# AGN Observation Team

Members: Nozomi Ishii, Kosei Matsumoto, Yuri Oku,
Hiroya Umeda, Ryota Ura, Yechi Zhang
Advisors: Yoshinobu Fudamoto, Masafusa Onoue

# Background

Recent observations show SMBHs ($M_\bullet > 10^9 M_\odot$) at z = 7.5.

Questions:

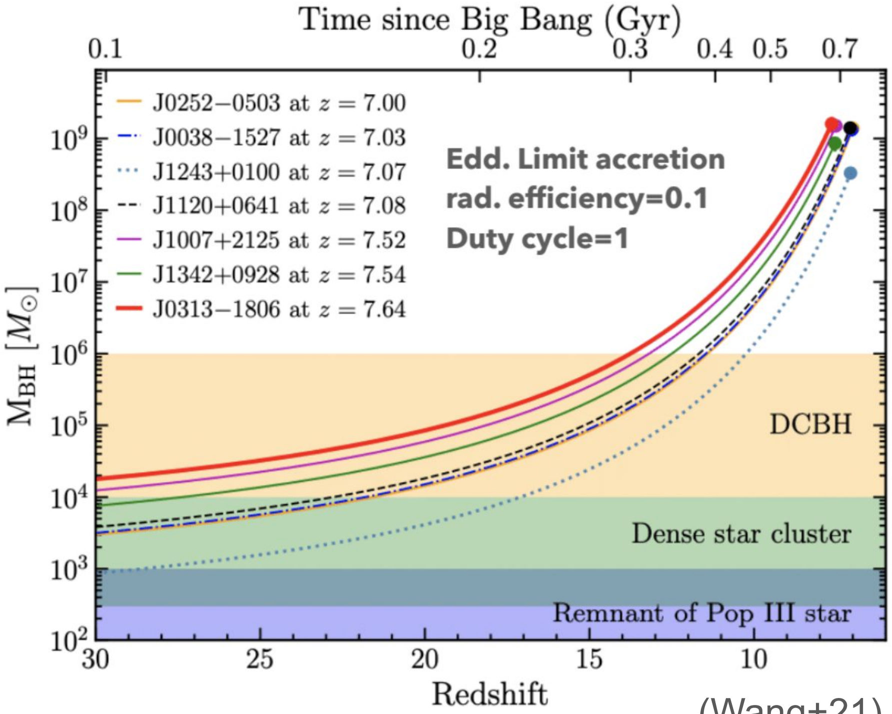
How did SMBHs form at high redshift ?

⇨ Proposal 1: Decide Initial condition of SMBH: Discovery of $10^6 M_\odot$ BH at z~15

How did they accrete $10^9 M_\odot$ at early universe ?

⇨ Proposal 2: Constrain growth of SMBH:

Estimate Accretion rate and Outflow rate at z=6~7.



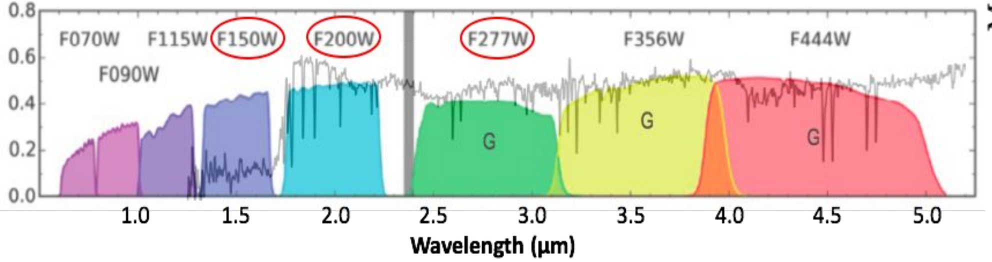

(Wang+21)

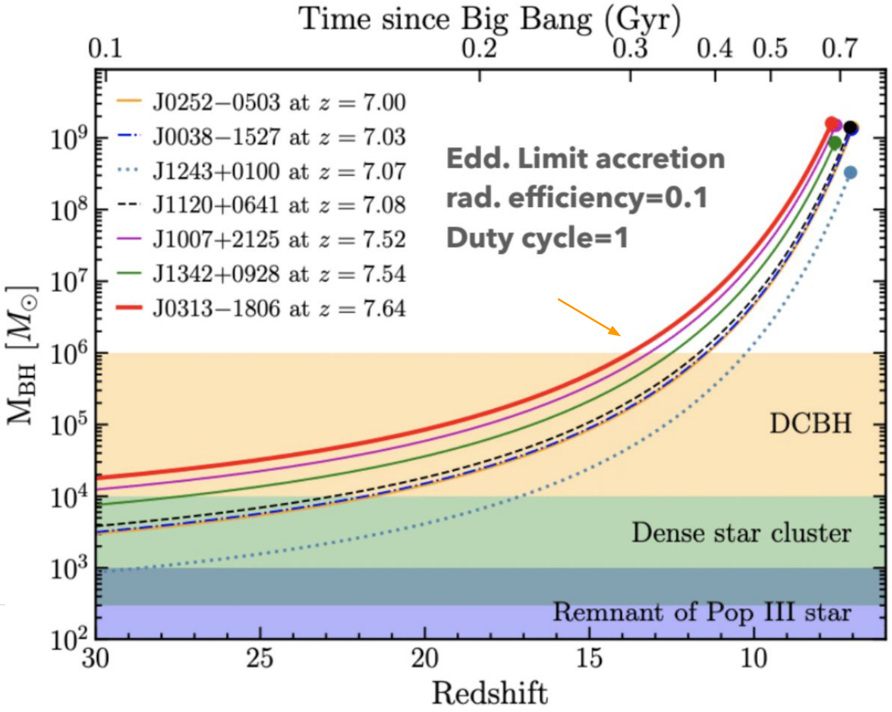
# Part1: Direct Observations of z~15 QSOs?

- Faint ($M_\bullet \sim 10^6\ M_\odot$)
- Rare at high z

Large space telescope needed

- JWST NIRcam




*bg. spec: z=7.54 QSO (Onoue+20)

# Observability

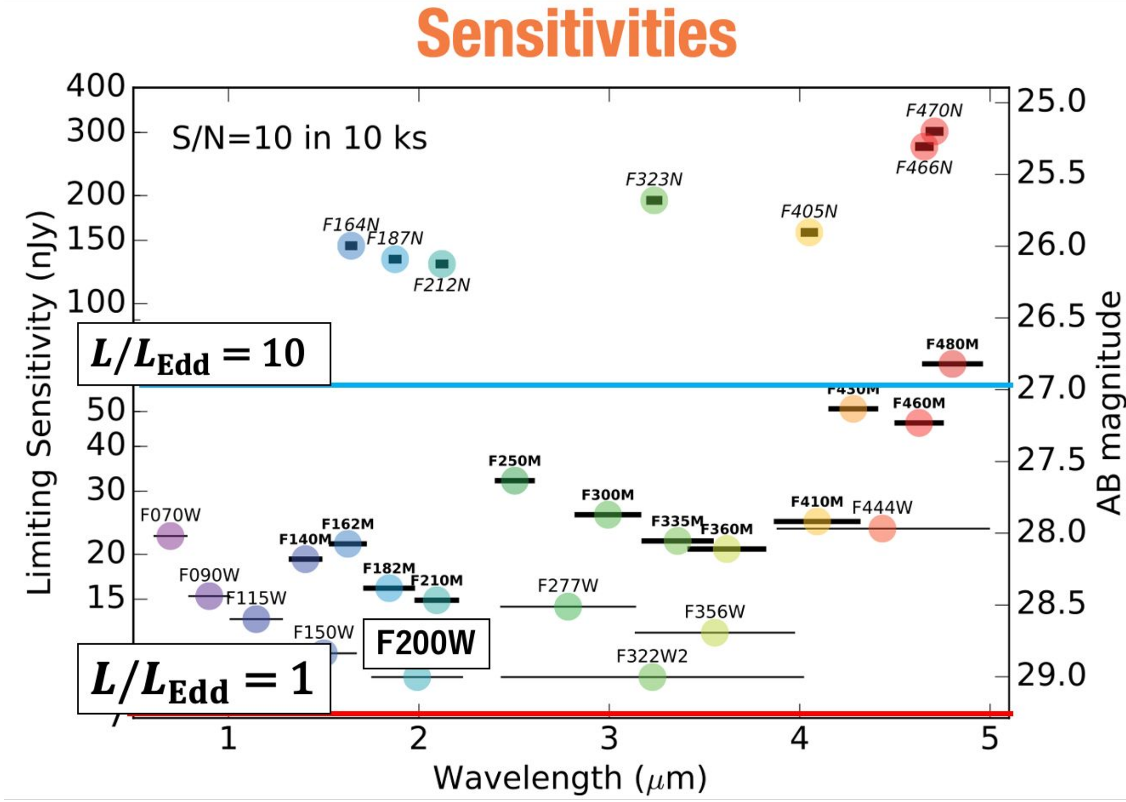
$M_{AB}$ = -26 @ z=7.5, M~$10^9$ $M_\odot$

(Wang+21)

→$m_{AB}$ = 29.5 @ z=15, M~$10^6$ $M_\odot$

(if $L/L_{Edd}$=1)

→Observable?



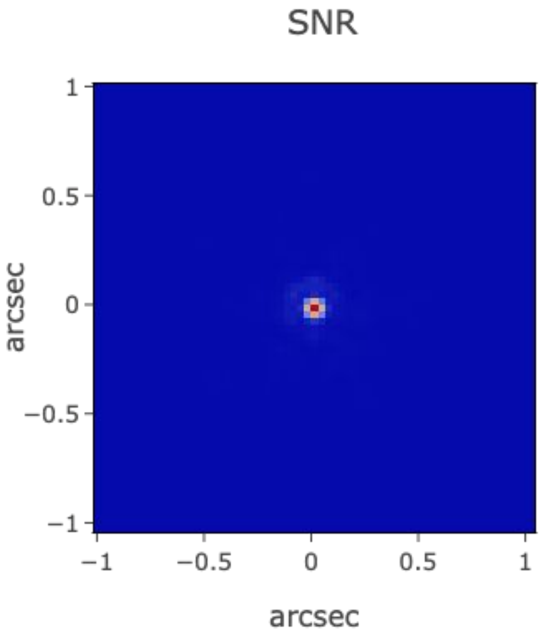

JWST Pocket Guide

# Time Scale of the Obsevations

Setting:

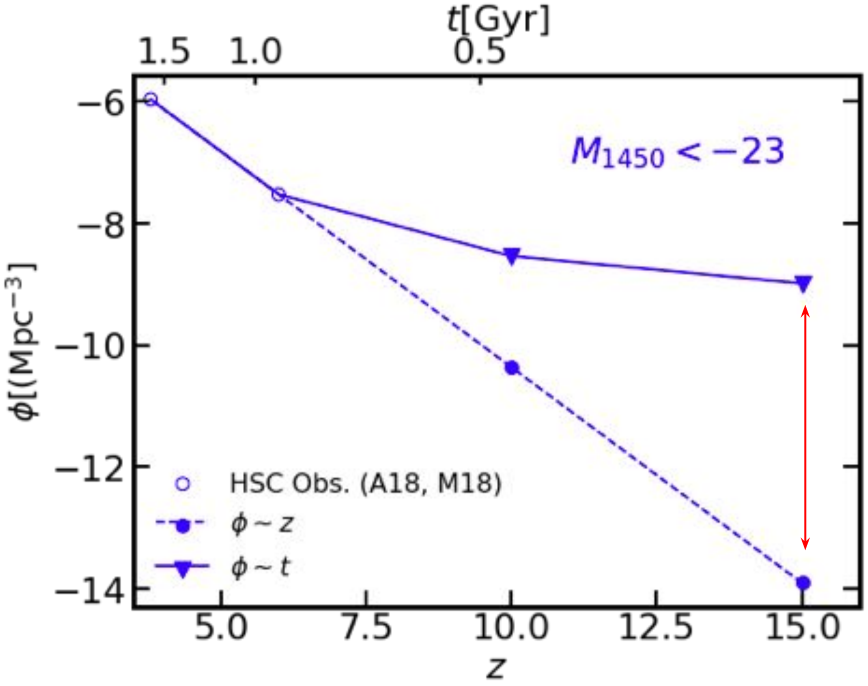
- Filter: **F200W**
- Deep8
- QSO Composite Spectrum

Aim: **SNR~5**




| Luminosity ($L/L_{Edd}$) | $m_{AB}$ | Exposure Time Required (sec) | Time Scale for All Sky Survey with 3 filters (yr) |
|---|---|---|---|
| 1 | 29.5 | 10,000 | 20,000 |
| 10 | 27 | 100 | 200 |

# Expected Number Density




1 obj. per 50 deg$^2$

- ~ 1500 hr (Super-Edd.)

$10^{-3}$ all sky

# Part2:  Constraint of BH growth curve

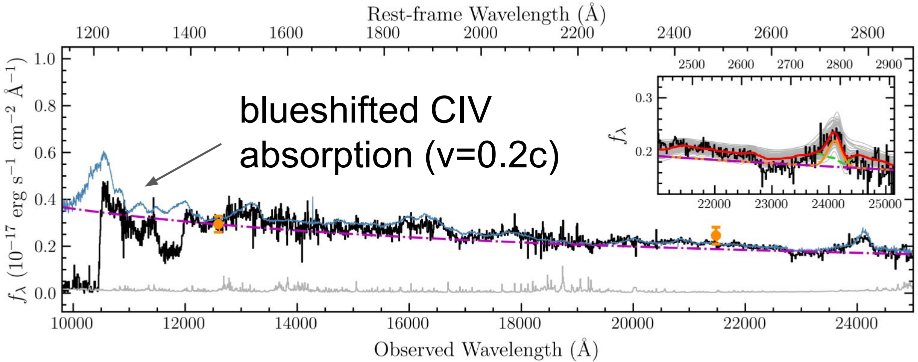
**Mass outflow rate** and **Accretion rate in to BH** at the ealry BH evolutionaly stage are important parameters in hydrodynamical simulations.

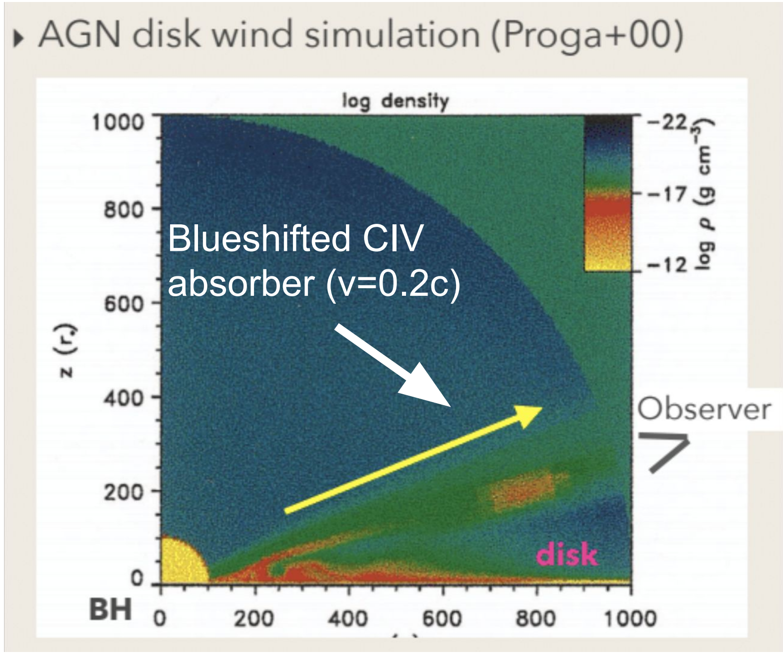
However, it is difficult to know those parameters

**Target: Broad Absorption Line (BAL) quasar**

UV continuum → accretion into BH

CIV absorption → Outflow rate around BH



# Constraint of BH growth curve

**A equation of BH mass growth for BAL quasar**

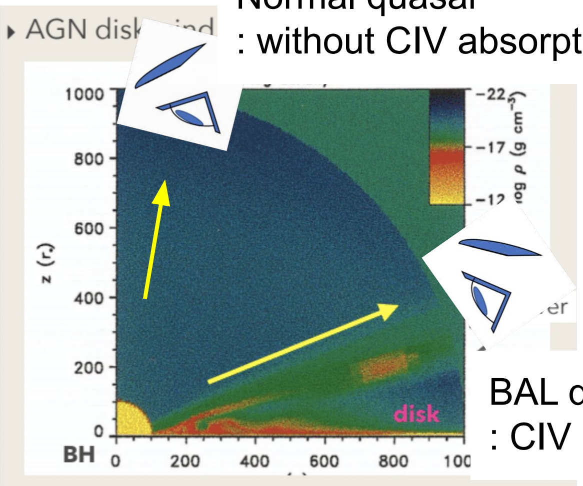
$$\dot{M}_{BH} = \dot{M}_{acc} - \dot{M}_{out}$$

$$\dot{M}_{acc} = \left(\frac{4\pi c G m_H}{\sigma_t}\right) \lambda_{edd} M_{BH} \quad \leftarrow \lambda_{edd} \text{ from UV continuum}$$

$$\dot{M}_{out} = \frac{m_p N_H v}{R} Q$$

**Covering Fraction Q** is only a missing part to complete outflow rate equation

➪ **we can estimate covering fraction using the fraction of existence of BAL quasars statiscally.**



# Proposal observation 2

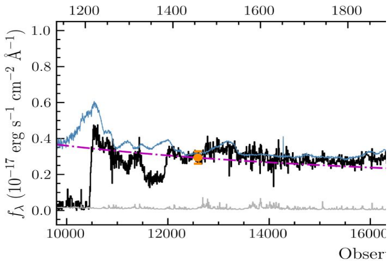
**Purpose:** Finding the covering fraction of low-mass BH (M_BH <10^9 Mo) at the ealry BH evolution stage

Telescope: JWST

Targets: Dark Quasar 70 samples

(Absolute magnitude>-24.5, z>6.0 )

Feasibility: Detecte CIV broad absorption lines at SNR ~10



Observased wavelength (Aumstrong)

Instrument/band: NIRspec fixed slit/grism: PRISM (R~100, wavelength: 6000~53000 A )

Exposure time: 10 hours (if using ground-based telescope (Gemini) ~ 450 hours)

## Expectations:

Get Covering fraction of BAL quasars.

Get λ_edd and M_BH of each objects

⇨ Get outflow rate and accretion rate of each object

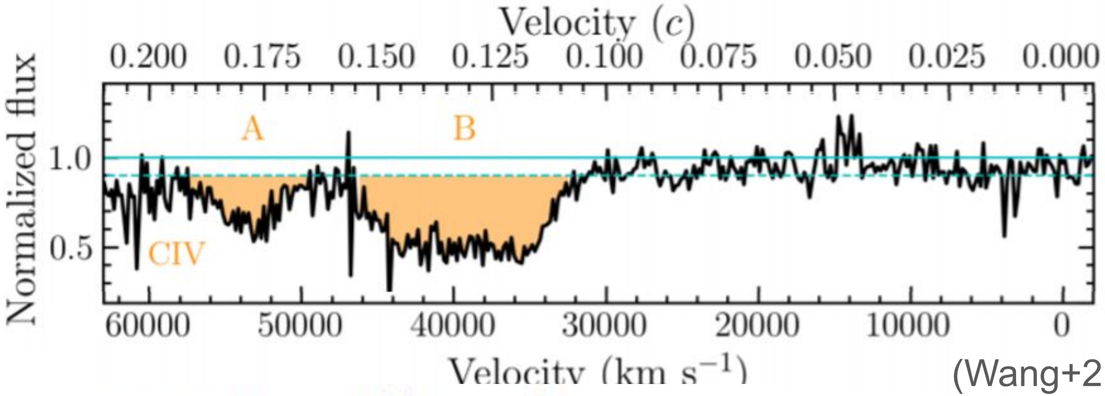
$$\dot{M}_{BH} = \dot{M}_{acc} - \dot{M}_{out}$$

$$\dot{M}_{acc} = \left(\frac{4\pi c G m_H}{\sigma_t}\right) \lambda_{edd}\, M_{BH}$$

$$\dot{M}_{out} = \frac{m_p N_H v}{R} Q$$

# Column density

Estimate from
absorption spectrum →




(Wang+21)

$$N_{ion} \geq \frac{m_e c}{\pi e^2} \frac{1}{\lambda_o f_{ik}} \int \tau(v) dv = \frac{3.7679 \times 10^{14}\ \mathrm{cm}^{-2}}{\lambda_o f_{ik}} \int \tau(v) dv,$$

(Arav+91)

$f = 0.19$ : oscillator strength
$\lambda = 1548$ Å

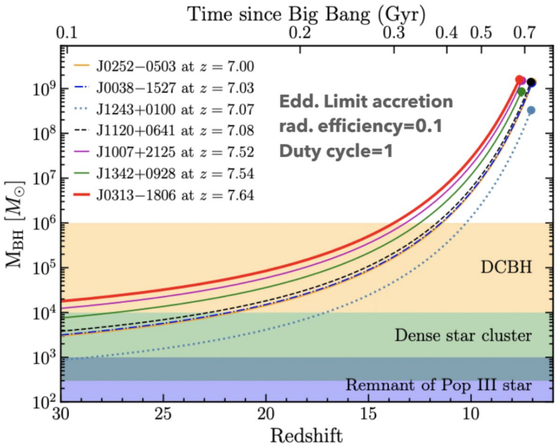
$$N_{C\ IV} = 1.3 \times 10^{16}\ \mathrm{cm}^{-2}$$

Asuume $N_C = N_{C\ IV}$, $\log N_H / N_C = 3.5$ (solar abundance ratio),

$$N_H = 4.1 \times 10^{19}\ \mathrm{cm}^{-2}$$

Ionization state depends on geometry, ionization parameter, density (Hagginbottom+13)

# Summary




Questions:

How did SMBHs form at high redshift ?

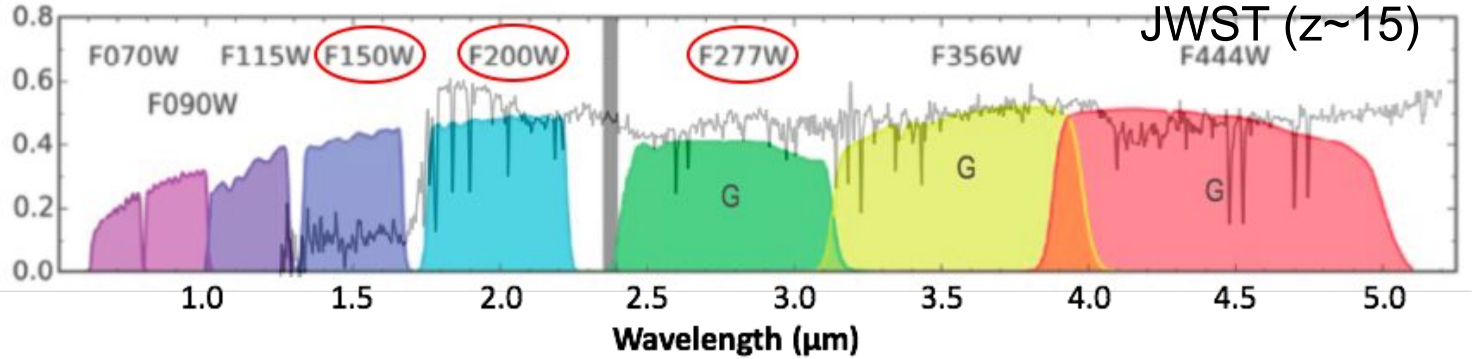
⇨ Proposal 1: Searching for $10^6$ $M_\odot$ BH w/ super-Edd. accretion at z~15.

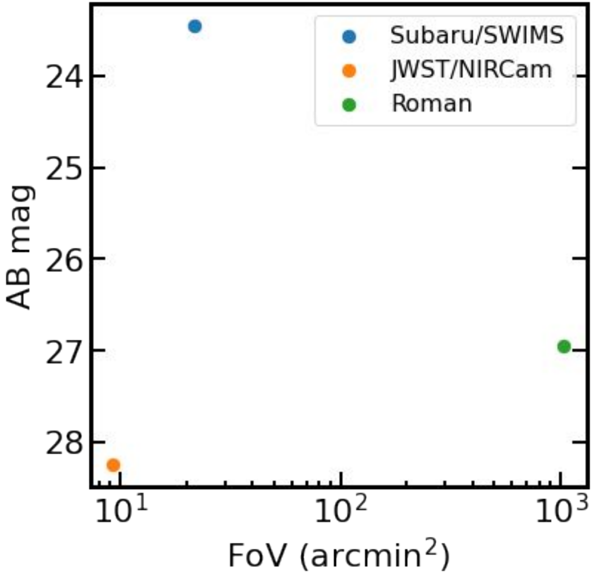
$10^6$ $M_\odot$ BH w/ super-Edd. accretion can be observed by JWST NIRcam with ~$10^3$ hr observing time.

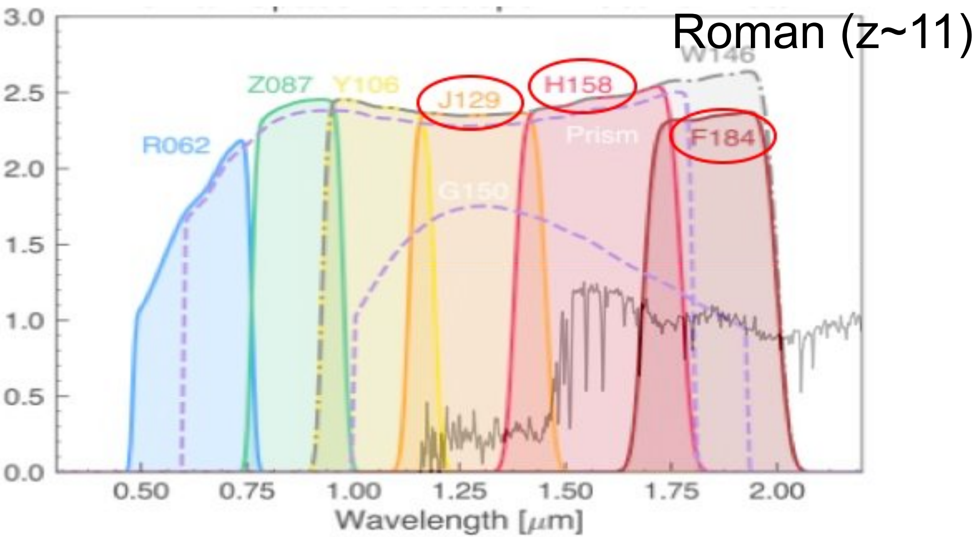
How did they accrete $10^9$ $M_\odot$ at early universe ?

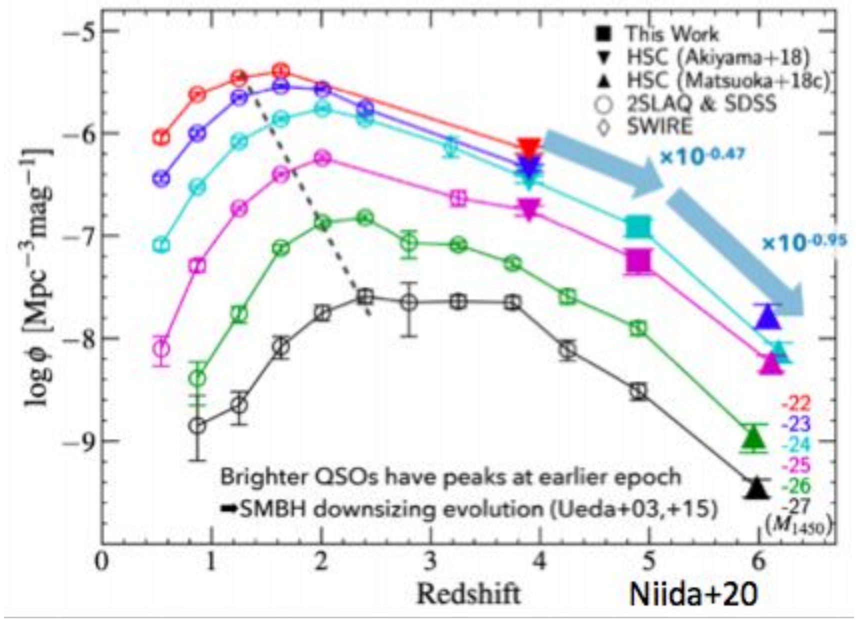
⇨ Proposal 2: Dark Quasar 70 samples can be observed for 10 hours to estimate Accretion rate and Outflow rate at z=6~7 (JWST NIRspec fixed slit/grism: PRISM detects CIV absorption line at SNR~10)

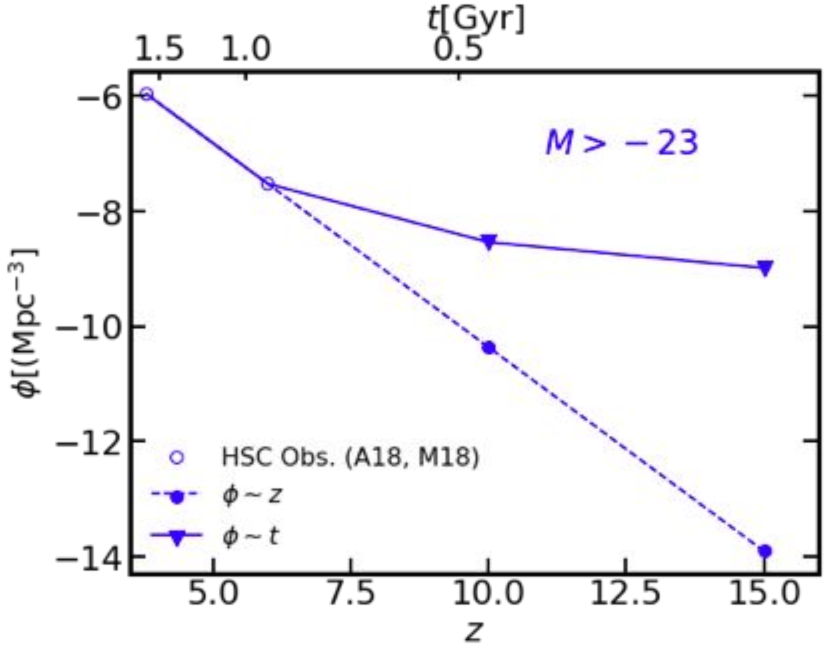
# Appendix


JWST (z~15)
F070W
F090W
F115W
F150W
F200W
F277W
F356W
F444W
G
G
G
0.8
0.6
0.4
0.2
0.0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Wavelength (μm)


Subaru/SWIMS
JWST/NIRCam
Roman
AB mag
24
25
26
27
28
$10^1$
$10^2$
$10^3$
FoV (arcmin$^2$)


Roman (z~11)
W146
R062
Z087
Y106
J129
H158
F184
Prism
G150
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Wavelength [μm]



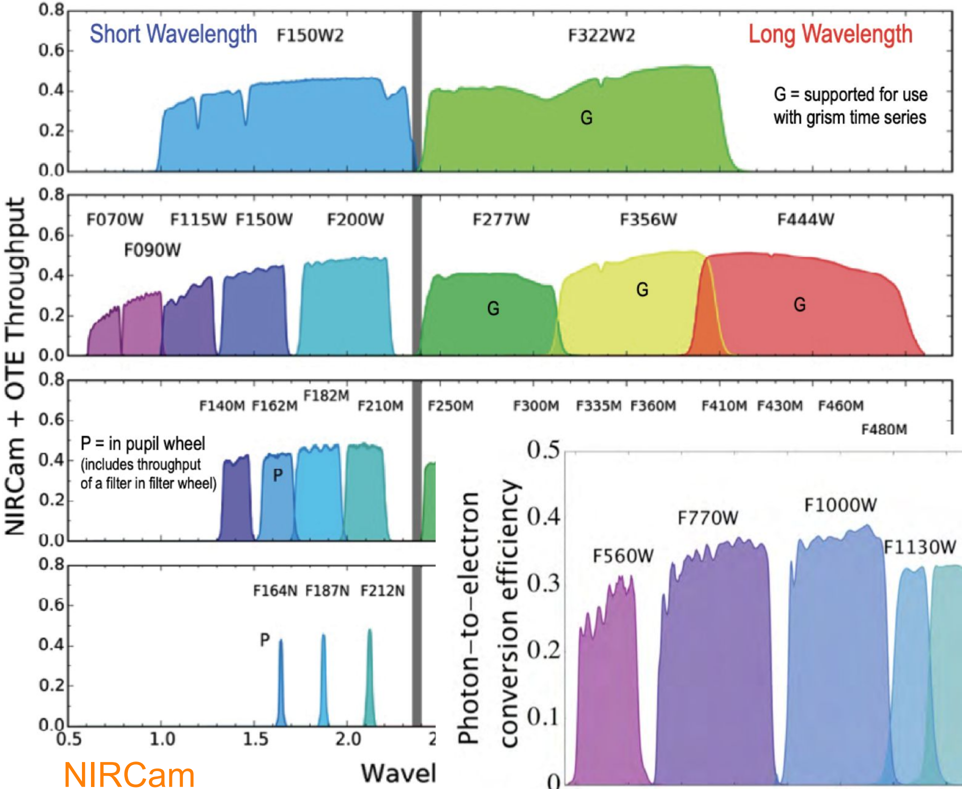




QLF Models

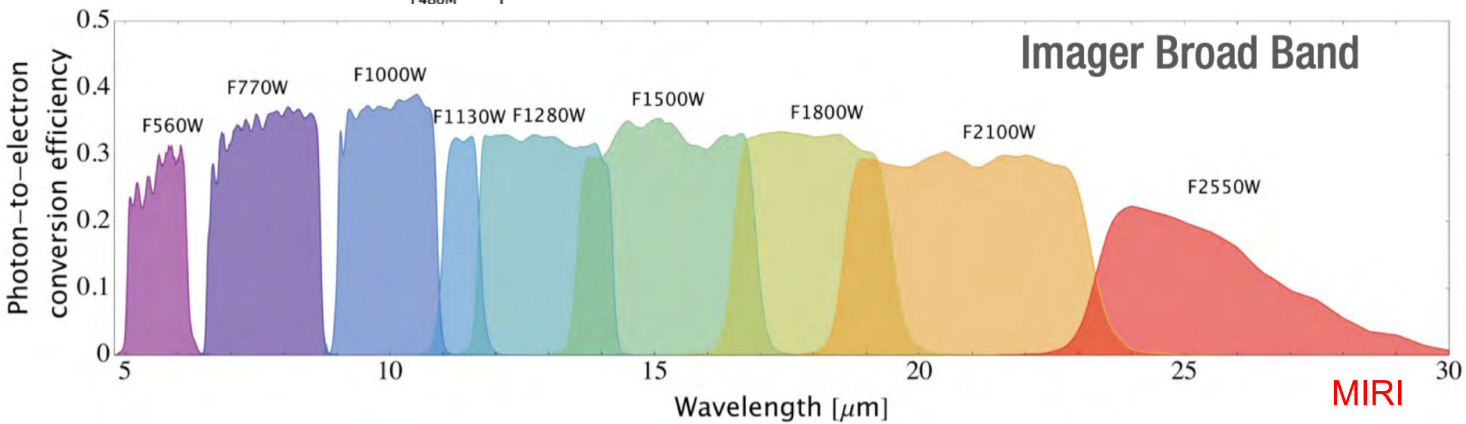
(Kulkarni+17, Kim+21)

- $\phi(z)$, not $\phi(t)$
- Biased towards low-$z$

# Follow-up observation




NIRCam




| $\lambda_{rest}$ | $\lambda_{obs}$ (z = 15) | |
|---|---|---|
| CIV : 150nm | CIV : 2.4um | CIV : × |
| MgII : 280nm | MgII : 4.5um | MgII : NIRCam |
| Hβ : 490nm | Hβ : 7.8um | **Hβ : MIRI** |

$$Log M_{BH} = 6.91 + 2Log\frac{FWHM(H\beta)}{1000km/s} + 0.50Log\frac{\lambda L_{5100\text{Å}}}{10^{44}erg/s}$$