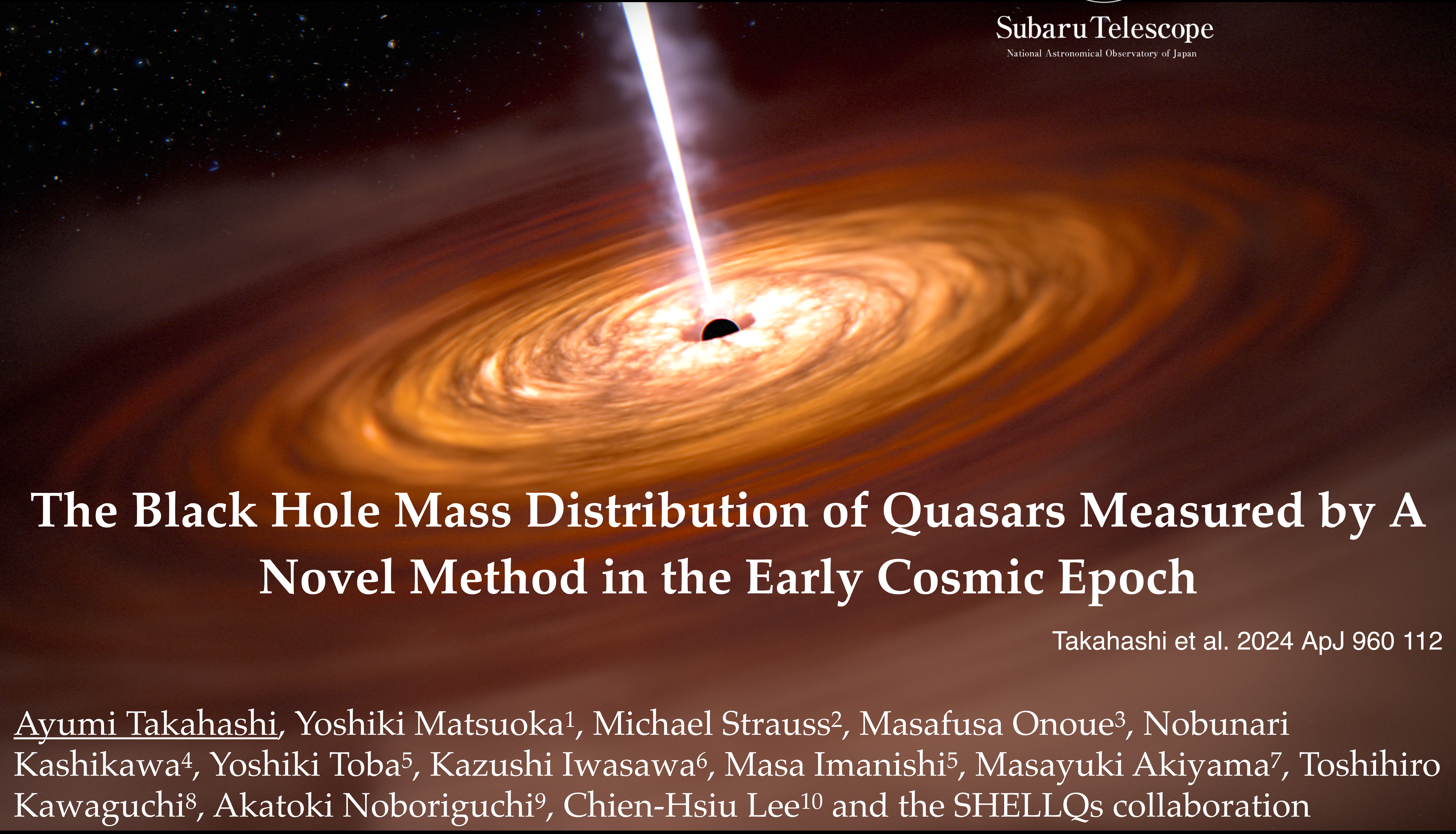
2025.01.29 Subaru Users Meeting

Subaru Telescope
National Astronomical Observatory of Japan

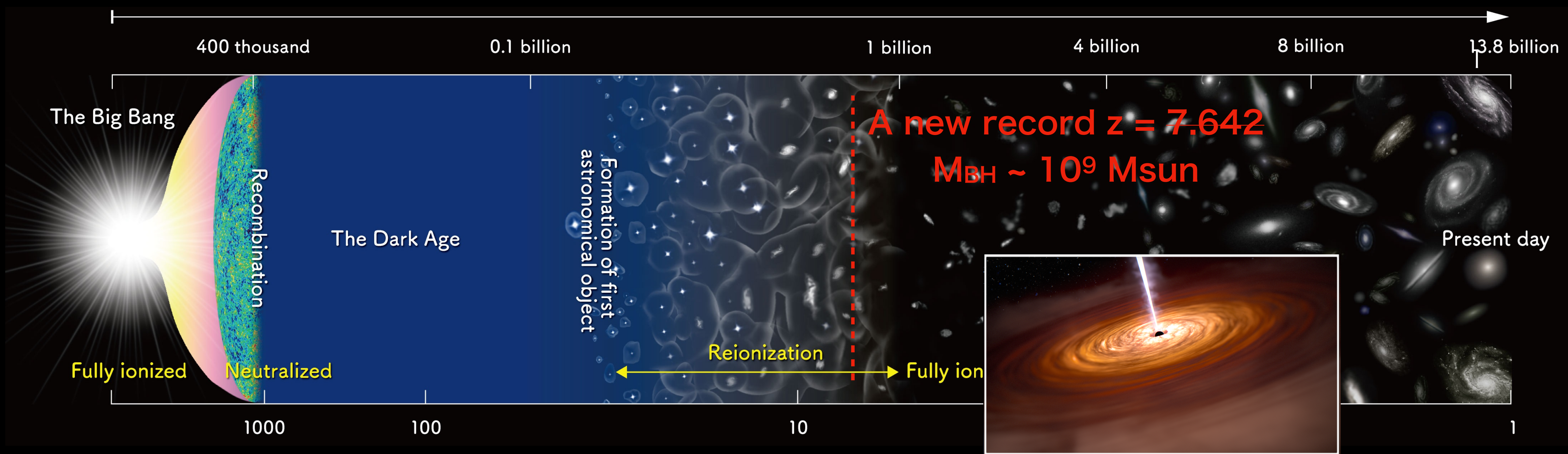


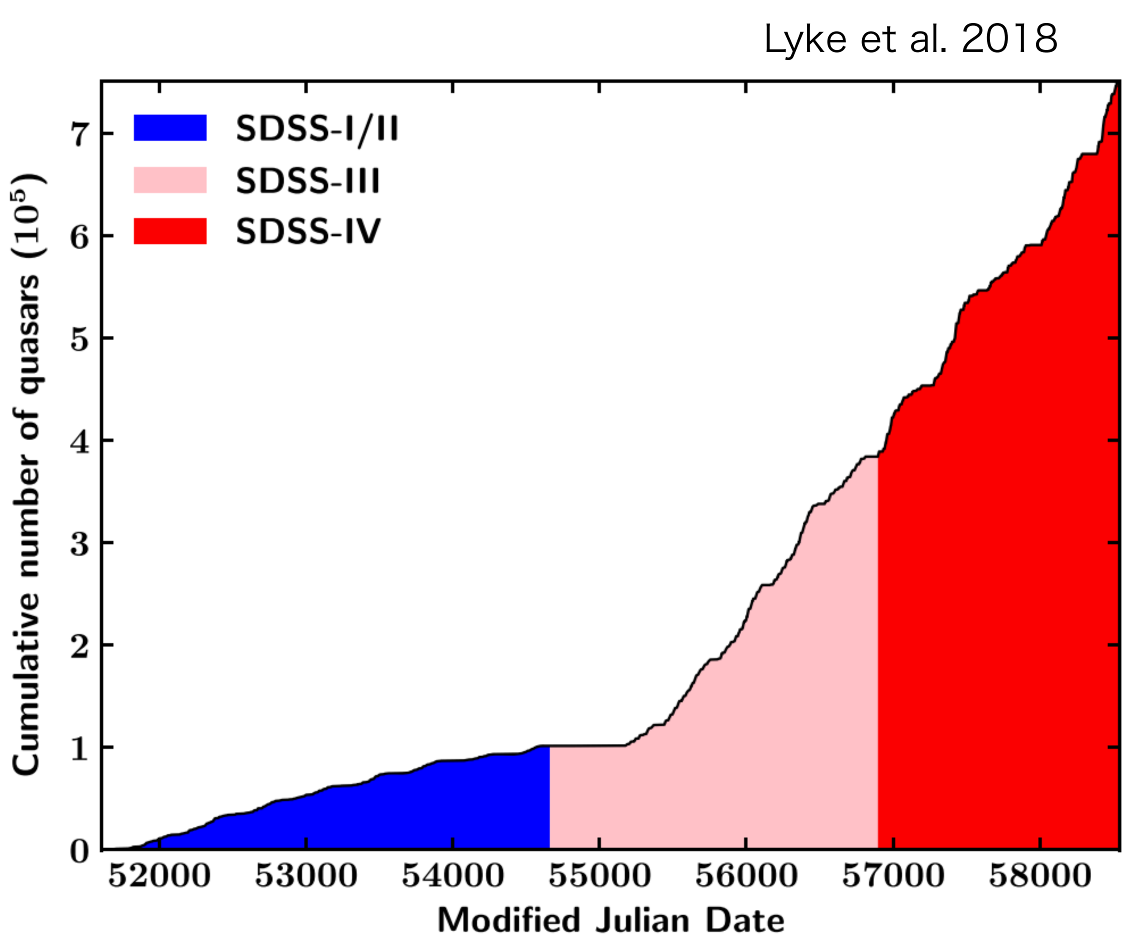
The Black Hole Mass Distribution of Quasars Measured by A Novel Method in the Early Cosmic Epoch

Takahashi et al. 2024 ApJ 960 112

Ayumi Takahashi, Yoshiki Matsuoka[1], Michael Strauss[2], Masafusa Onoue[3], Nobunari Kashikawa[4], Yoshiki Toba[5], Kazushi Iwasawa[6], Masa Imanishi[5], Masayuki Akiyama[7], Toshihiro Kawaguchi[8], Akatoki Noboriguchi[9], Chien-Hsiu Lee[10] and the SHELLQs collaboration

Super Massive Black Holes (SMBHs) in the early universe





SOME SERIOUS QUESTIONS about SMBH

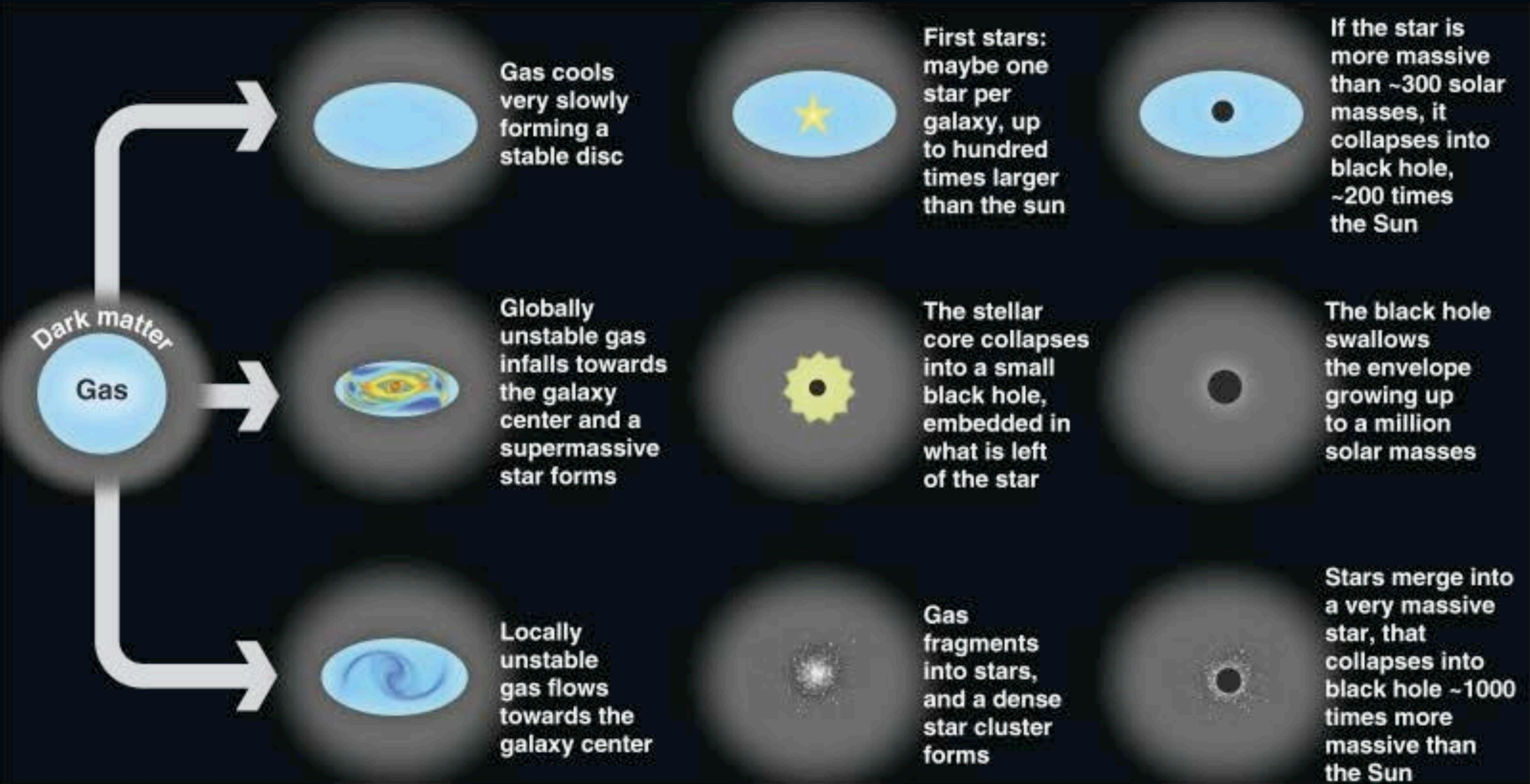
✦When and how their seed populations are born?

✦What is the typical mass of the seed?

Important parameters to solve these questions are **BH masses** of high-z quasars and **Eddington ratios** which are related to

1. **The time when BH began to grow**
2. **Radiation efficiency**

Forming a black hole

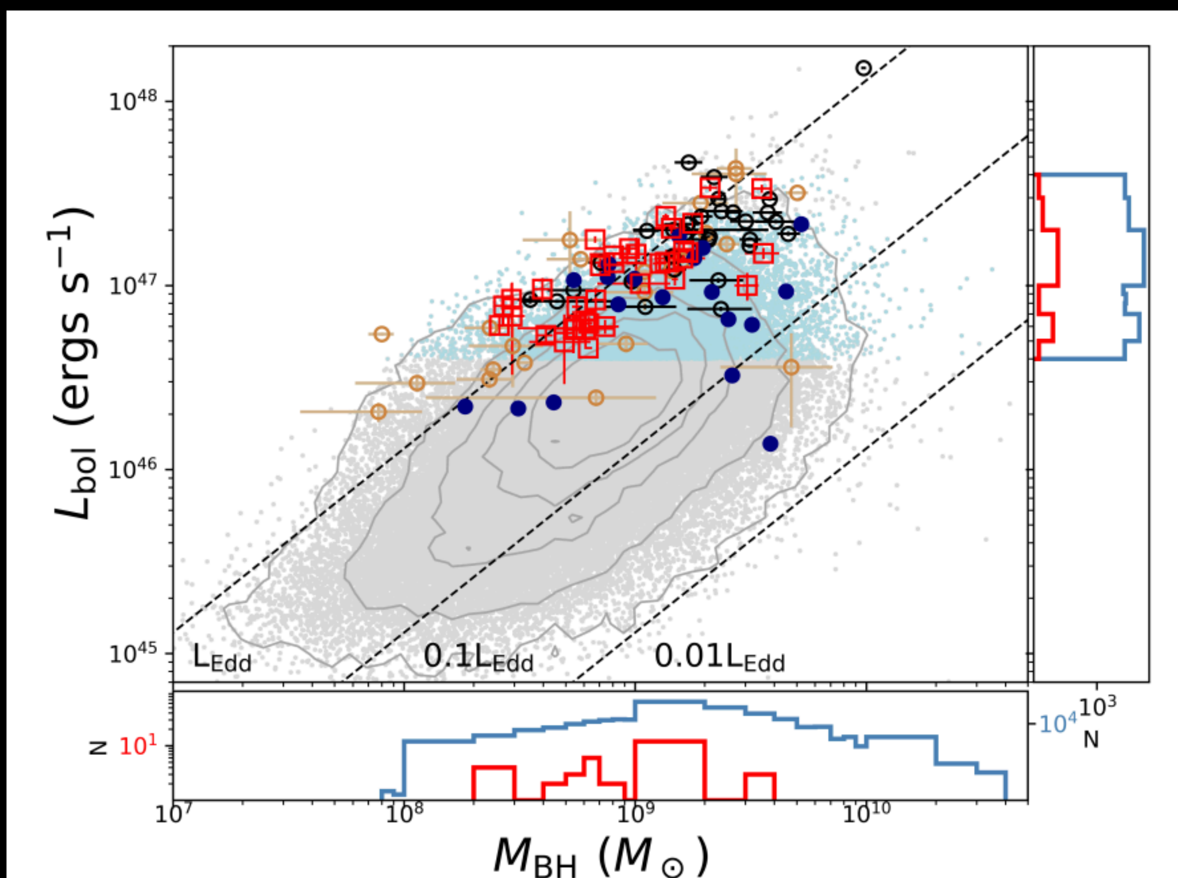


Review by Volonteri

Super Massive Black Holes (SMBHs) in the early universe

- Distribution of M_{BH} of $z \sim 6 - 7.6$ quasars

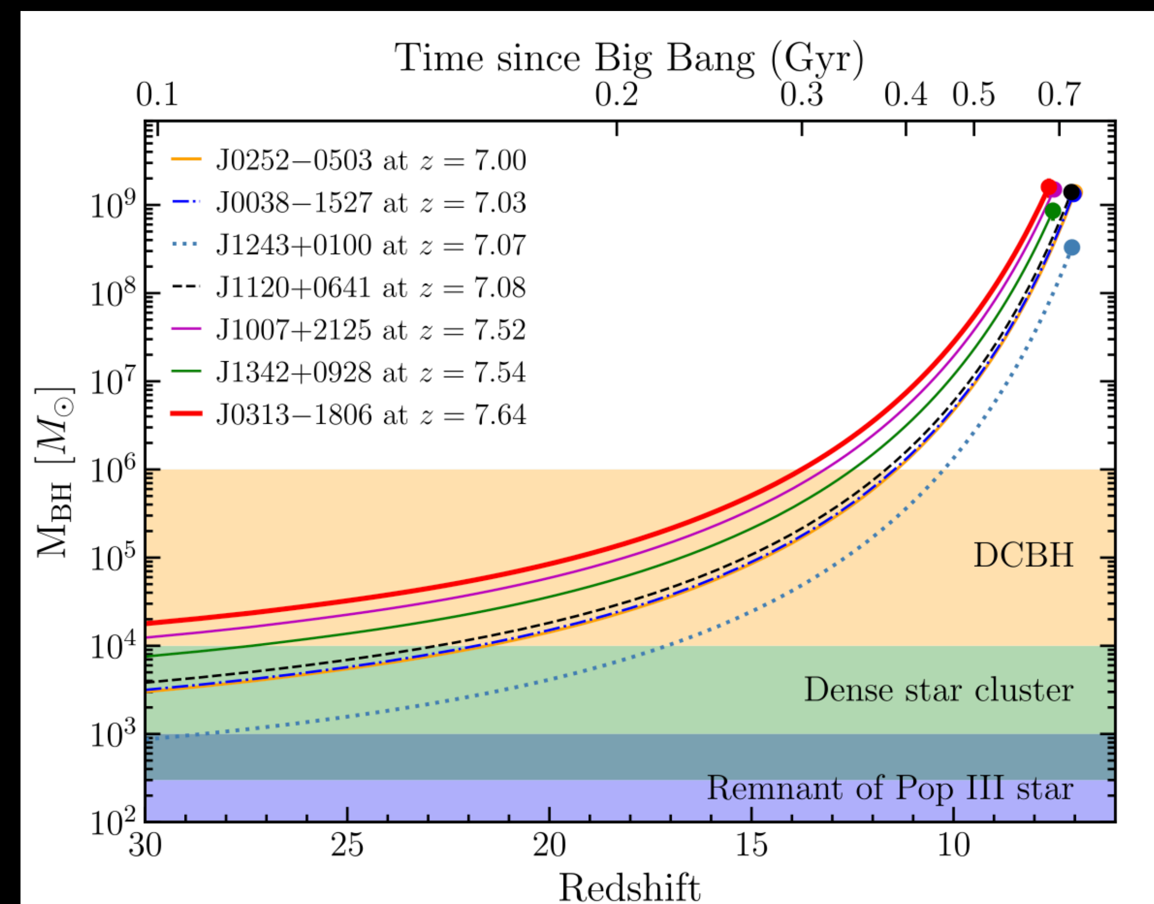
(Yang et al. 2021)



$M_{\rm BH} \sim 10^8$ to 10^{10} [$M_\odot$]

-Black hole grow track of z ≥ 7 quasars with $\lambda_{Edd} = 1,\ \eta = 0.1$

(Wang et al. 2021)

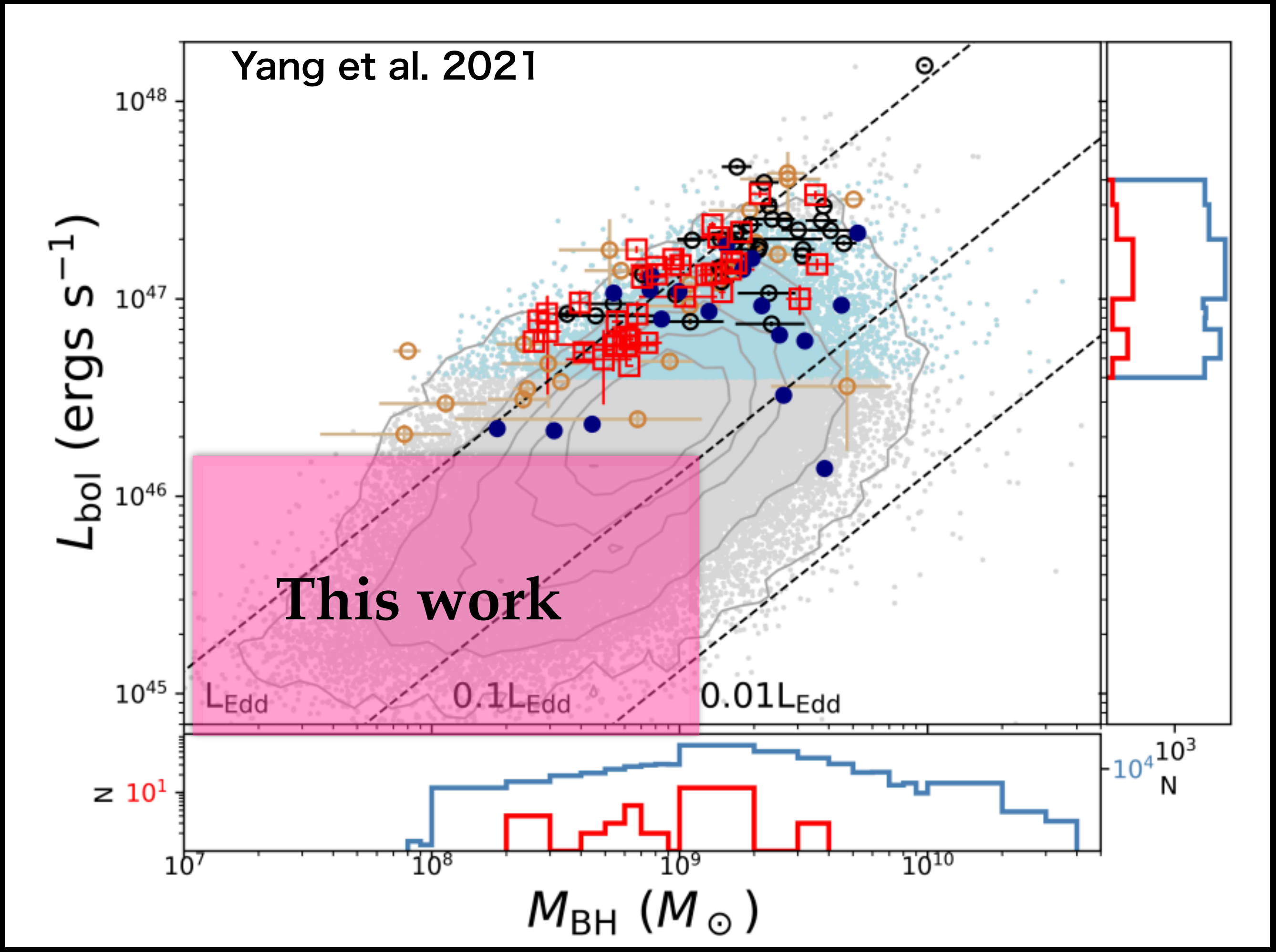


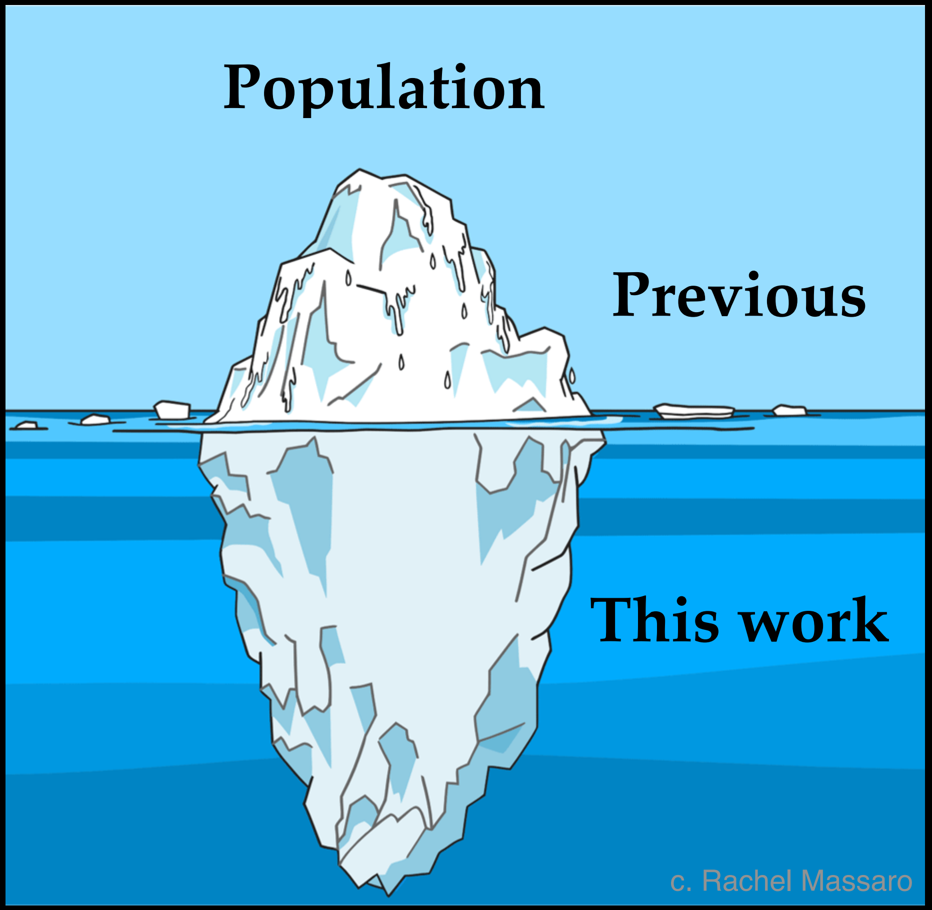
$M_{seed} \sim 10^3$ to 10^4 [$M_\odot$]

- Previous results support the rapid growth of Black Hole
- It is hard to explain to form SMBHs from the remnants of Pop-III stars.

Super Massive Black Holes (SMBHs) in the early universe

The number of quasars $M_{BH} < 10^8$ [$M_\odot$] was very limited!



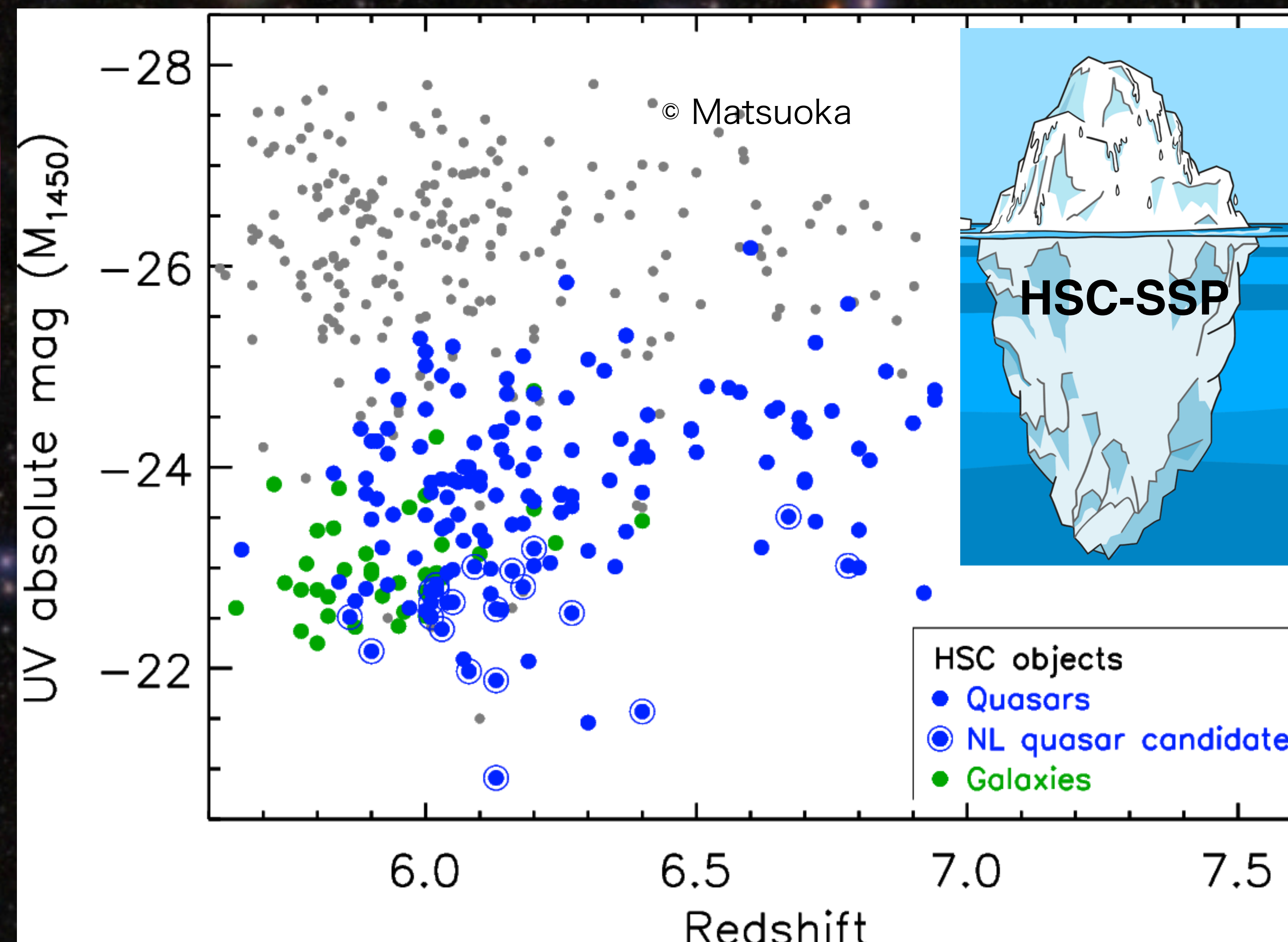


Focus on a deeper sample that is a "typical" species in the quasar population in the early cosmic epoch.

SHELLQs project

"Subaru High-z Exploration of Low-Luminosity Quasars" (PI: Yoshiki Matsuoka)

Spectroscope install on



SHELLQs sample is composed of 180 quasars

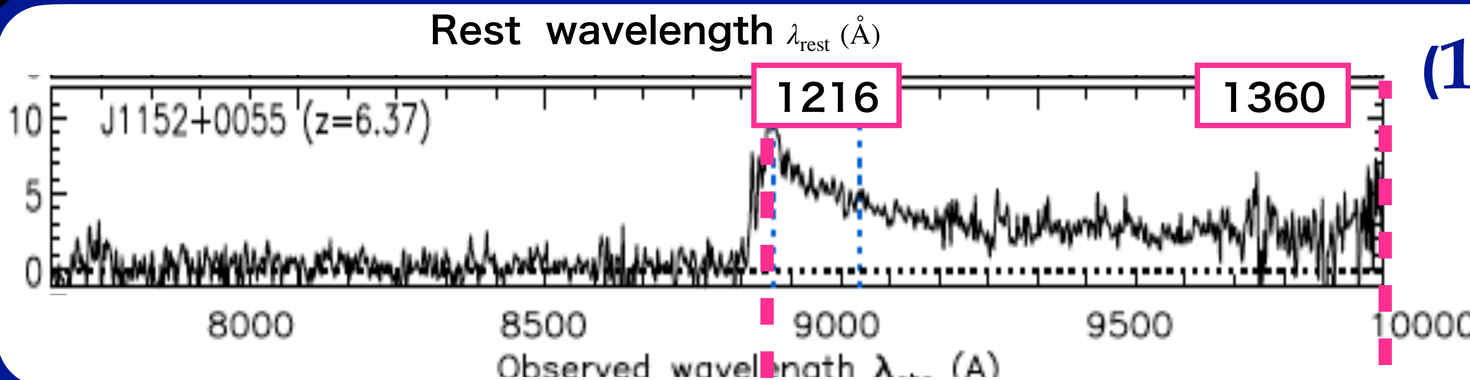
This low-luminosity sample may contain the low-mass quasars…

High-z quasars sample in this work:

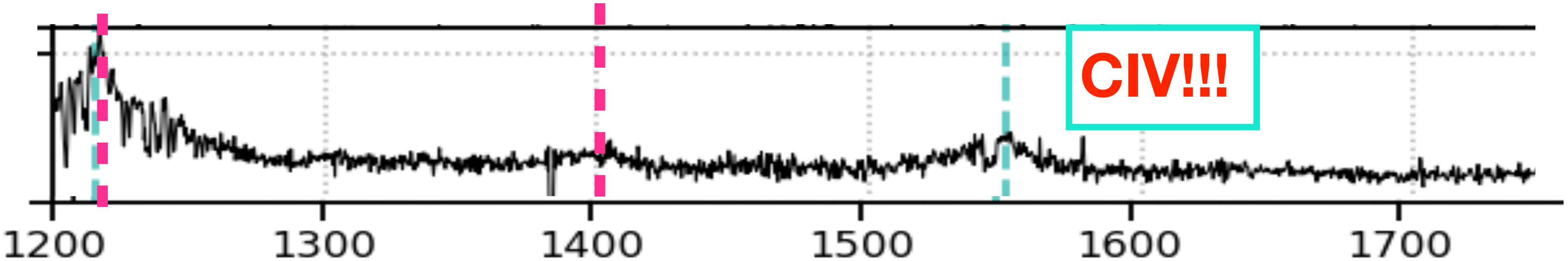
- 131 type-1 objects (published in Matsuoka+16, 18ab, 19ab, 21, 22)

Method

We substituted longer spectra of SHELLQs quasars with SDSS quasars



(1) SHELLQs discovery spectra do not cover SMBH mass indicators (CIV 1549, Mg II 2800, and/or Hβ)



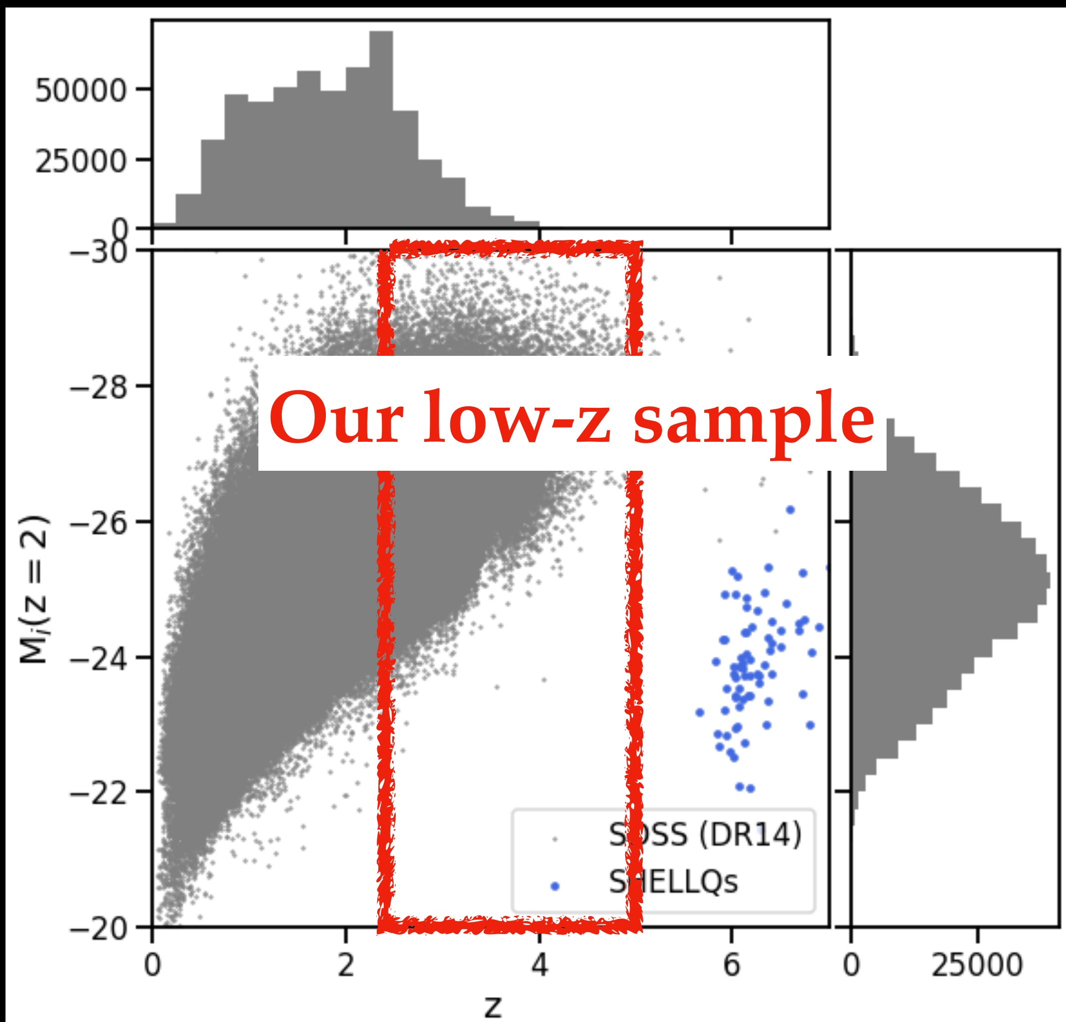
(2) We find a low-z quasar ("counterpart") that has the best-match spectrum to each SHELLQs quasar in the overlapping spectral coverage ($1216 < \lambda_{rest} < 1400$ A), through $\chi 2$ fitting.

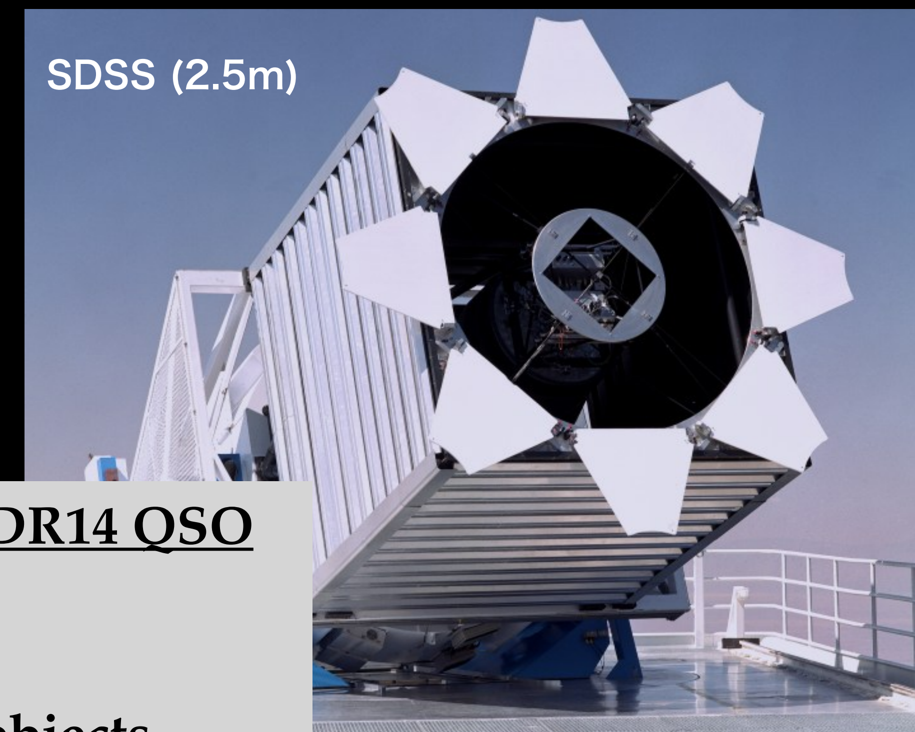
(3) Black hole mass is derived using the CIV profile of the counterpart spectrum.

SHELLQs — CP (SDSS)

$$\log\left(\frac{M_{BH}}{M_{\odot}}\right) = A + B\log\left(\frac{\lambda L_{\lambda}}{10^{44}\mathrm{ergs}^{-1}}\right) + 2\log\left(\frac{\mathrm{FWHM}}{\mathrm{kms}^{-1}}\right)$$

Sloan Digital Sky Survey Quasar Catalog (release14)





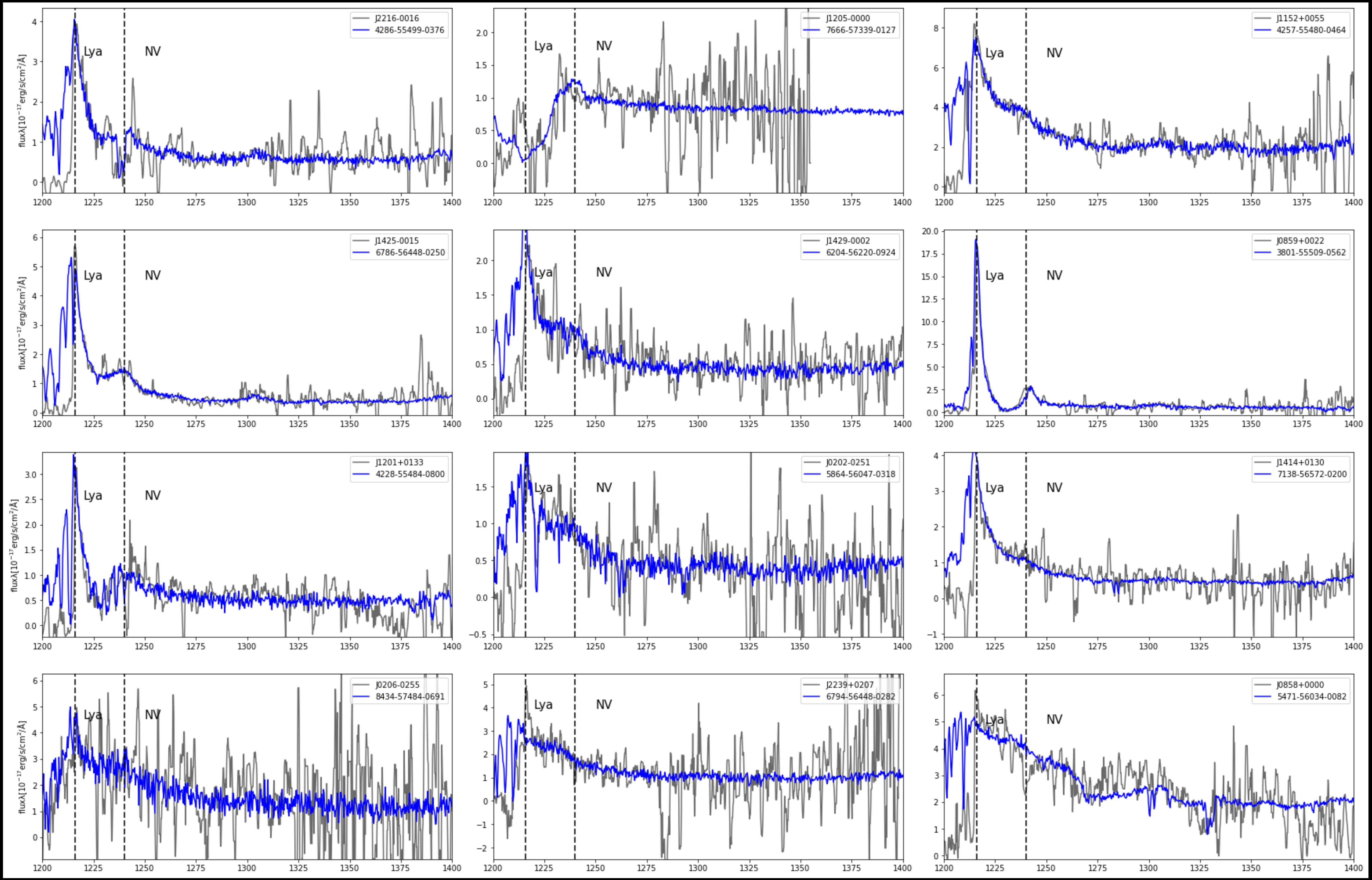
Basically information of DR14 QSO catalogue

- Mi[z = 2] < -20.5
- Constructed by 526356 objects,
- coverage： 3610 - 10140 A,
- resolutions： 1300 < R < 2500
- Survey field : A quarter of the sky

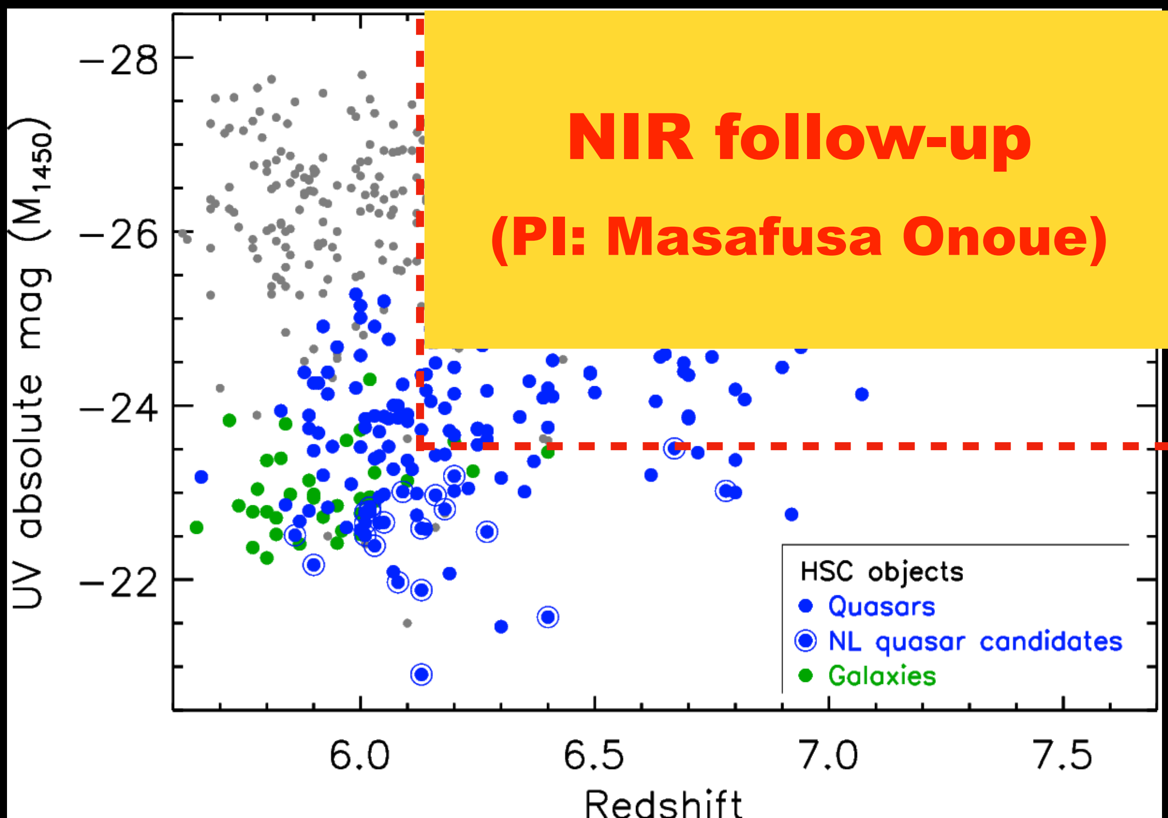
In this work, we selected SDSS quasars at 2.5 ≤ z ≤ 5.0; 101489 objects whose spectra cover the rest-UV portions around Lya emission lines.

Substitute BH mass tracers in the low-z sample for each SHELLQs quasar.

An example of counterpart's spectra



Our measurements vs. Literatures

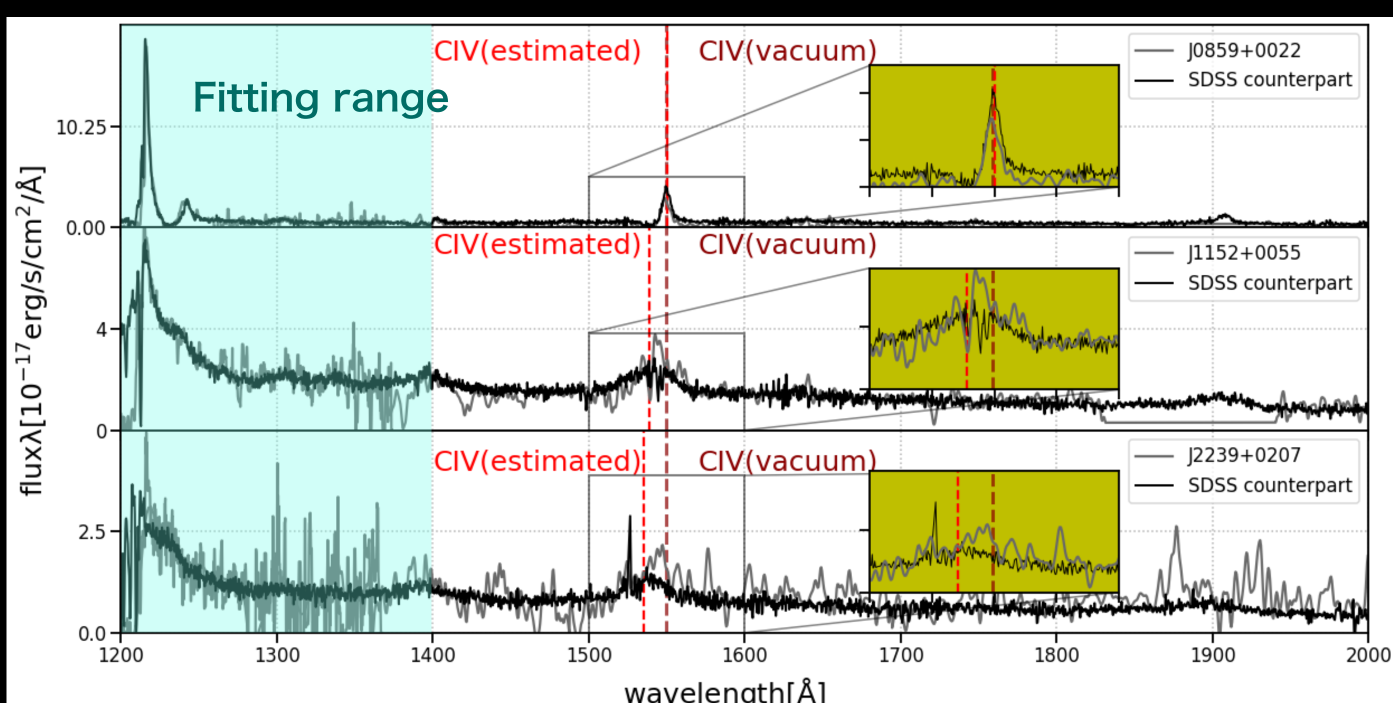


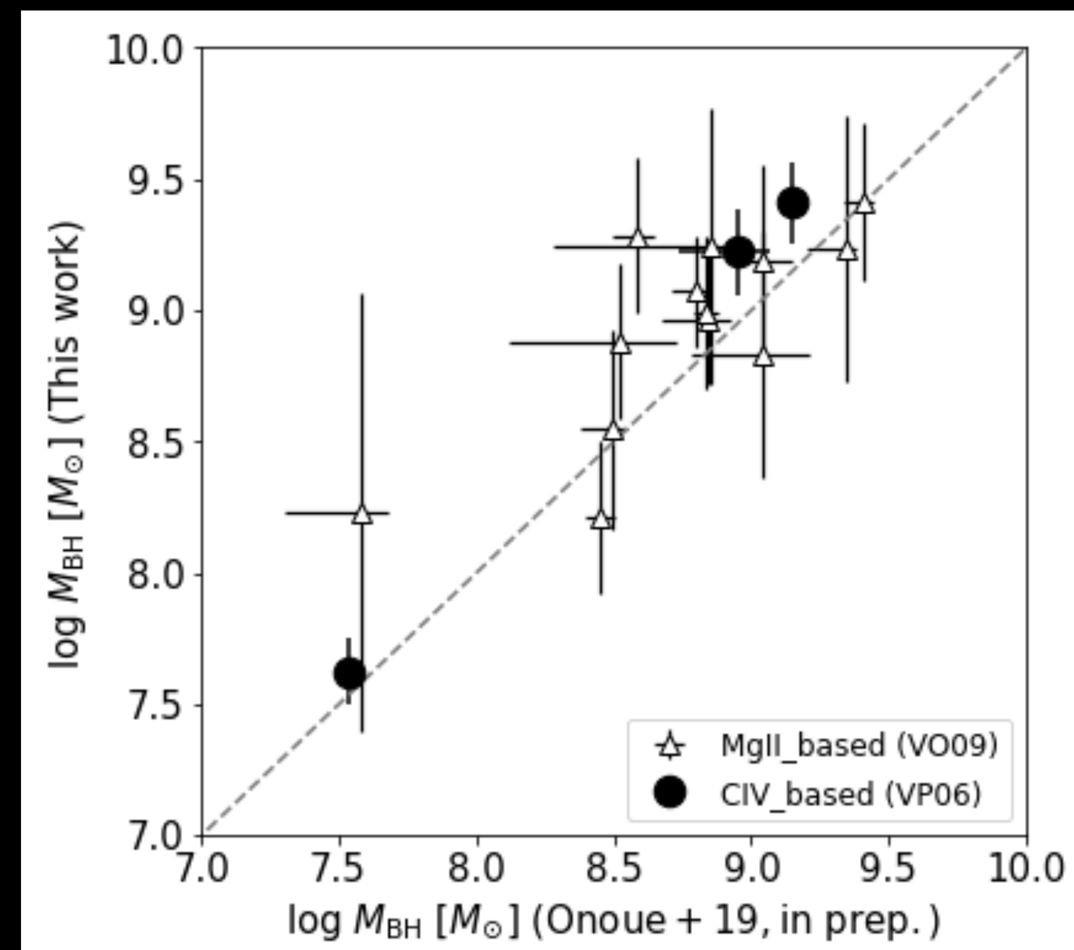
Our predicted BH masses :

SHELLQs

CP (SDSS)

$$\log\left(\frac{M_{BH}}{M_\odot}\right) = A + B\log\left(\frac{\lambda L_\lambda}{10^{44}\text{ergs}^{-1}}\right) + 2\log\left(\frac{\text{FWHM}}{\text{kms}^{-1}}\right)$$

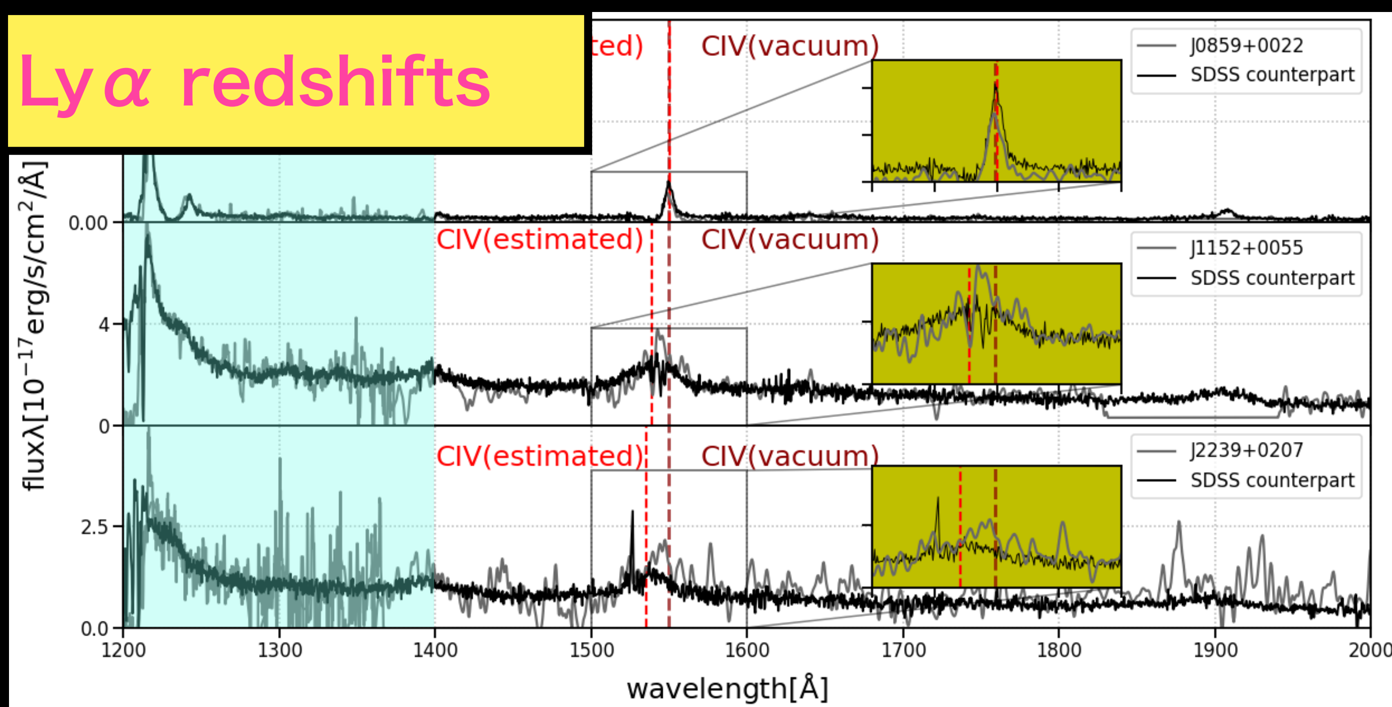


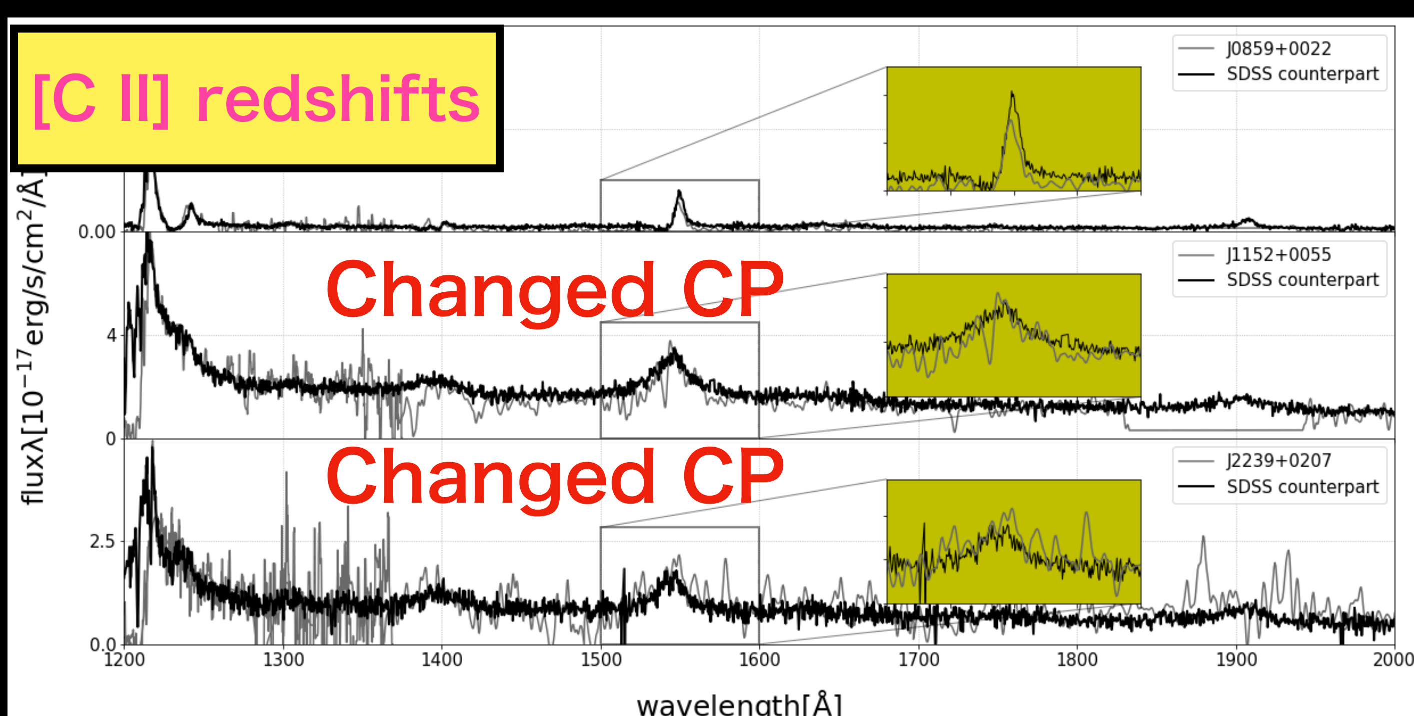


It is possible to predict BH masses of high-z quasars with high accuracy without their actual spectra by just doing spectral matching with low-z quasars.

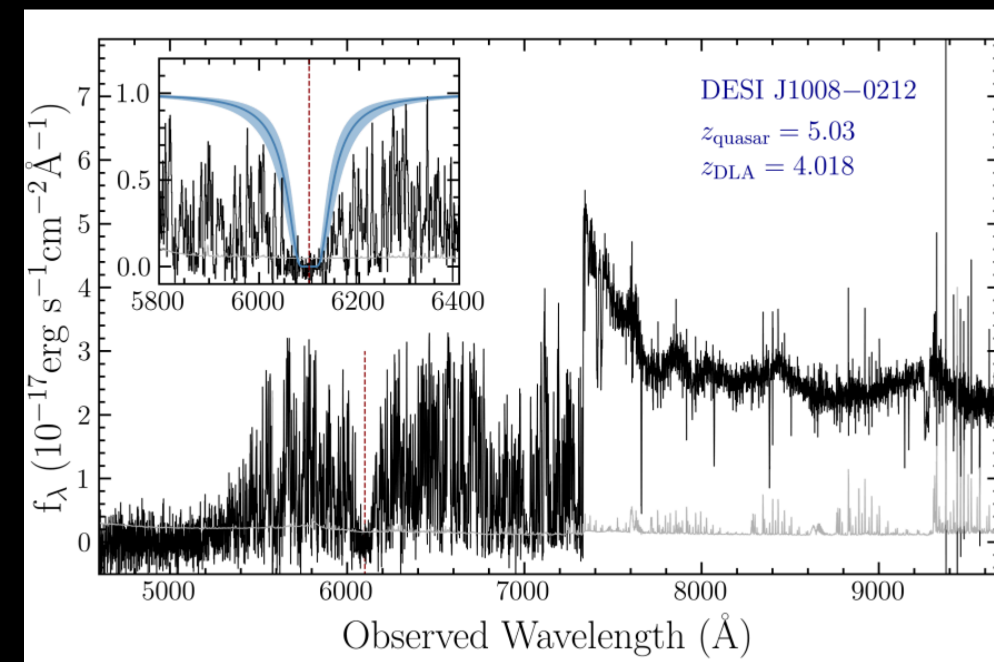
Our measurements vs. Literature with [C II] redshifts

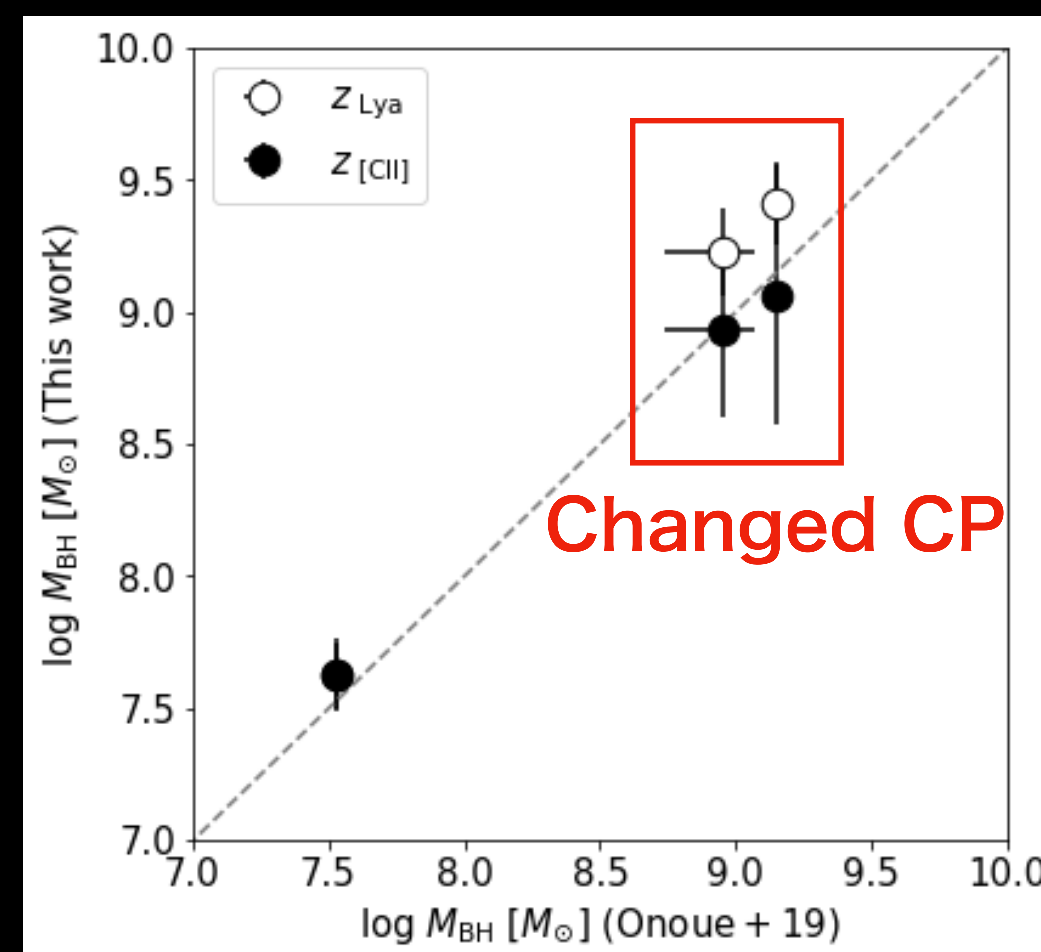
- The 3 quasars have [C II] redshifts, 2 of which have different counterparts from the cases with Lyα redshifts.
- Improved C IV peak off-set.



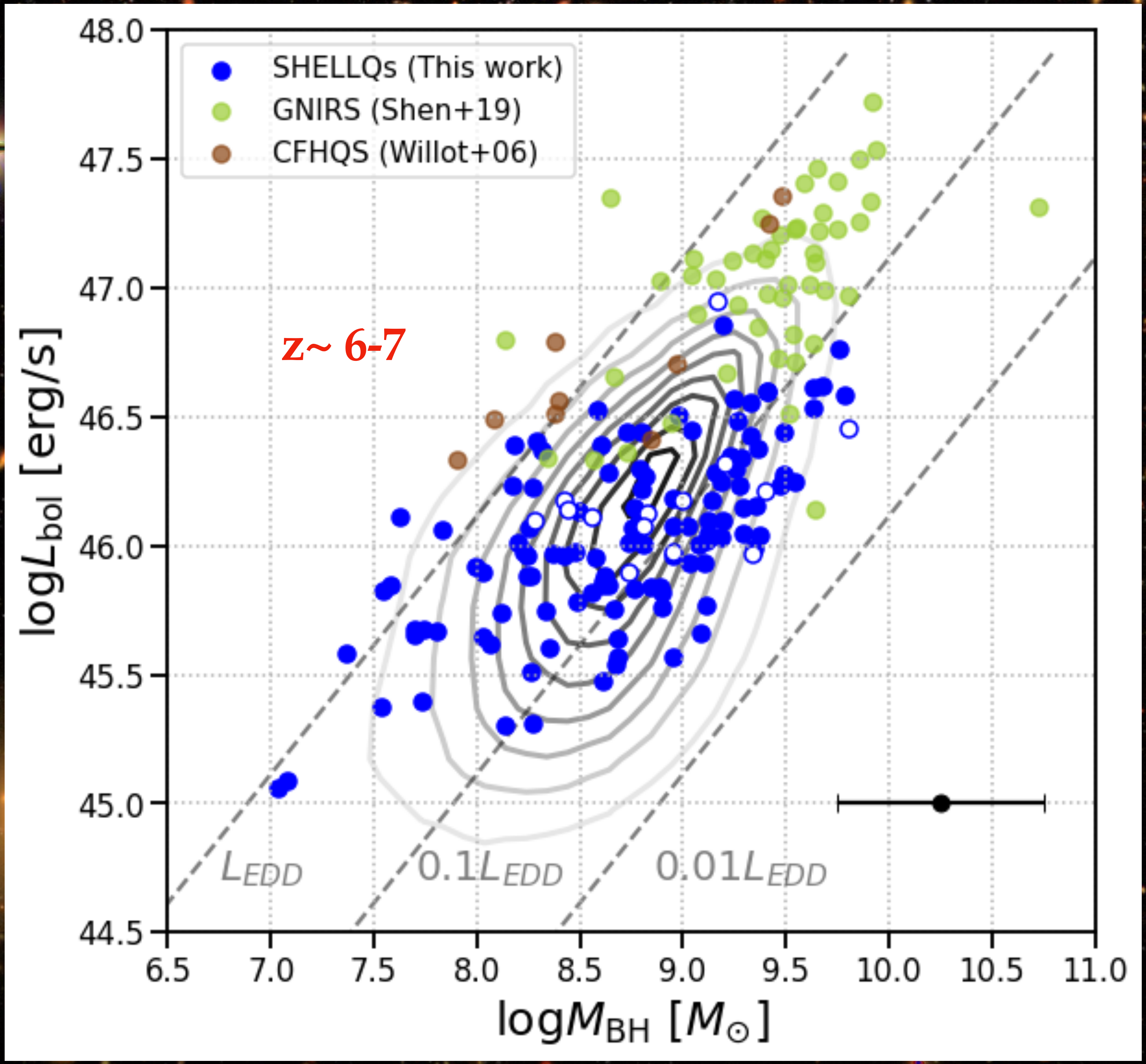


Yang et al. arXiv:2302.01777v1





We revealed the low-mass end of the M_{BH} distribution at high redshift

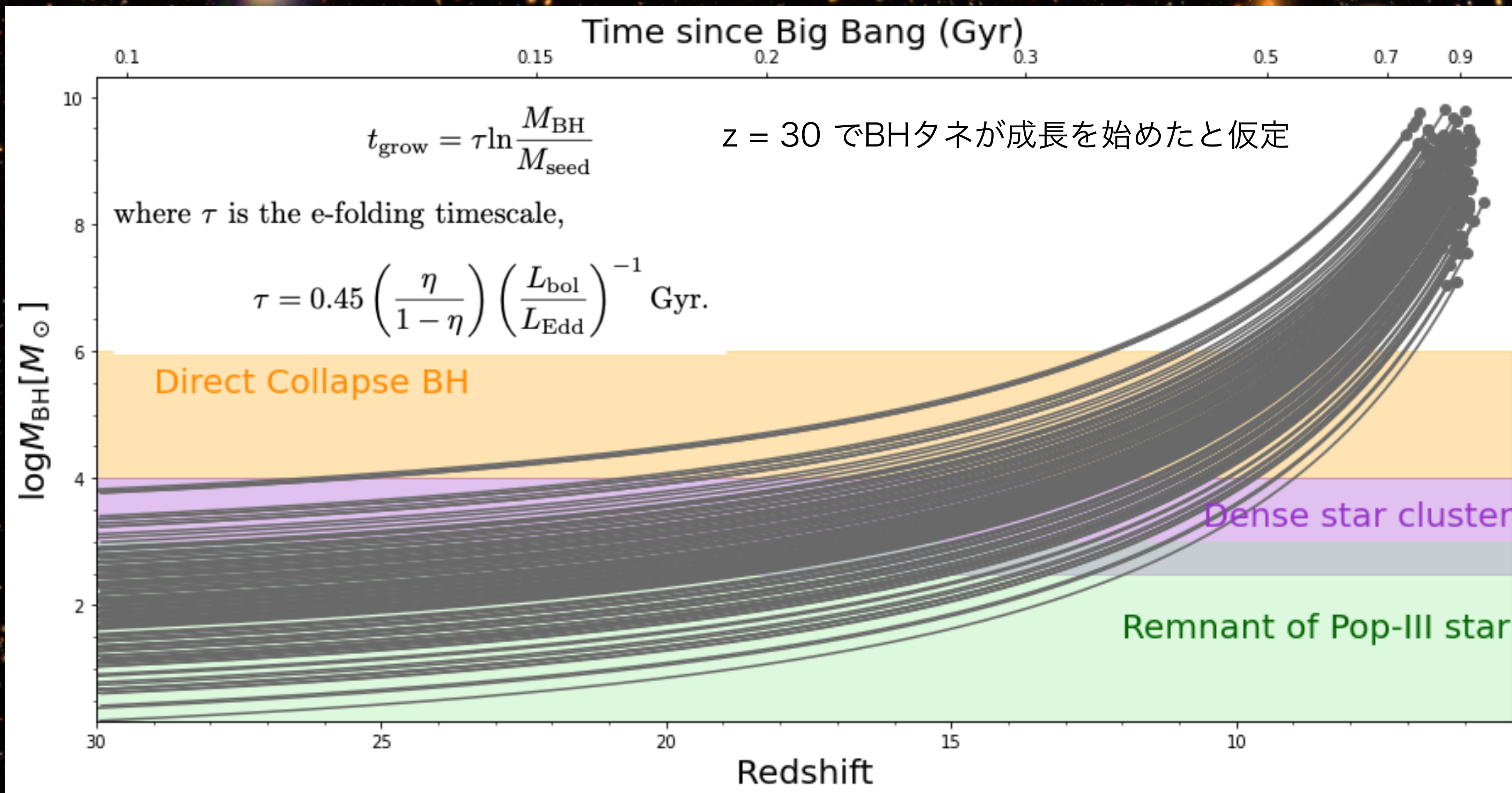


- M_{BH} range of our sample of $M_{BH} \sim 10^{7.0} - 10^{9.8}$ [$M_\odot$] (without Type-2 candidates)
- The majority of our sample accrete at sub-Eddington rates
- Our BH masses are lower by 1-1.5 orders of magnitude than the previous sample.

Estimated growth history of SHELLQs quasars

$L_{EDD}/L_{BOL} = 1$

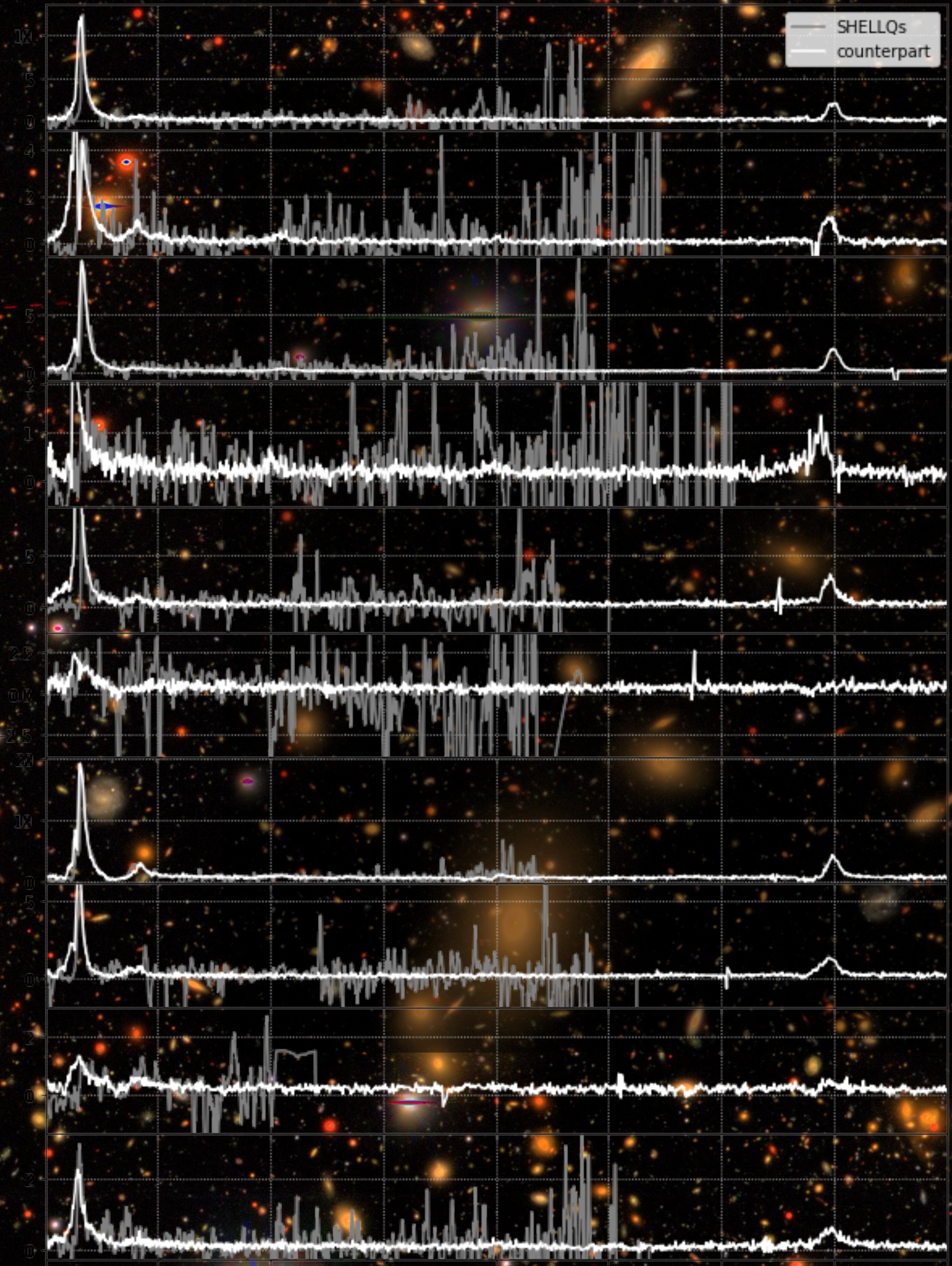
$\cdot\ \eta = 0.1$ (i.e., Shakura & Sunyaev 1976)



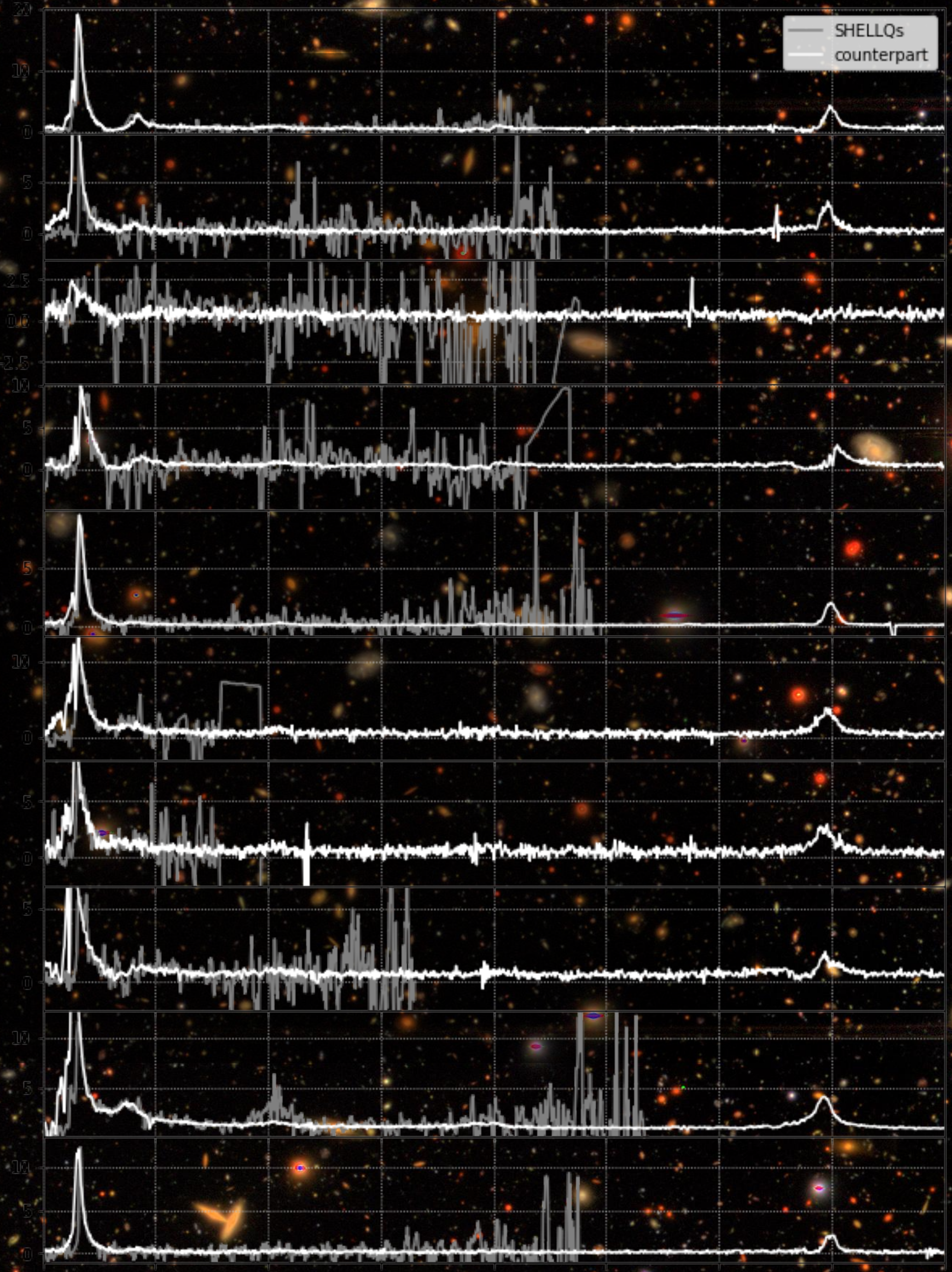
Most of SHELLQs quasars BH seed into the Pop-III remnants

Do active low-mass SMBHs have higher EW?

Lower-mass candidates in SHELLQs sample

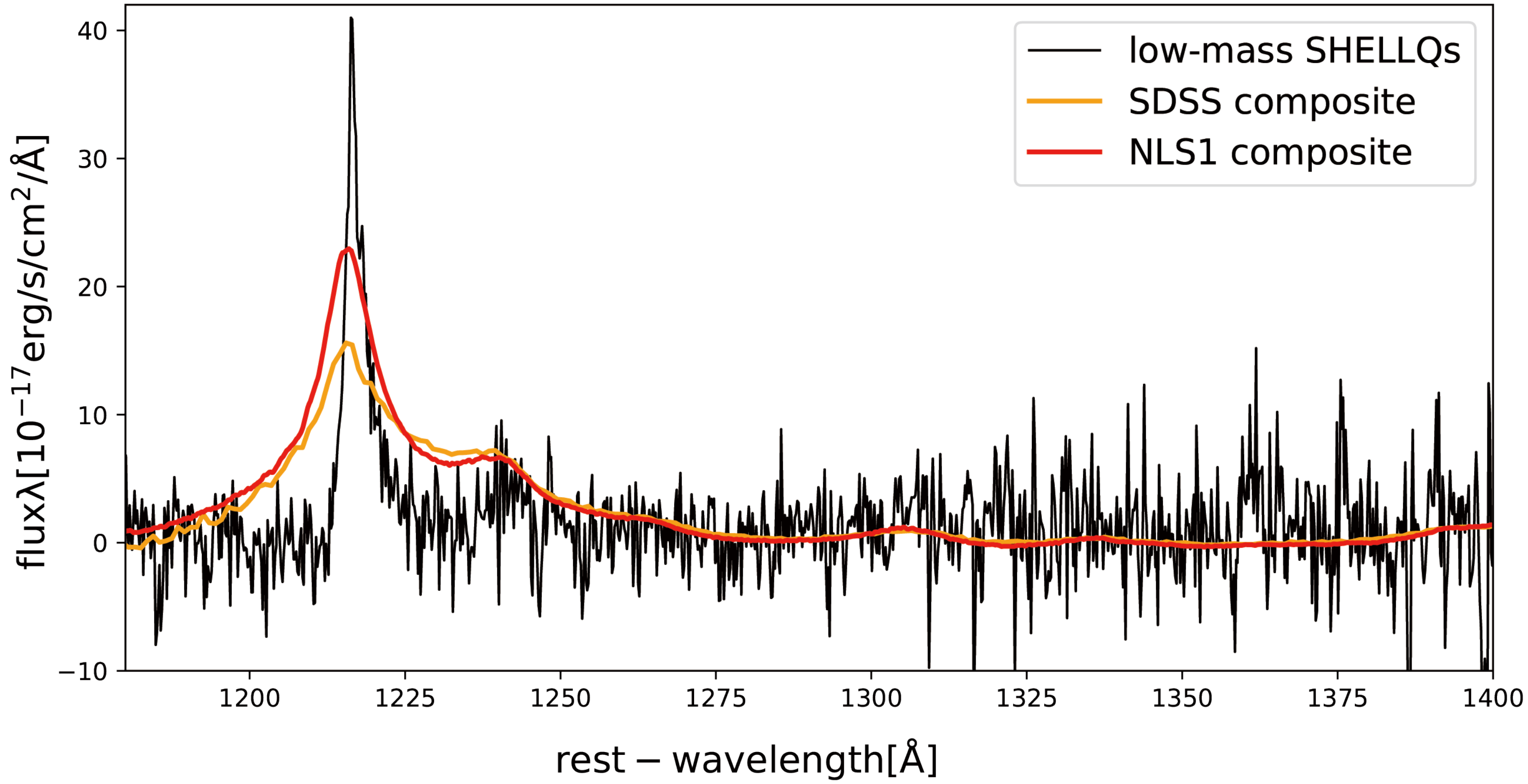


High-λ_{Edd} candidates in SHELLQs sample



Is the new quasar population at high redshift?

Compare spectral shapes with those of the quasar template and Narrow Line Syfert 1 catalog



Our low-mass candidates have narrow line spectral shapes, which are quite different from the typical quasar spectra (more than two times higher EW of Lya than those of the typical quasars).

- the gas-rich environment around the central black holes?
- According to high-accretion rate and low masses, these quasars may be in the early growing phase. -> HSC depth unveiled the young quasar population in the early universe.

Future prospects with PFS

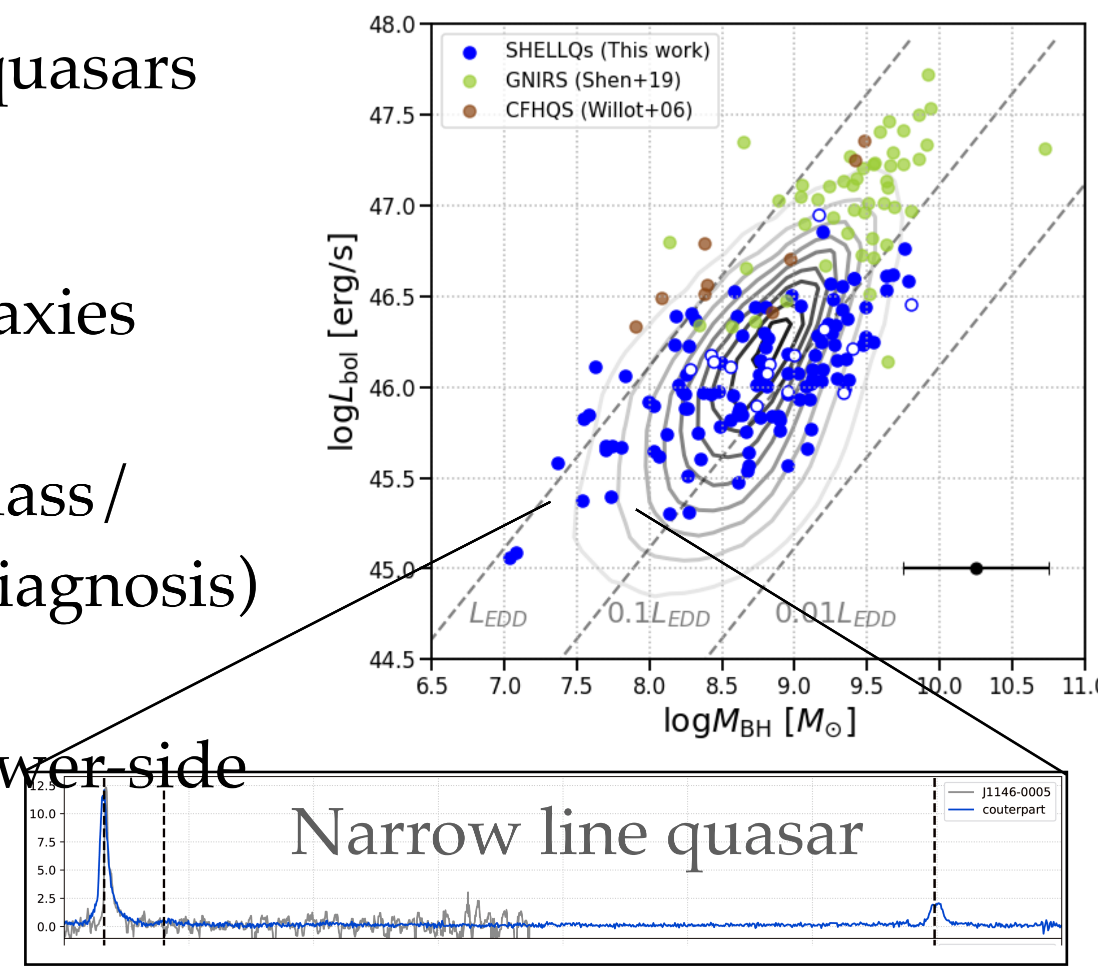
- PFS-SSP filler program will observe ~5000 broad line AGN

We may find at least ~500 narrow line quasars. (assuming a rough fraction)

The upcoming PFS survey will provide us with spectroscopic information about these unique quasars; we will be able to do their first statistical population analysis!

Obtaining numerous numbers of the narrow line quasars allows us to…

- Co-evolution study: relation with their host galaxies
- Evolution study of SMBHs (e.g., not only BH-mass/ Eddington ratio estimates, but also metalicity diagnosis)
- Constrain mass limit of quasar black holes at lower-side



I cannot wait to facilitate these studies of this "rare" population with statistical samples in the early universe!

Conclusion

- High-z quasars share the spectral shapes with those of low-z quasars.
- Estimated black hole masses are consistent with the actual measurements.
- The success of this novel method is based on the tight correlation between the line properties of Lya and CIV, which suggests the gas could emitting Lyα is closely related to those of CIV that is emitted from the closest region of central black holes.
- From the test with a massive low-z quasar sample, the counterpart method is valid over a wide range of redshift and luminosity.
- Our sample has large EWs of Lyα, twice the higher than those of the low-z control sample. The present result seems not consist with a native expectation from the Baldwin effect.
- We found 14 low-mass ($M_{\rm BH} < 10^8\, M_\odot$) quasars, including six super-Eddington accretion sources. They are featured by strong Lyα lines with weak continuum.
- With the spectral features, the low-mass active candidates resemble NLS1 galaxies identified at low-z Universe; thus, the low-mass active SHELLQs quasars can be called "NLS1-type quasars".
- Our NLS1-type quasars may be in the rapidly growing phases following their initial seeding and thus may represent one of the most crucial phases of the cosmological SMBH growth.