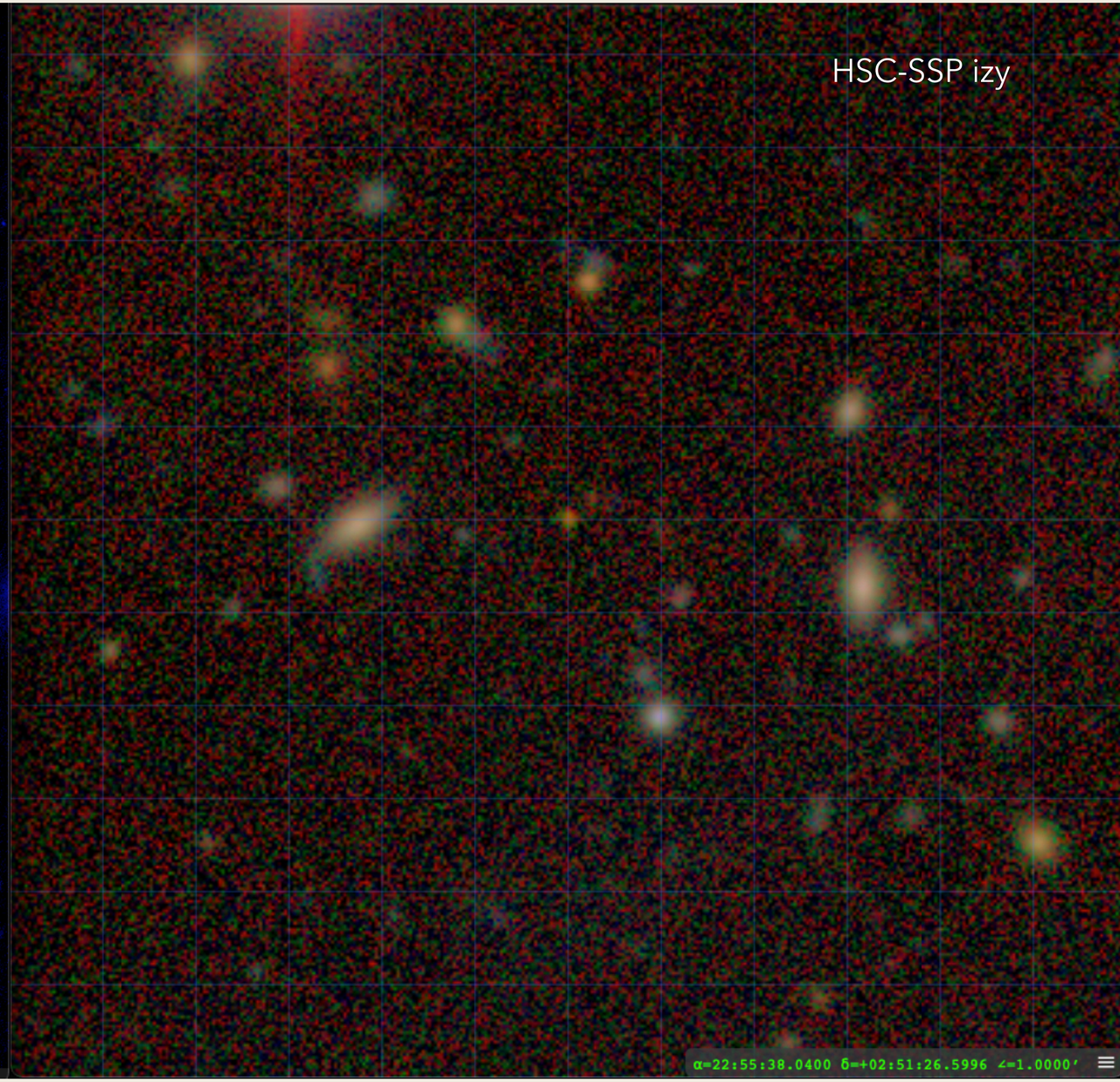

J2236+0032 (z~6.4)
J2255+0251 (z=6.34)
Lyα
NV
J152555.79+430324.0 (z=6.27)
J1146+0124 (z=6.27)
J0844−0052 (z=6.25)
J0217−0208 (z=6.20)
J0918+0139 (z=6.19)
J151248.71+442217.5 (z=6.19)
J0844−0132 (z=6.18)
J1425−0015 (z=6.18)
J1146−0005 (z=6.30)
J0911+0152 (z=6.07)

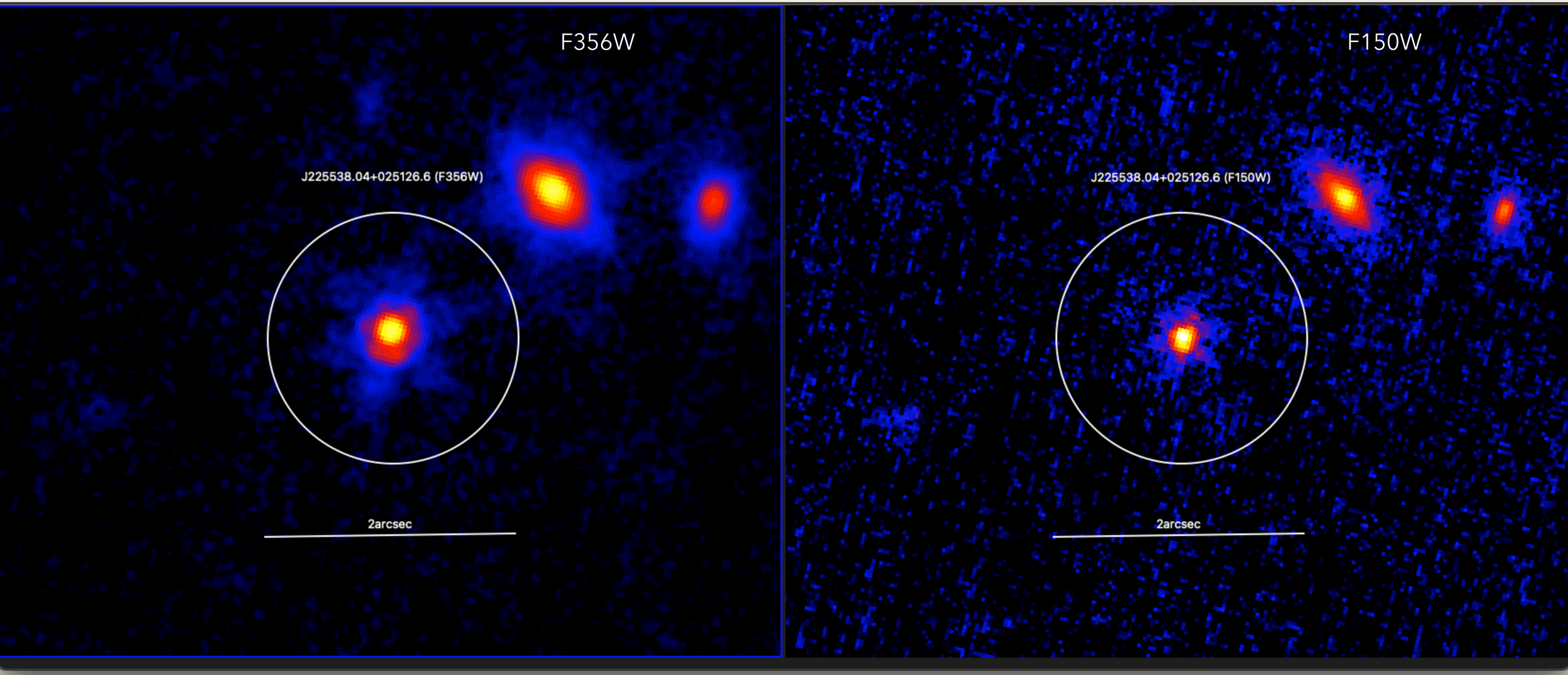
# NIRCam F356W: HSC J2255+0251 (z=6.33)

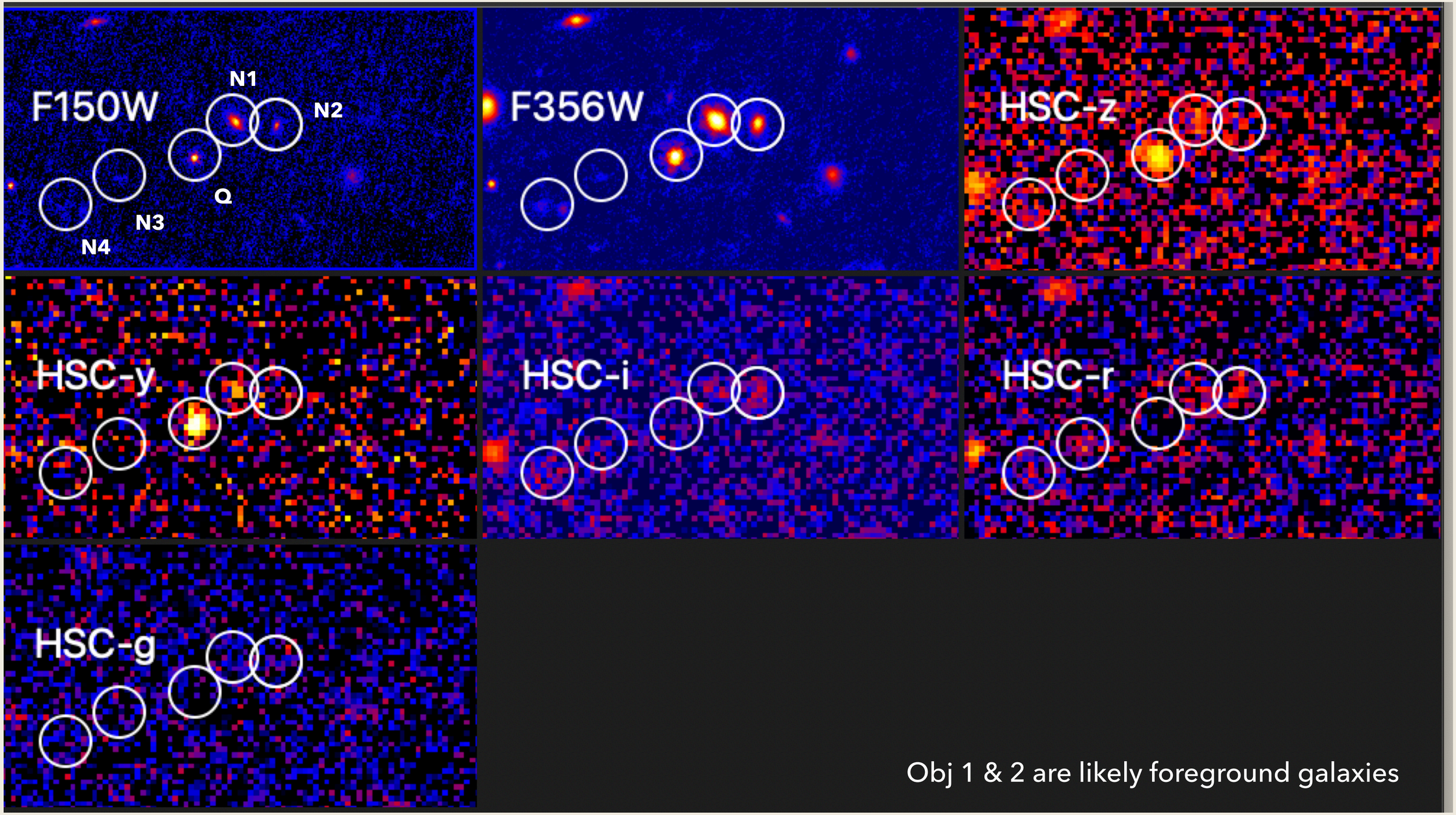
- Module B (FoV: 2.2x2.2 arcmin$^2$)
- 3100 sec exposure
  (4x4 primary x sub-pixel dither)
- Post-processed by JWST pipeline v1.8.0
- Resampled pixel scale: 0.0315”



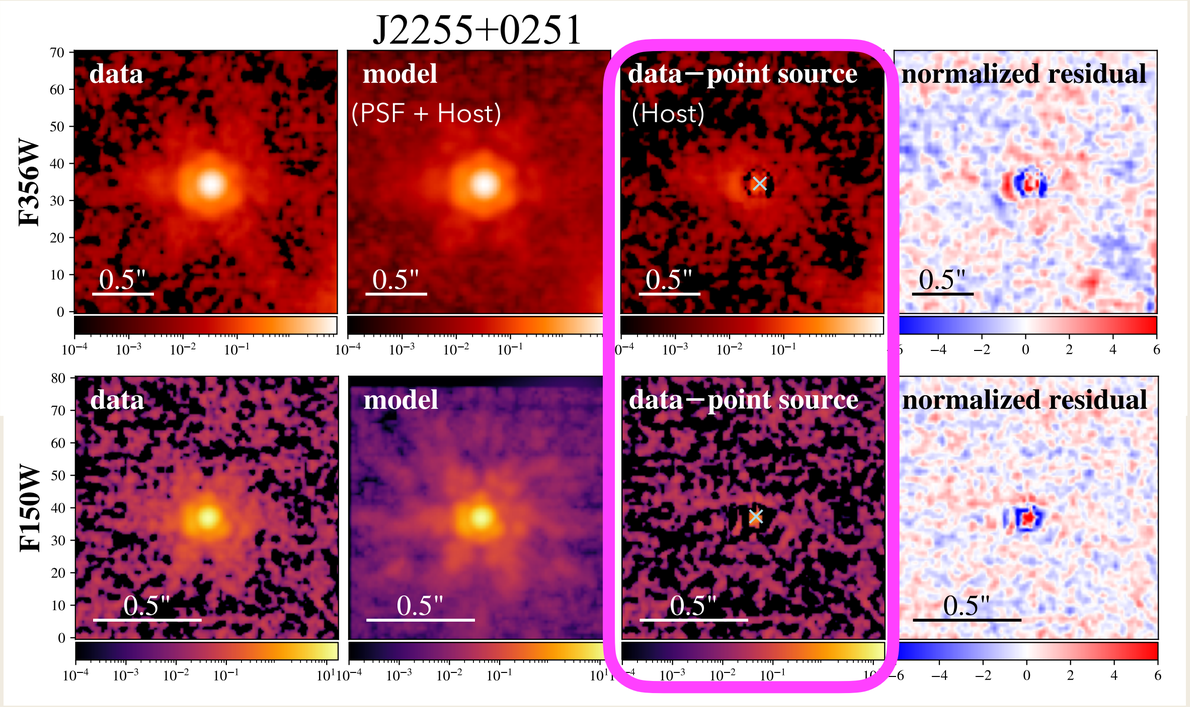

F356W, 1x1 amin2
J2255+0251 (z=6.33)


HSC-SSP izy
α=22:55:38.0400 δ=+02:51:26.5996 ∠=1.0000′

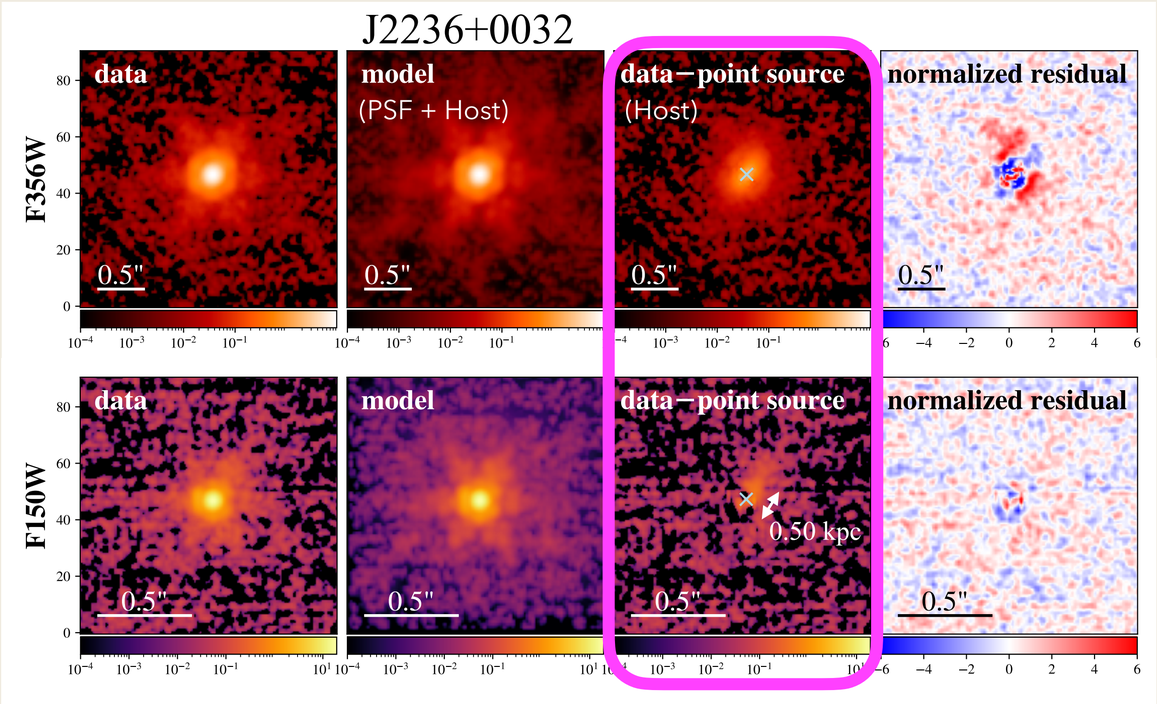

F356W
J225538.04+025126.6 (F356W)
2arcsec
F150W
J225538.04+025126.6 (F150W)
2arcsec


F150W
N1
N2
Q
N3
N4
F356W
HSC-z
HSC-y
HSC-i
HSC-r
HSC-g
Obj 1 & 2 are likely foreground galaxies

# The First Star Light Detection from z>6 Quasar Hosts




- log M*/$M_{sun}$= 10.53±0.20,
  host ratio = 7.8% (F356W), <3.1% (F150W)




- log M*/$M_{sun}$= 10.96±0.20,
  host ratio = 23.1% (F356W), 8.3% (F150W)

Ding, MO+22

# Summary

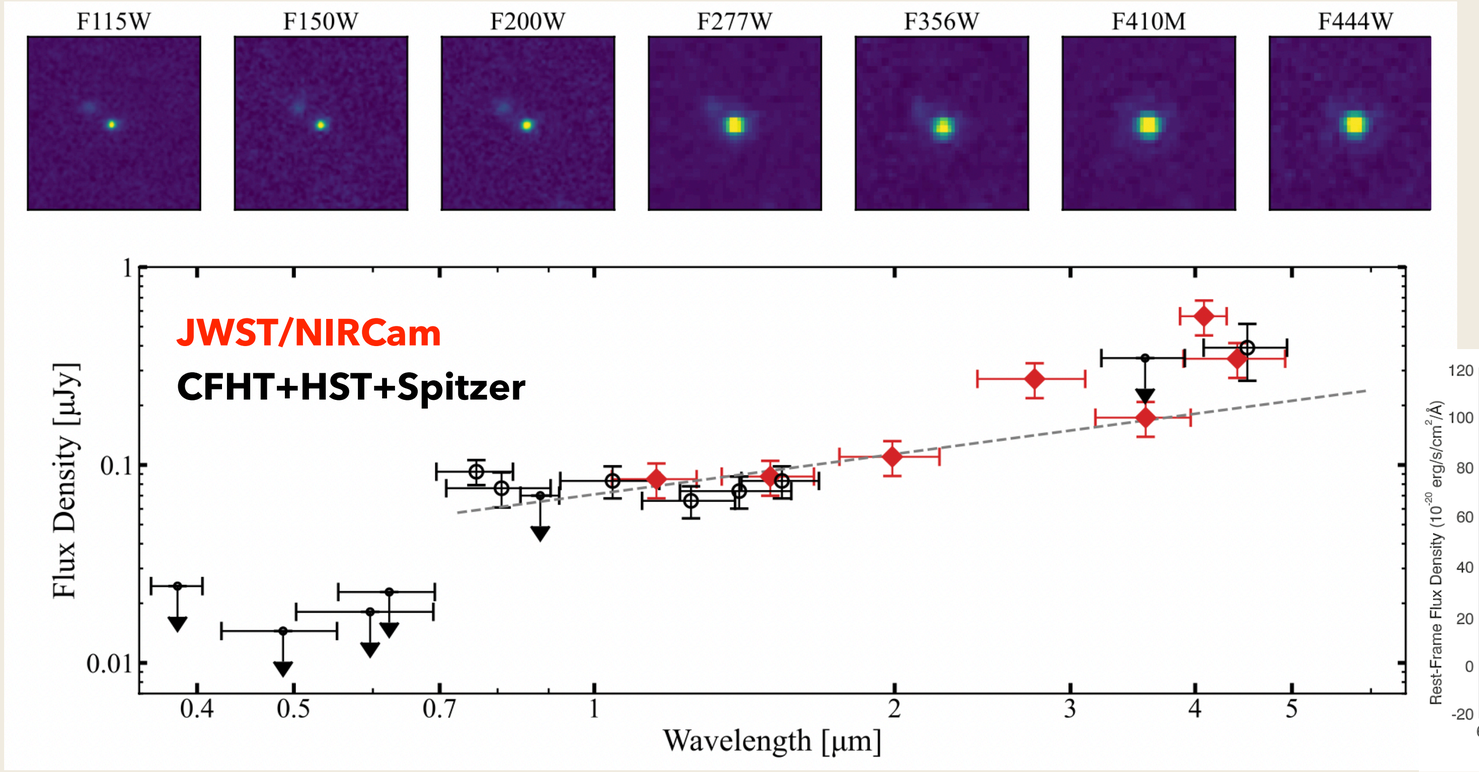
- JWST provides the opportunities to characterize M_BH and M_* of high-redshift low-luminosity quasars from the HSC-SSP

- Host stellar light is detected from the NIRCam F356W+F150W images of the first two targets with inferred stellar mass > 10^10 Msun. Spatial offset between quasar and host galaxy?

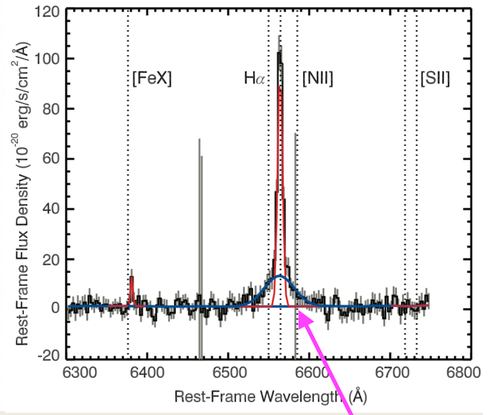
- NIRSpec rest-optical spectroscopy reveals many broad/narrow emission lines. Host stellar absorption detected from J2236. Hbeta-based BH masses suggest the two quasars are massive both in M* and $M_{BH}$. They are above the local $M_*$ - $M_{BH}$ relation.

- More images & spectra to come in 2023

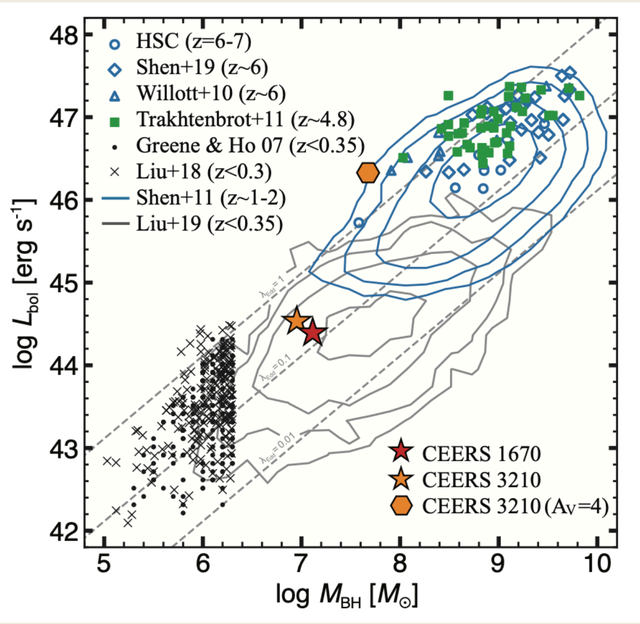
# A Low-Luminosity AGN at z>5




MO, Inayoshi+23




FWHM(Hβ,broad)=2060 km/s




Kocevski, MO+23

✦A z=5 faint ($L_{bol}$~$10^{44}$ erg/s) broad-line AGN in the CEERS field
✦JWST can be a survey telescope for high-z faint AGN!