2023/3/29

International Conference on the Physics of the Two Infinities at Kyoto

Black-hole mass distributions of the most distant low-luminosity quasars

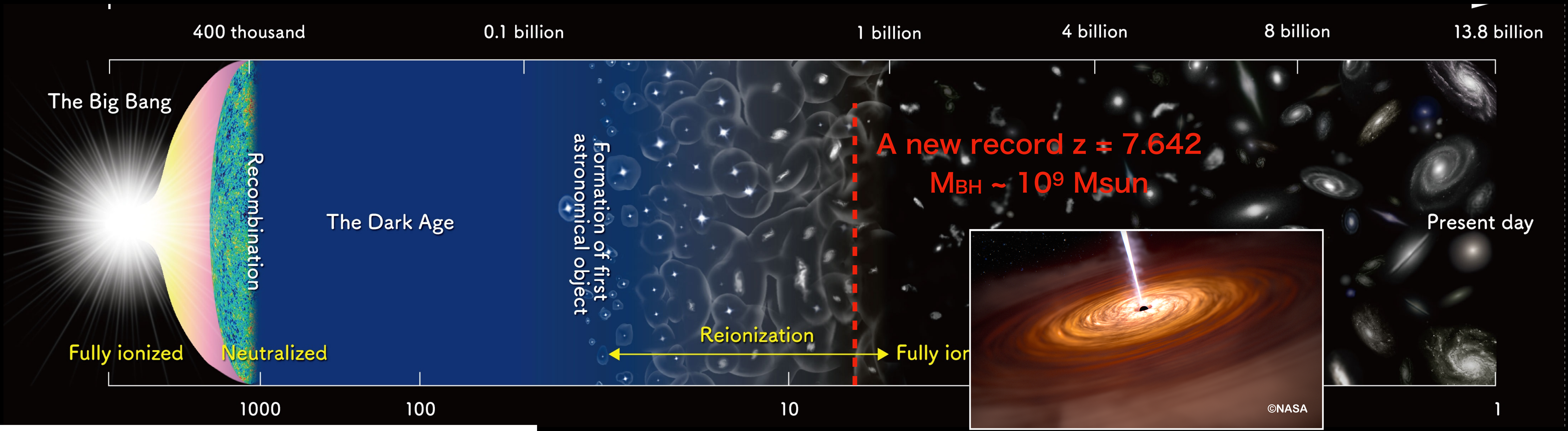
HSC

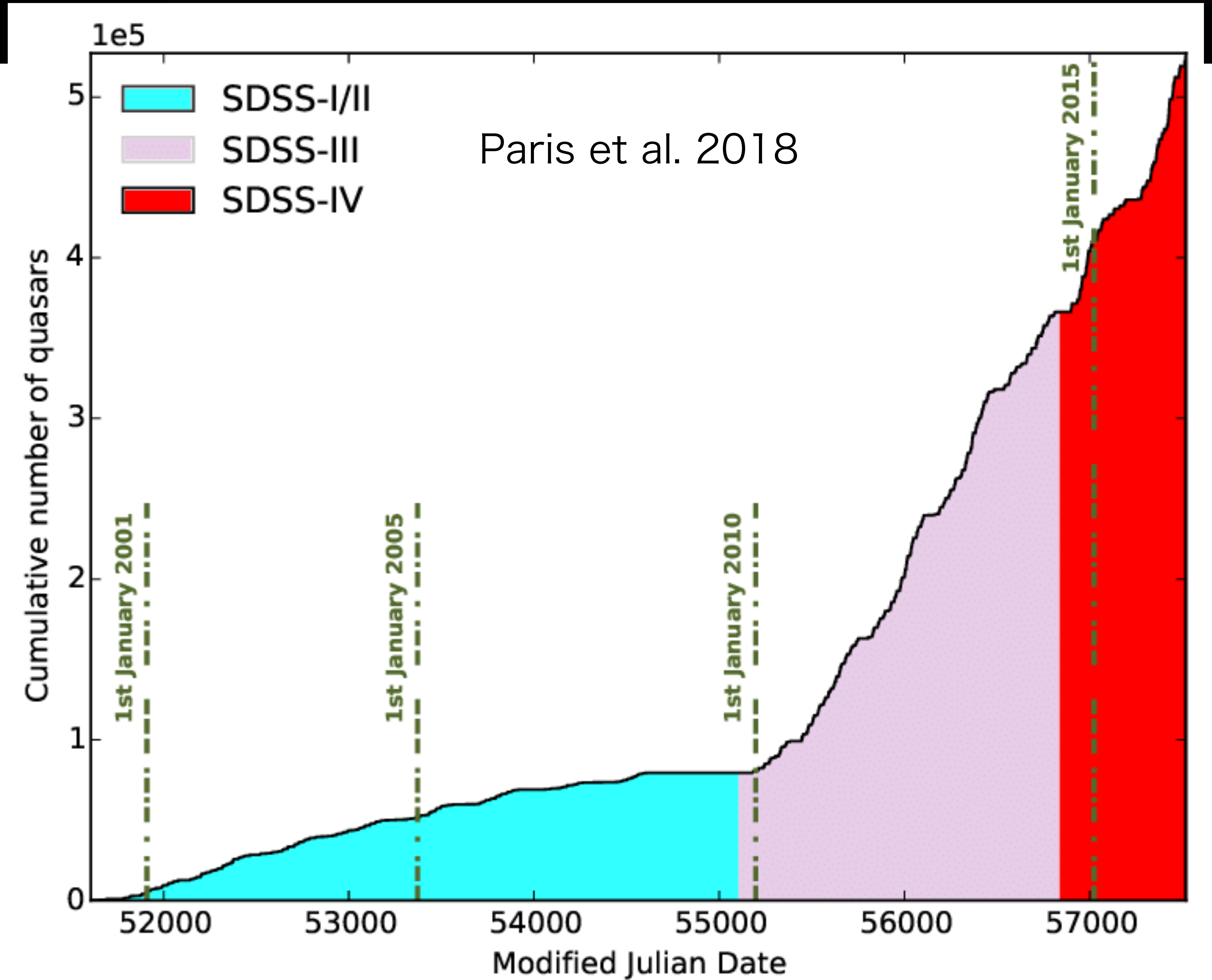
Ayumi Takahashi, Yoshiki Matsuoka[1], Michael Strauss[2], Masafusa Onoue[3], Nobunari Kashikawa[4], Yoshiki Toba[5], Kazushi Iwasawa[6], Masa Imanishi[5], Masayuki Akiyama[7], Toshihiro Kawaguchi[8], Akatoki Noboriguchi[9], Chien-Hsiu Lee[10] and the SHELLQs collaboration

1. Ehime 2. Prinston 3. KIAA(IPMU) 4. Tokyo 5. NAOJ 6. Barcelona 7. Tohoku 8. Onomichi 9. Shinshu 10. Keck


Lyα/NV
1216 & 1240
CIV
1549
CIII]
1909
CII]
2326
MgII
2798
[OII]
3727
[NeV]
3426
Hδ
4102
Hγ
4340
Hβ
4861
SiIV/OIV]
1400
[NeIII]
3869
[OIII]
4959 & 5007
Flux, λF(λ) (arbitrary units)
0
1
2
3
4
1000
2000
3000
4000
5000
Quasar Rest-frame Wavelength (Å)
Typical quasar spectrum
Supermassive Black holes (SMBHs)
Credit: Y.Matsuoka

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?

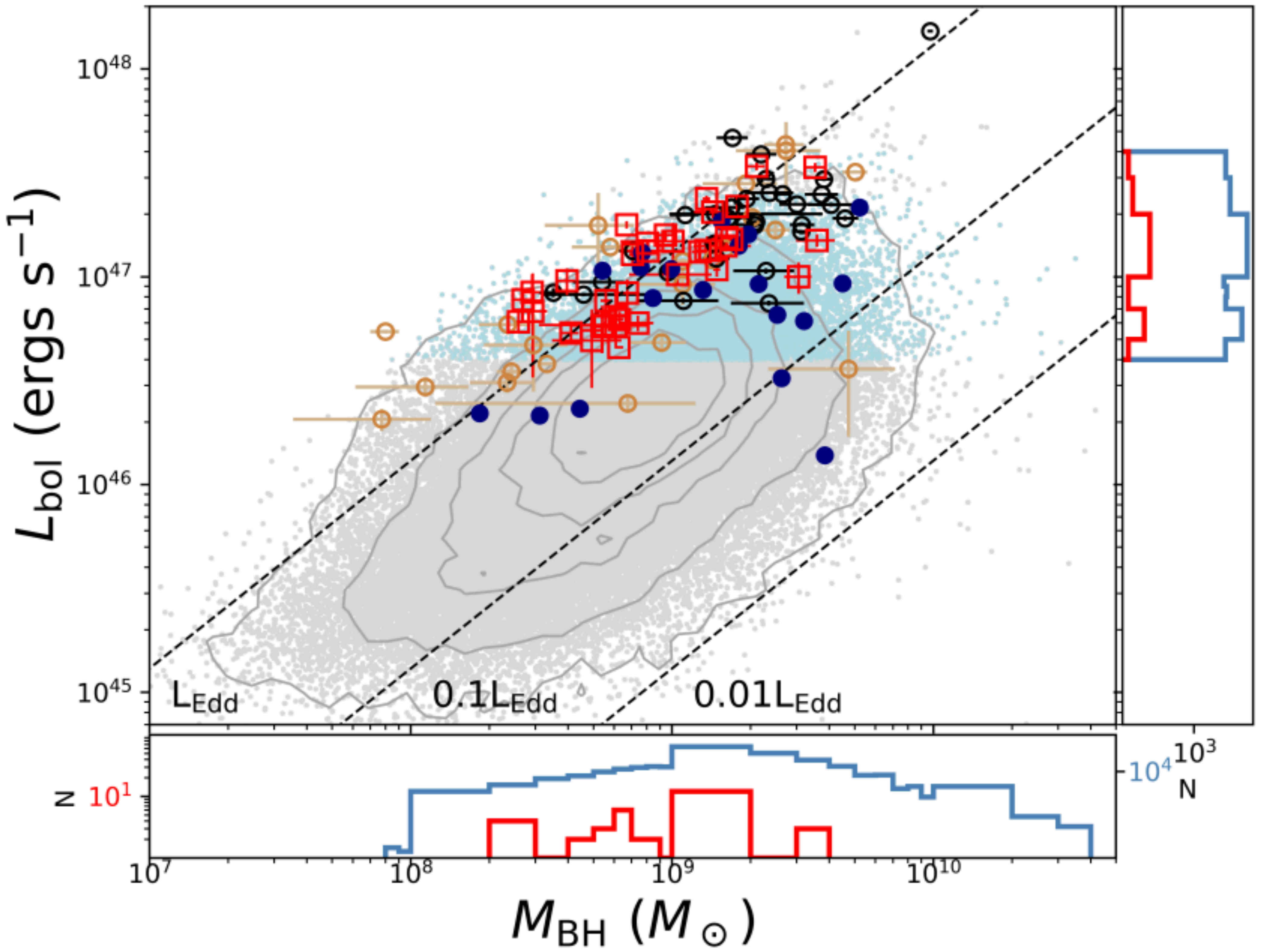
Important parameters to solve these questions are **BH masses** of high-z quasars and **Eddington ratios** which are related to

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

Super Massive Black Holes (SMBHs) in the early universe

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

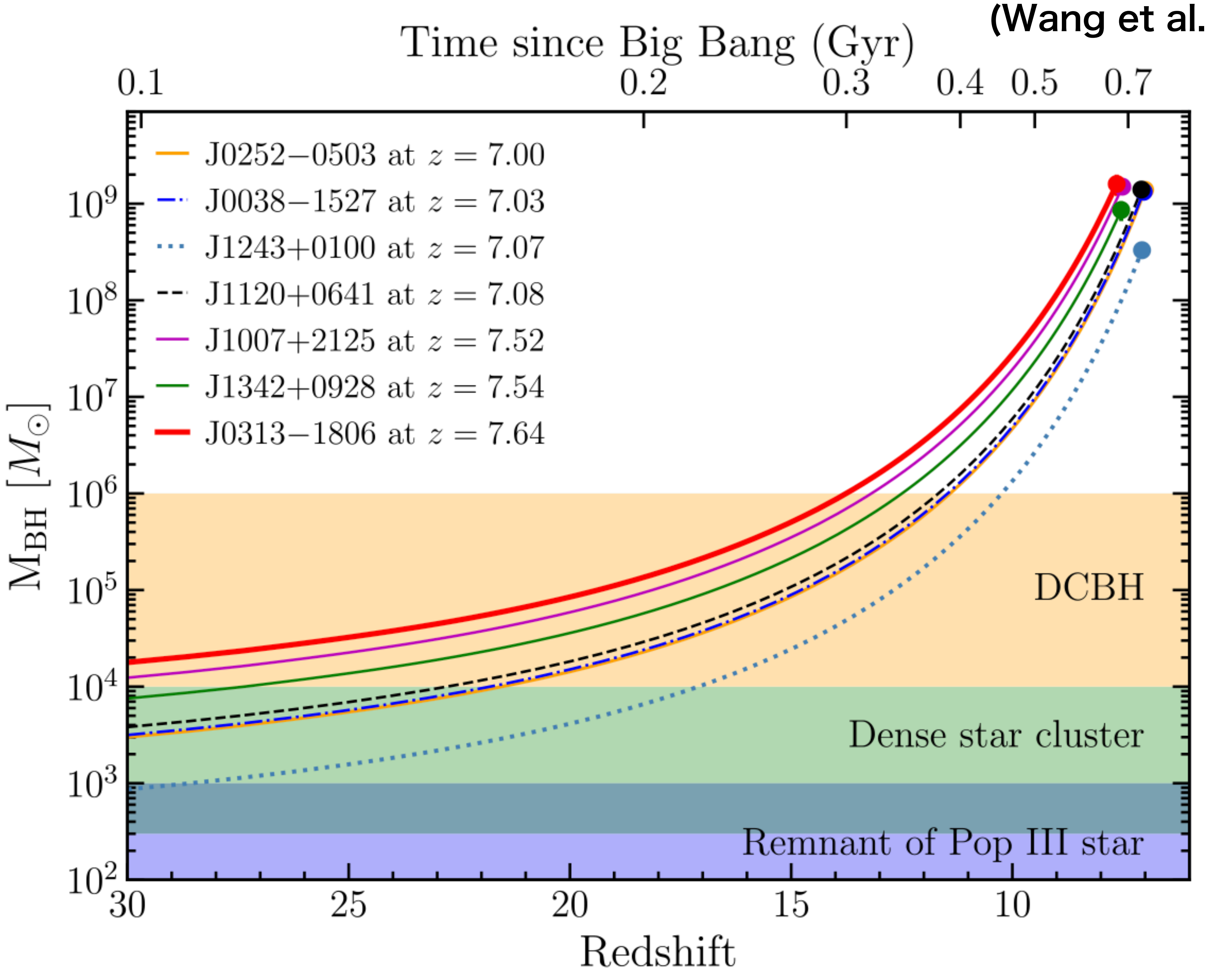
(Yang et al. 2021)



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

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

(Wang et al. 2021)

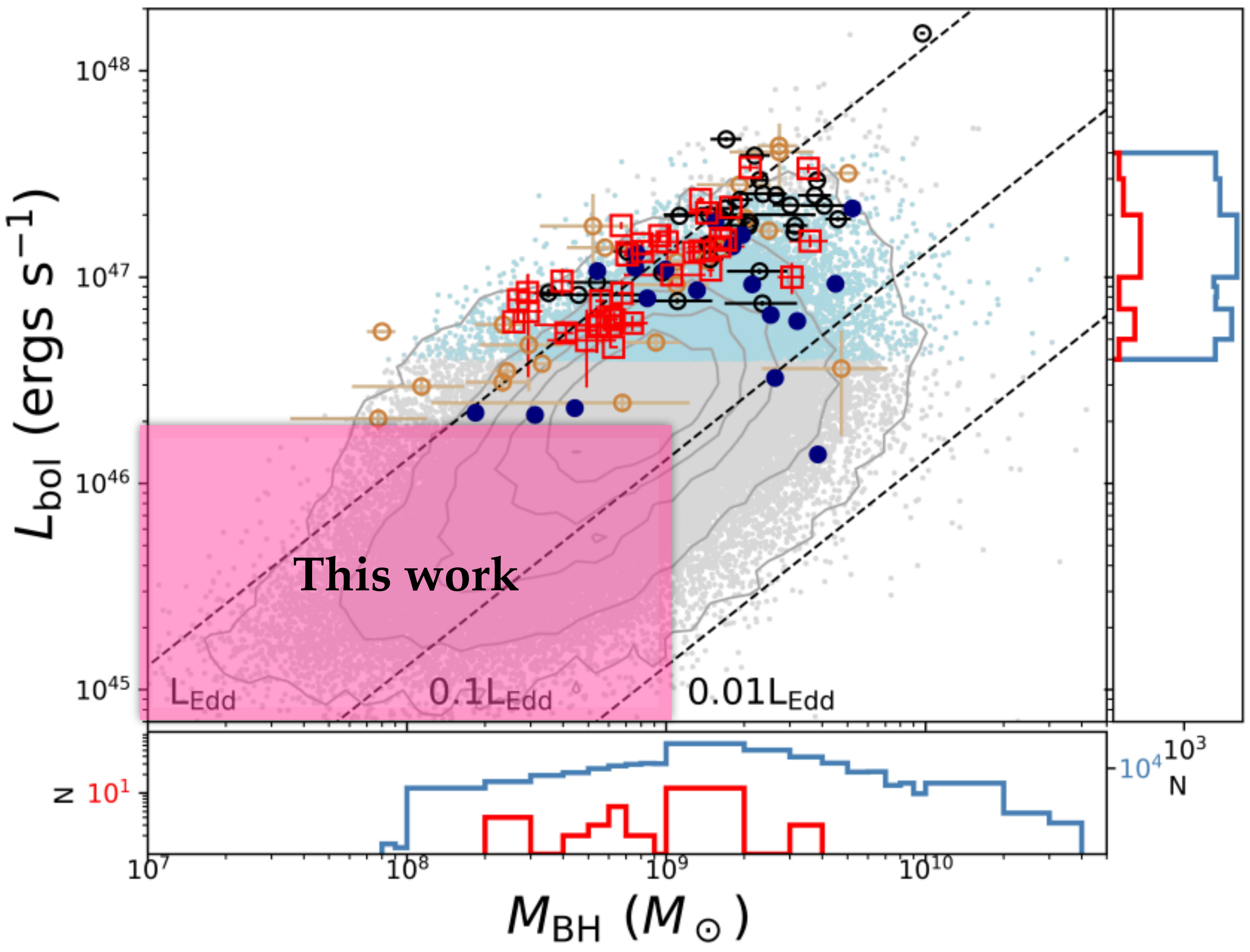


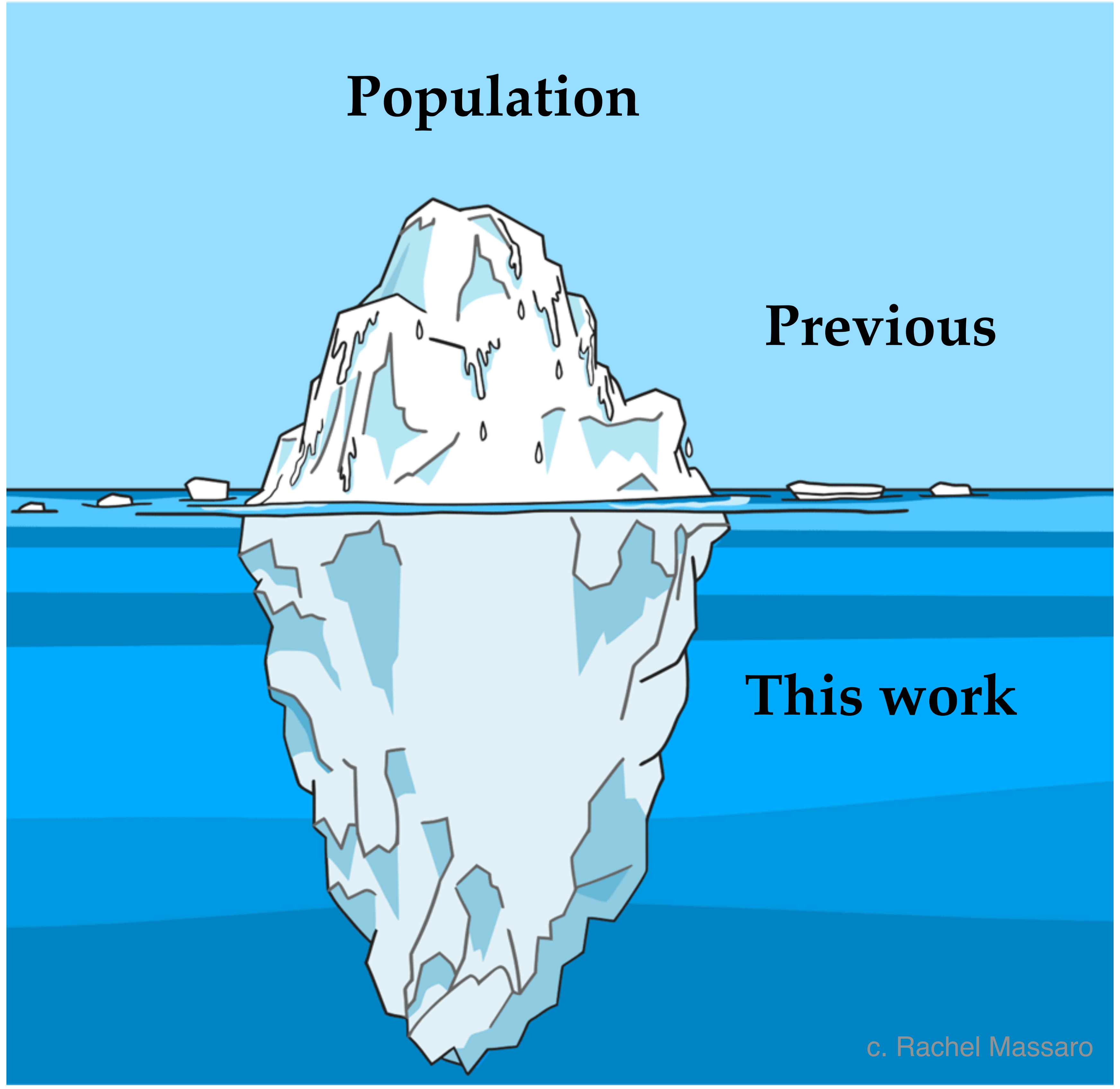
$M_{seed} \sim 10^3$ to 10^4 [$M_\odot$]

- Previous results support the rapid growth of Black Hole

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.

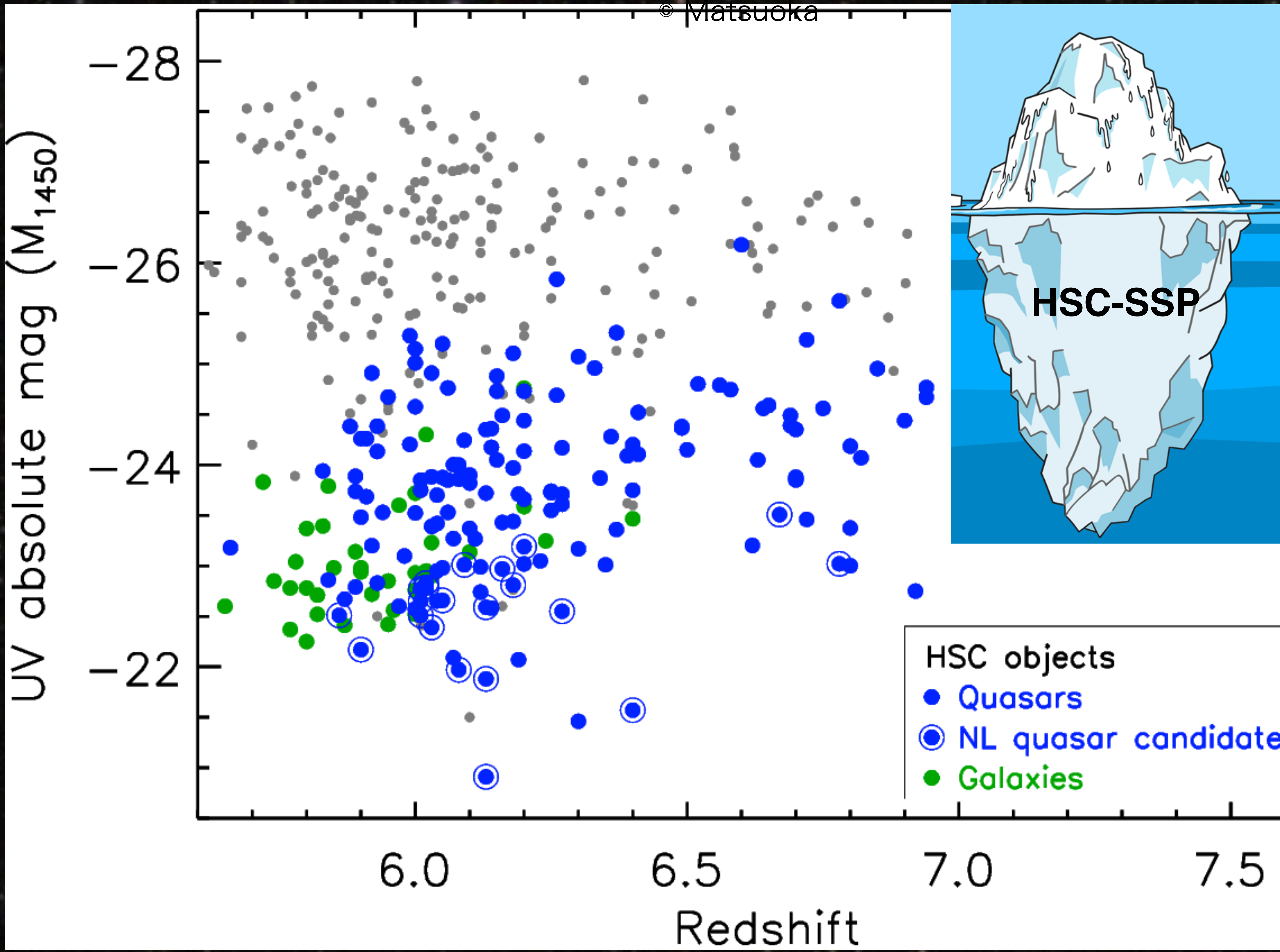
SHELLQs project (PI: Yoshiki Matsuoka)

"Subaru High-z Exploration of Low-Luminosity Quasars"

Spectroscope install on

SHELLQs sample is composed of 180 quasars

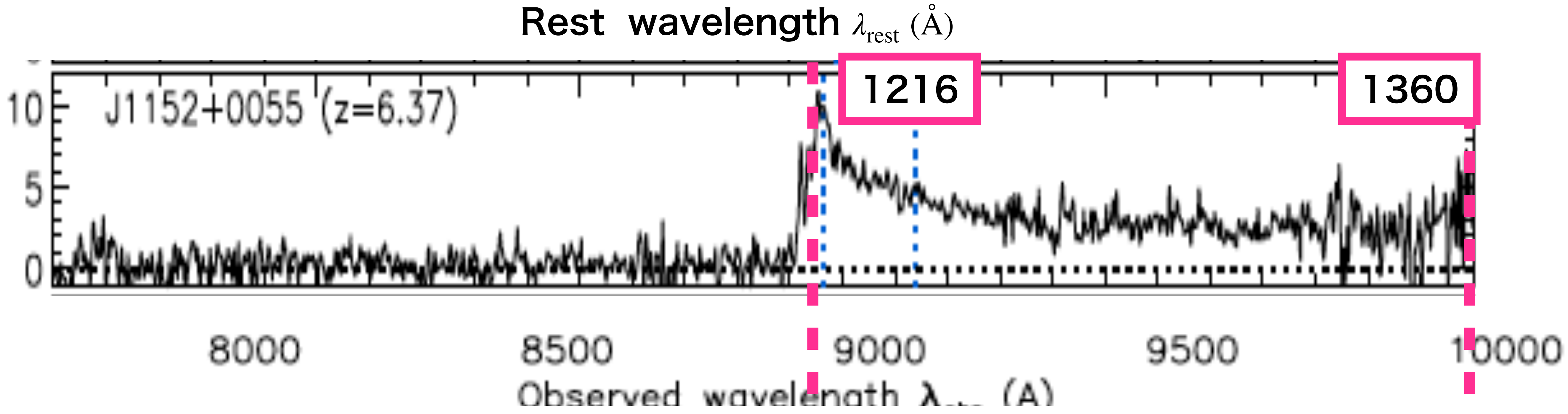
This low-luminosity sample may contain the low-mass quasars…



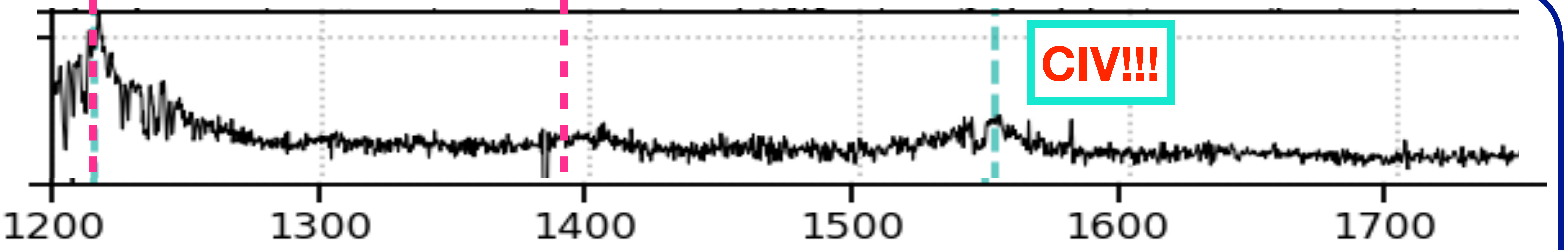
High-z quasars sample in this work:

- 75 type-1 objects (published in Matsuoka+16, 18ab, 19ab)

The problem of / solution to the mass measurements



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



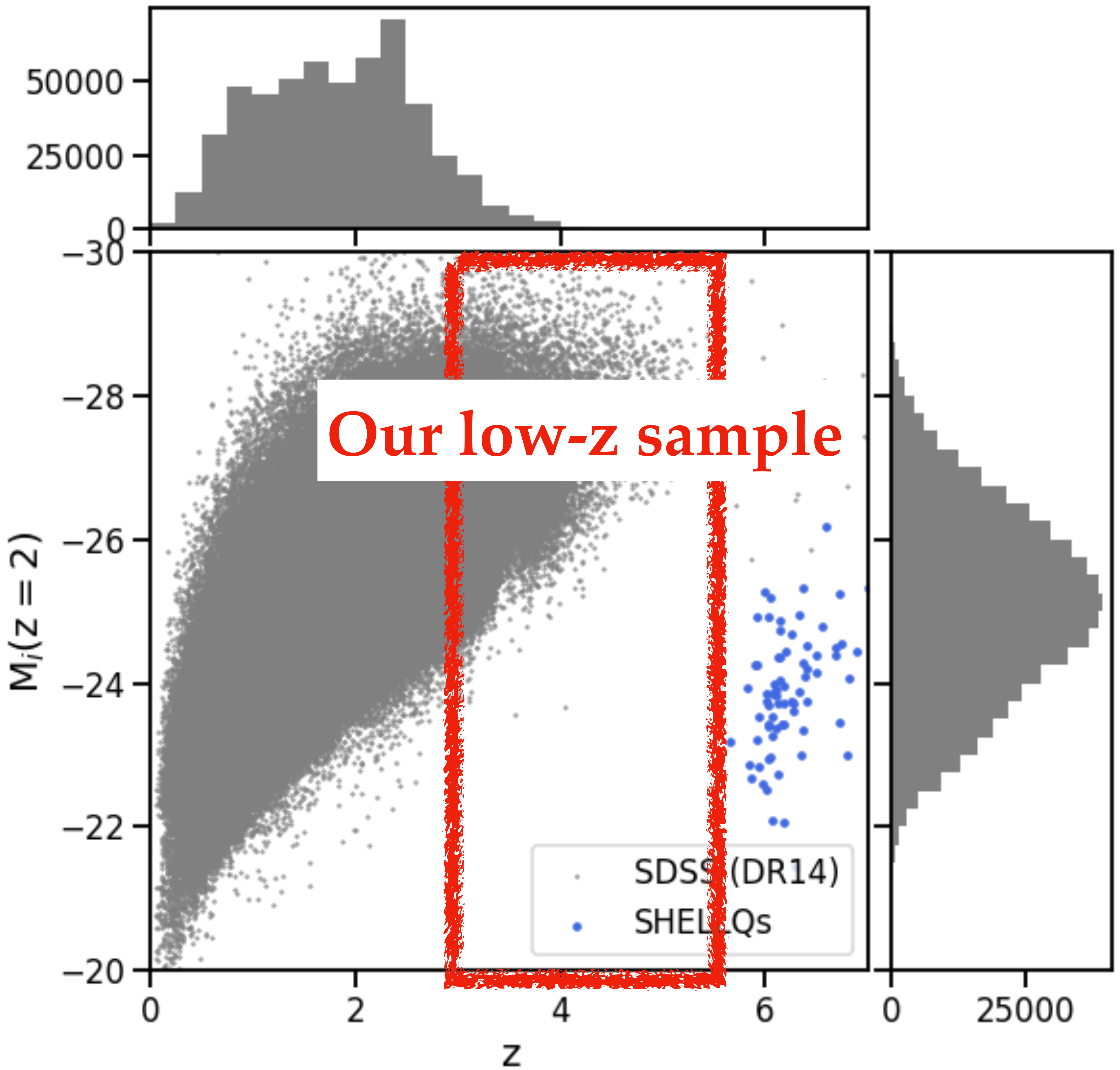
(2) We find a low-z quasar ("counterpart") that has the best-match spectrum to each SHELLQs quasar in the overlapping spectral coverage ($1216 < \lambda_{rest} < 1400$ A), through χ2 fitting.

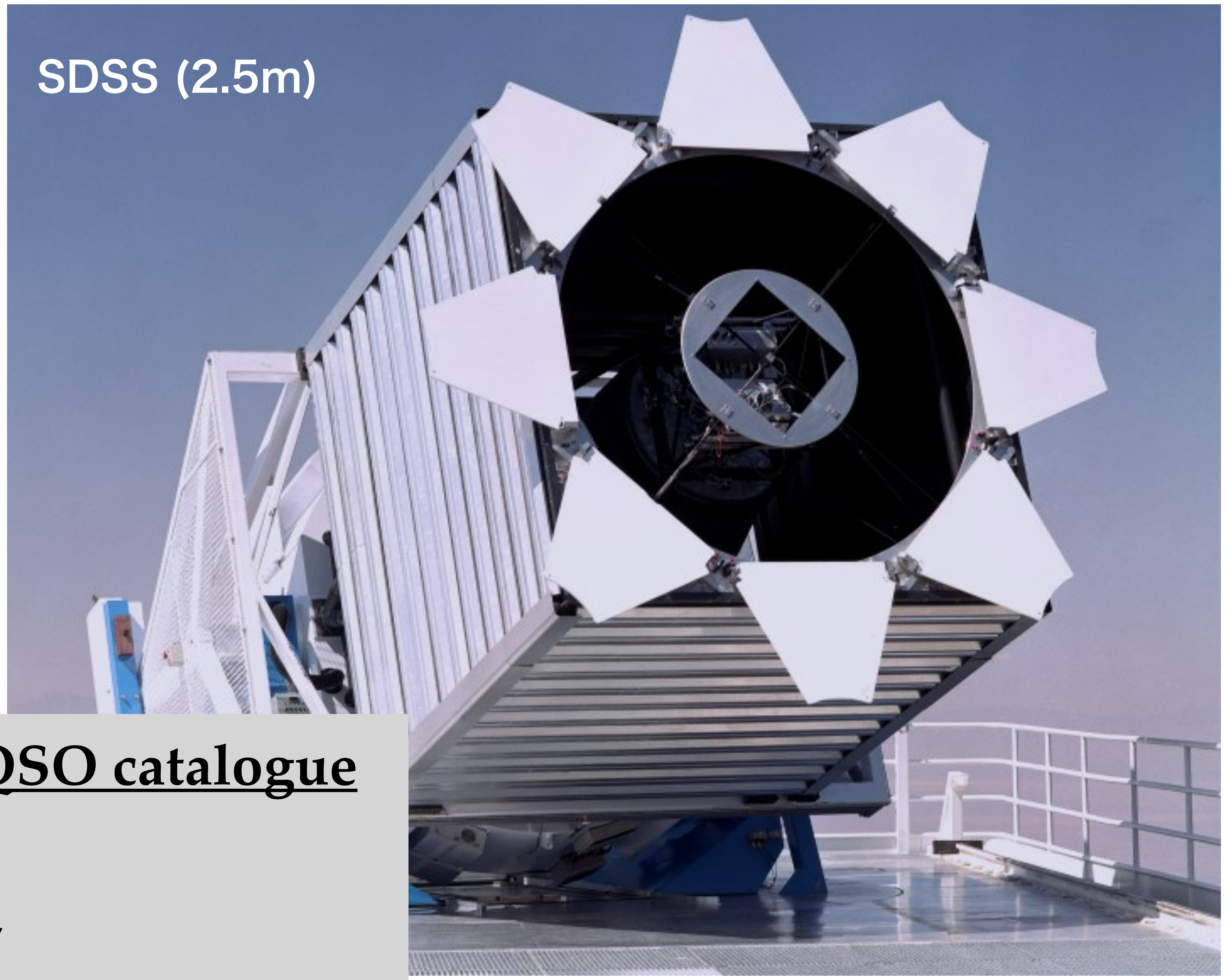
(3) Black hole mass is derived using the CIV profile of the counterpart spectrum.

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)





<u>Basically information of DR14 QSO catalogue</u>

- 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 $2.5 \leq z \leq 5.0$; 101489 objects whose spectra cover the rest-UV portions around Lya emission lines.

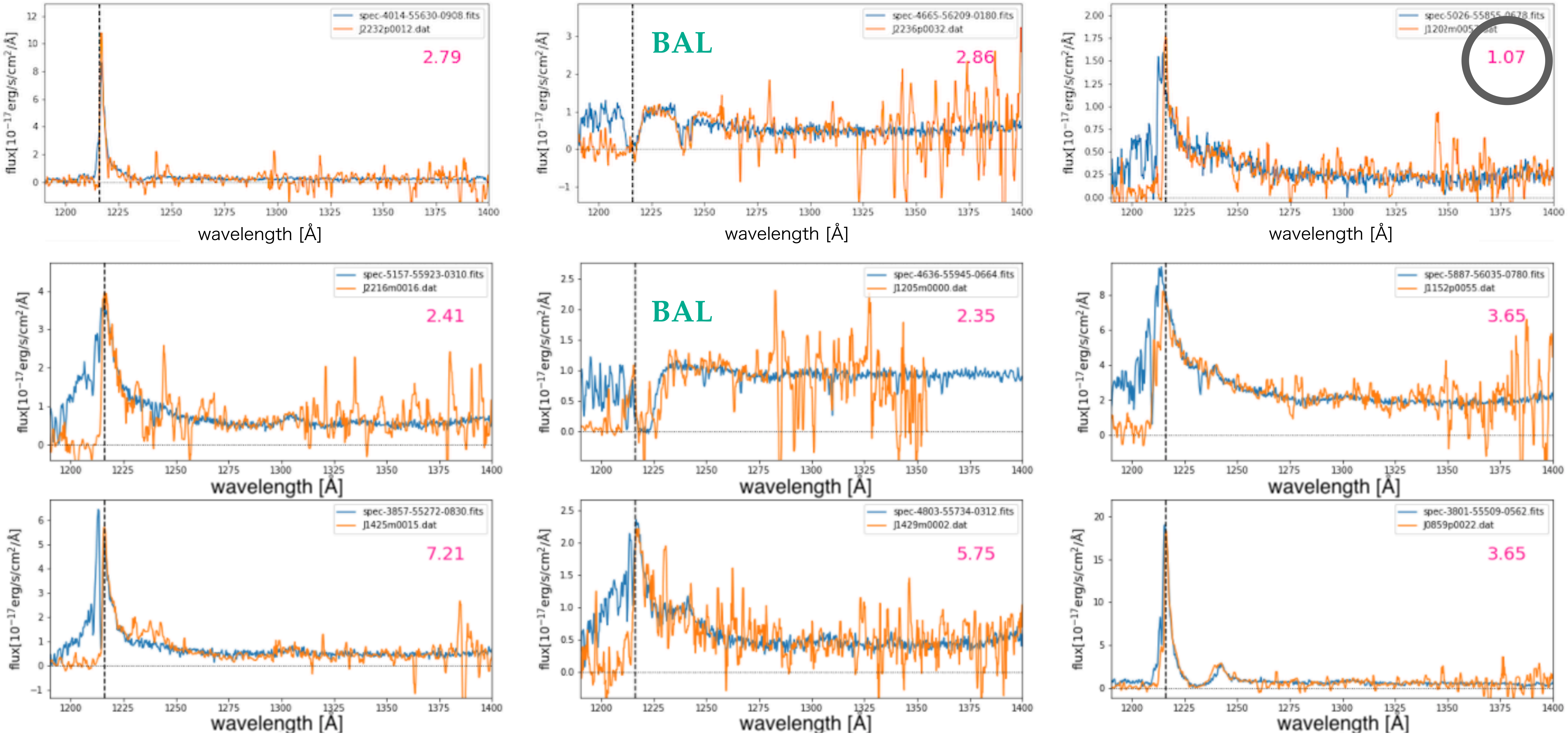
Substitute BH mass tracers in the low-z sample for each SHELLQs quasar.

A part of the counterpart’s spectra (9/93)

SHELLQs　　counterparts

- Successfully got spectrally matched counterparts with this method!
- Their spectral shapes much resembled each other, even in the absorbed cases.

reduced - $\chi 2$

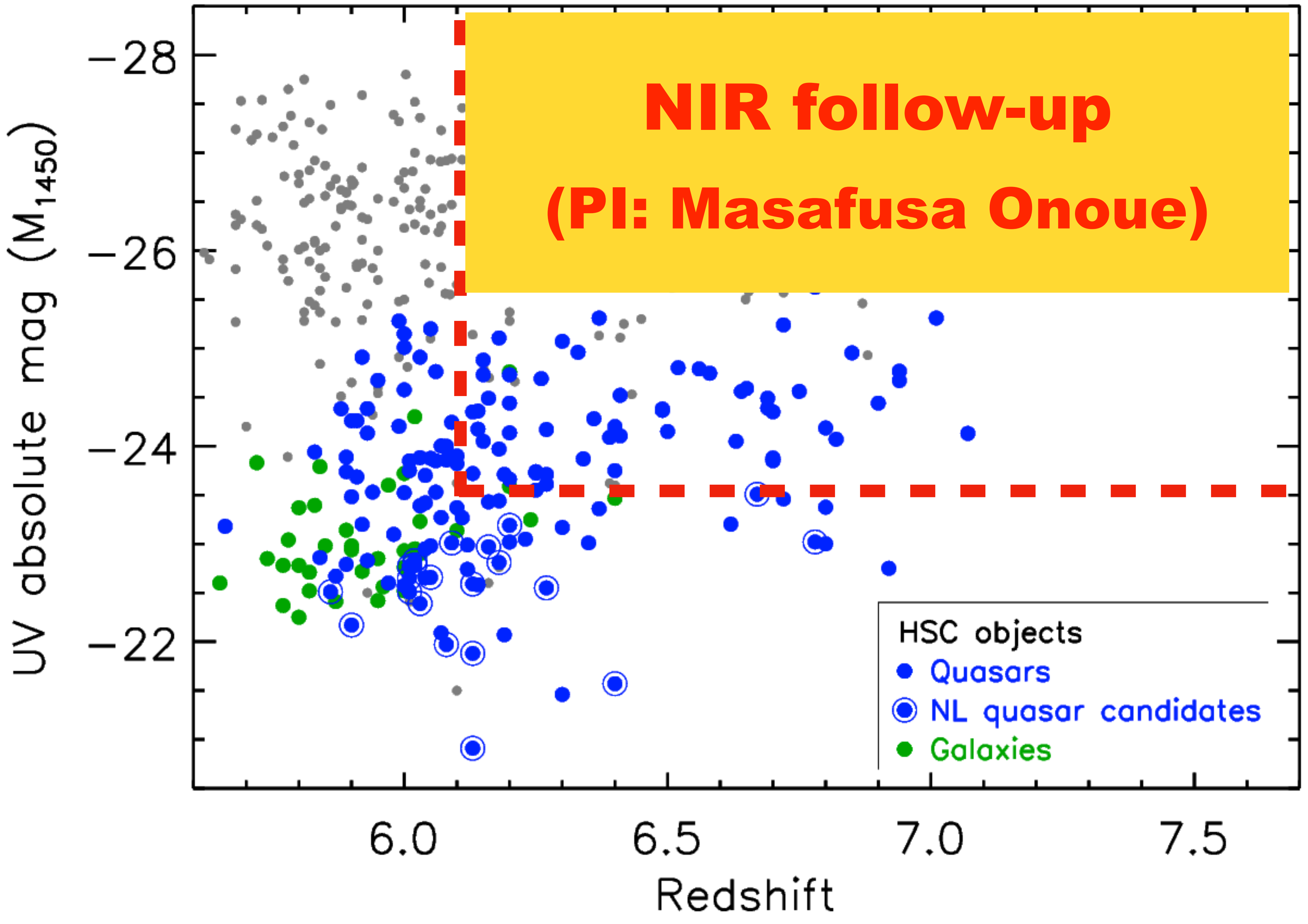


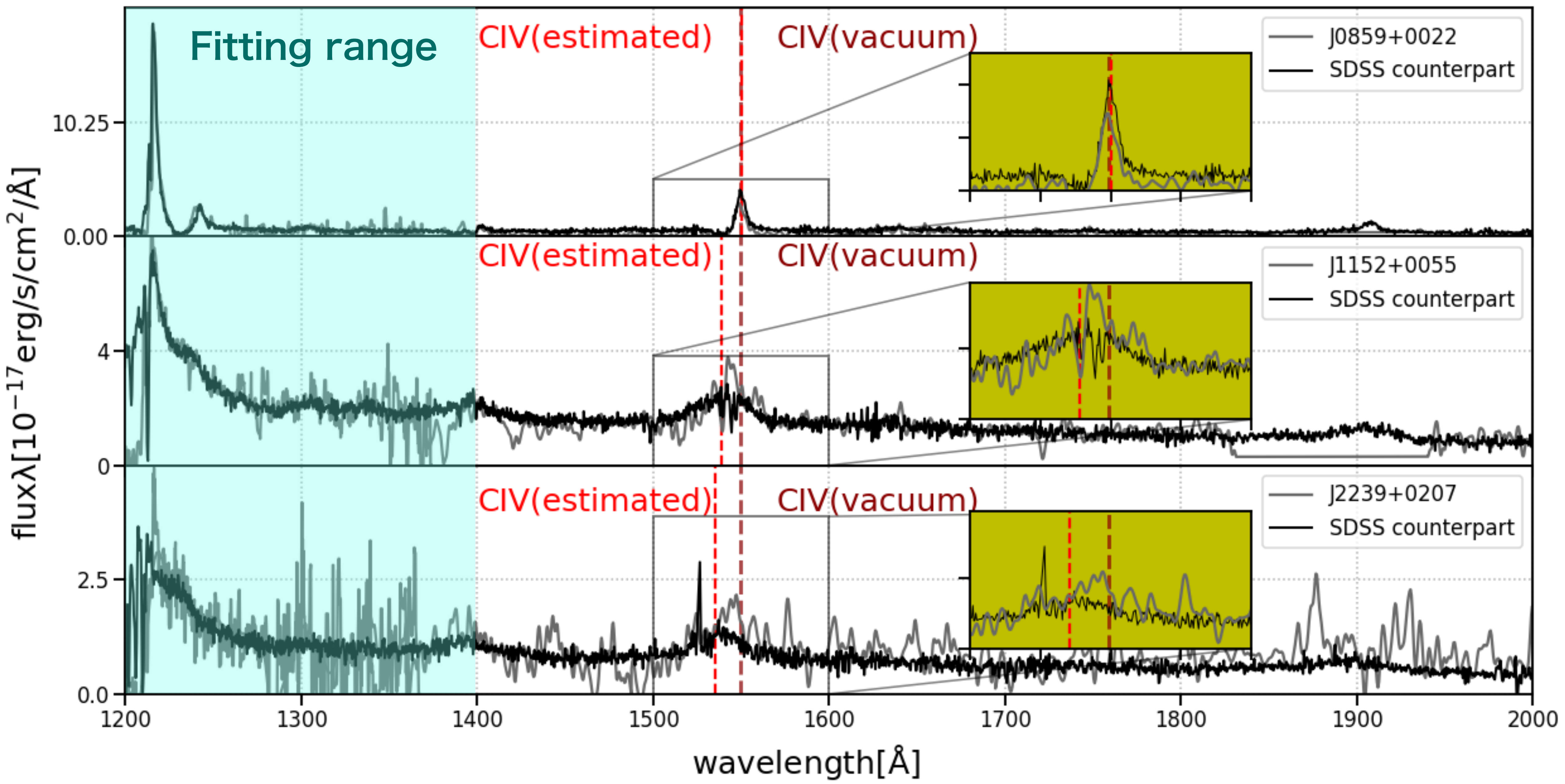
Random selected

Low-z quasars with the 10 smallest χ^2 values for 1 SHELLQs quasar (ex.1)

There are only 2 SHELLQs quasars with more than 1 counterparts meeting $\chi^2 < \chi^2_{\rm min} + 1$.

Our measurements vs. Literatures

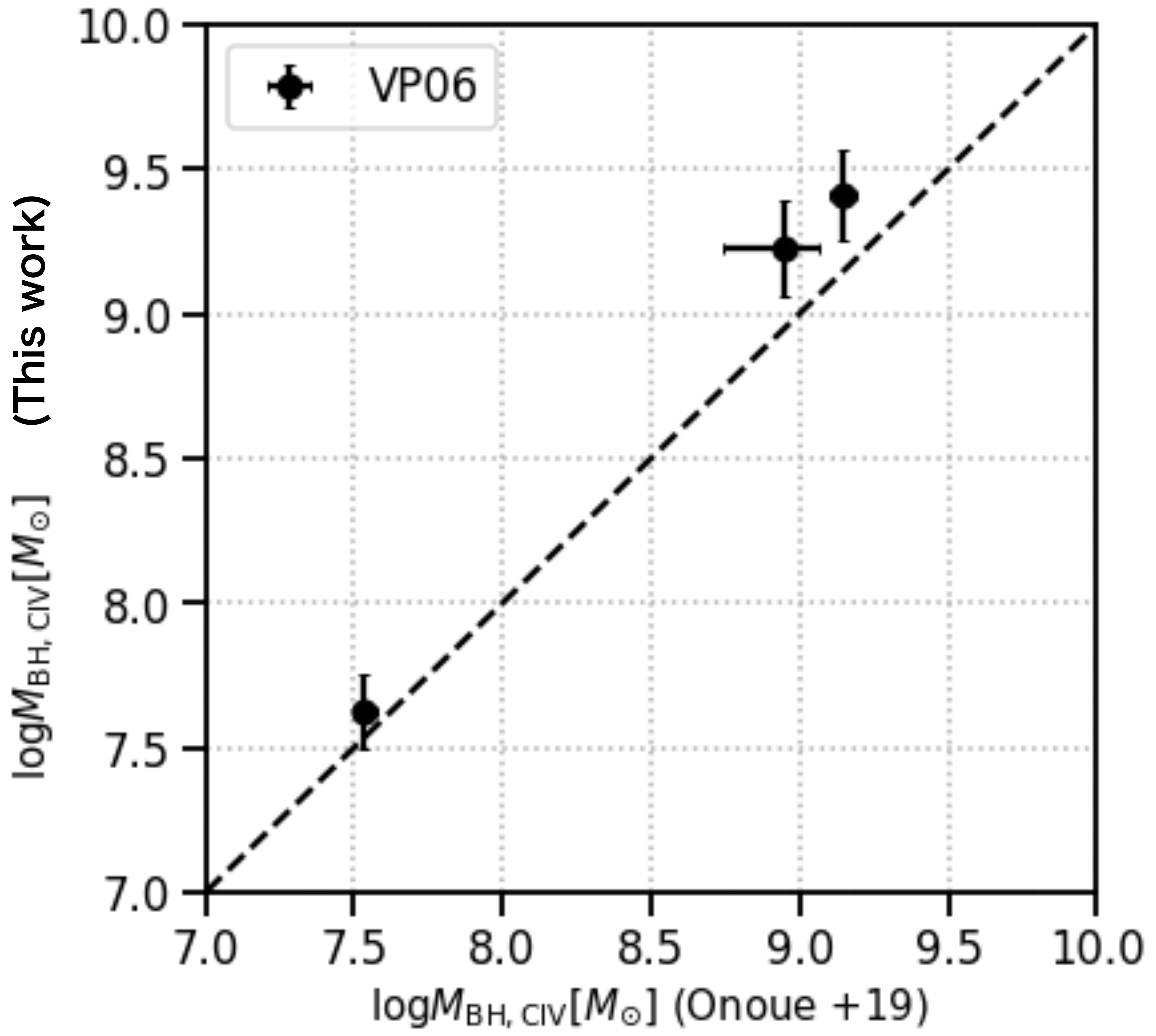




Our predicted BH masses :

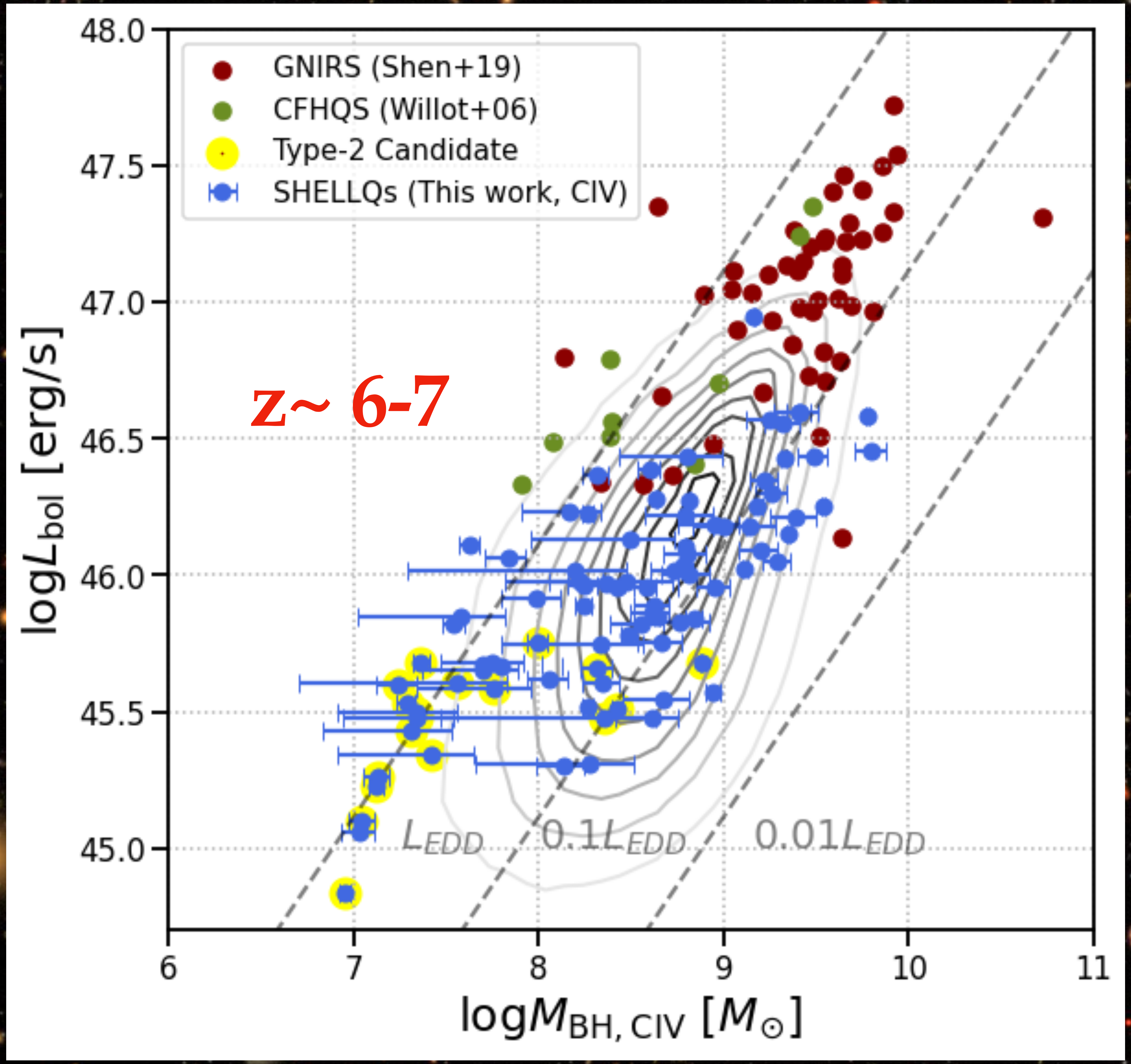
SHELLQs　　　CP (SDSS)

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



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.

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



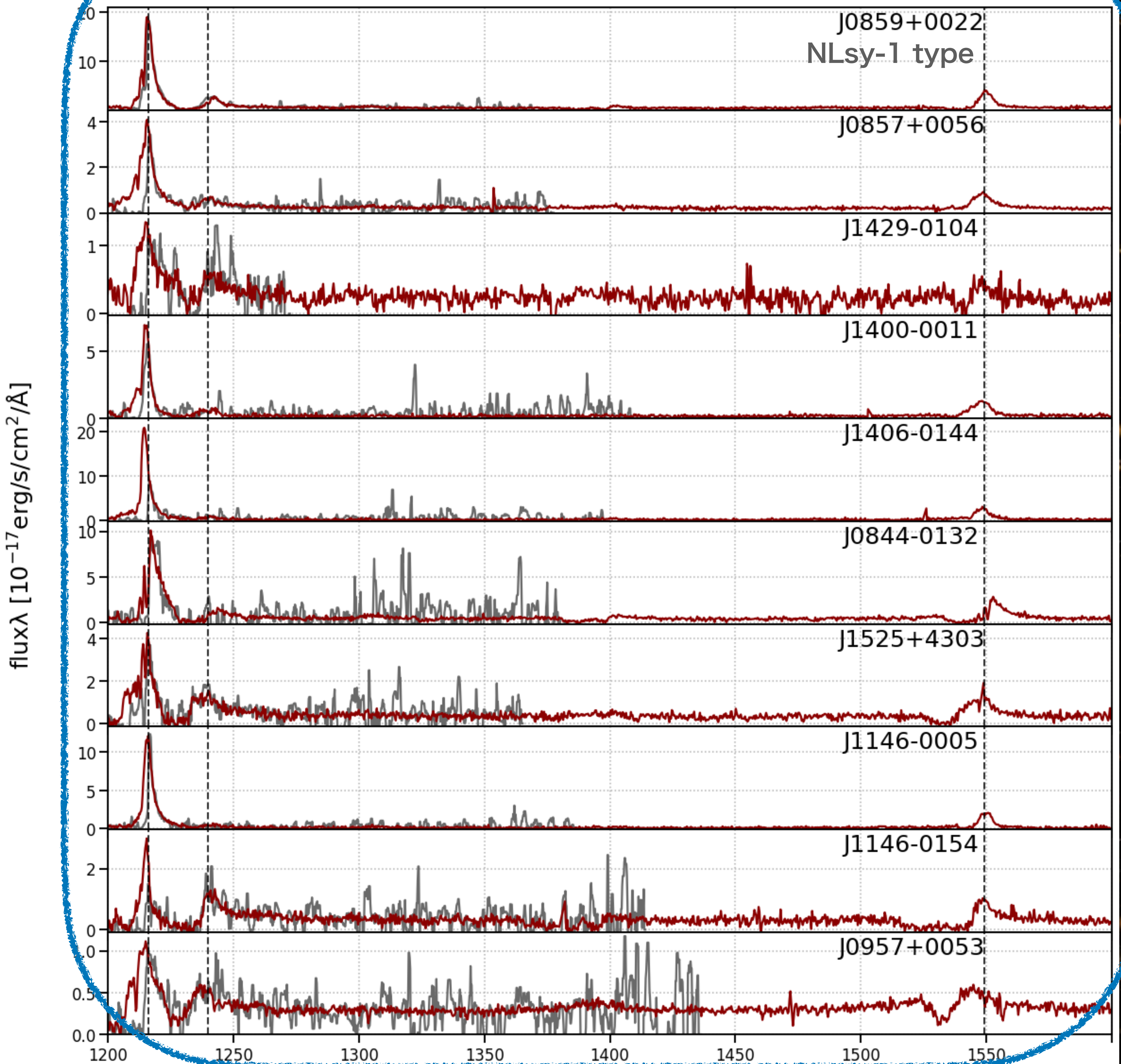
M_{BH} range of our sample of $M_{BH} \sim 10^{7.0} - 10^{9.8}$ [$M_\odot$] (without Type-2 candidates)

The majority of our sample accrete at sub-Eddington rates

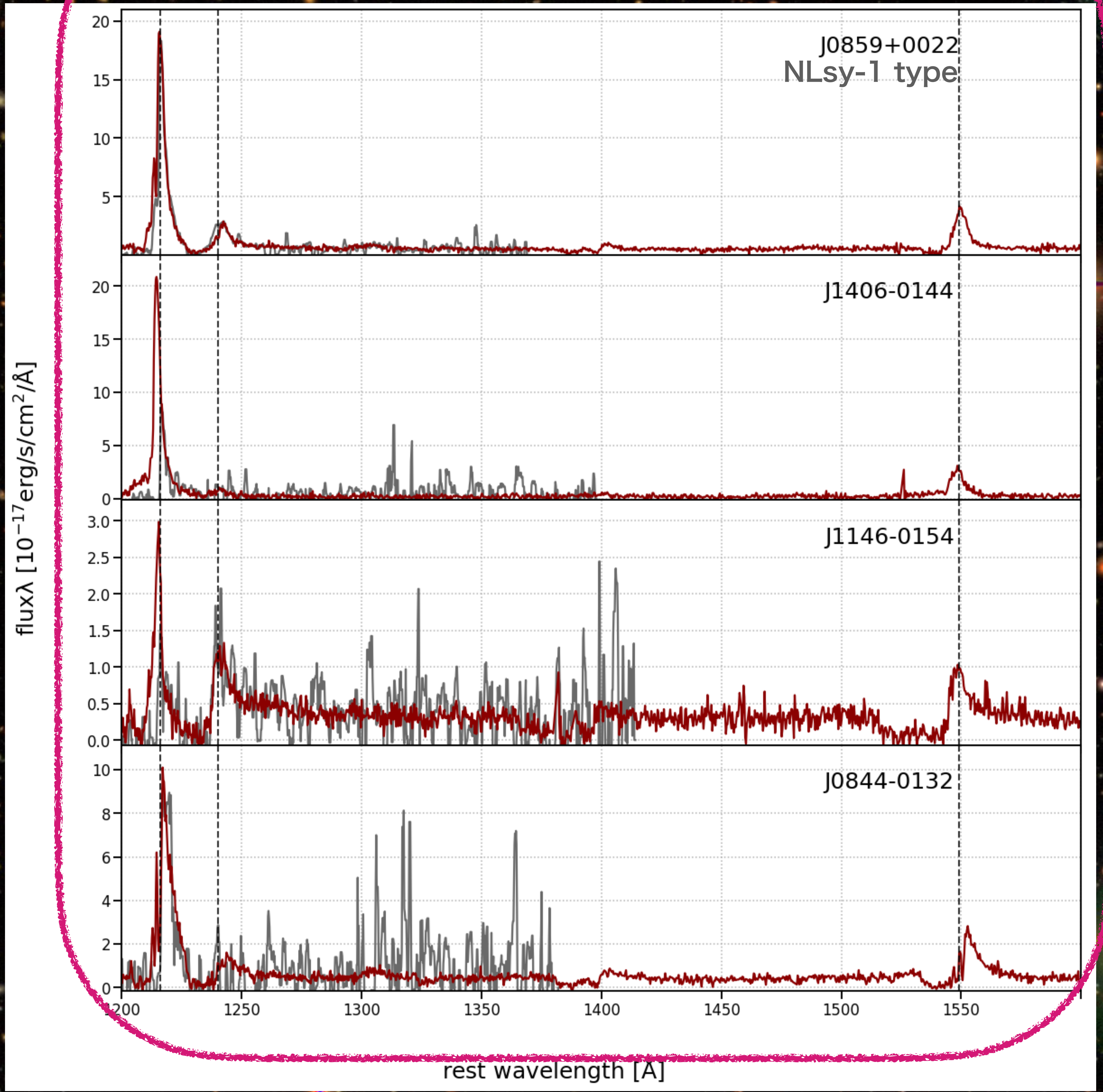
Our BH masses are lower by 1-1.5 orders of magnitude than the previous sample.

Do active low-mass SMBHs have higher EW?

Lower-mass candidates in SHELLQs sample



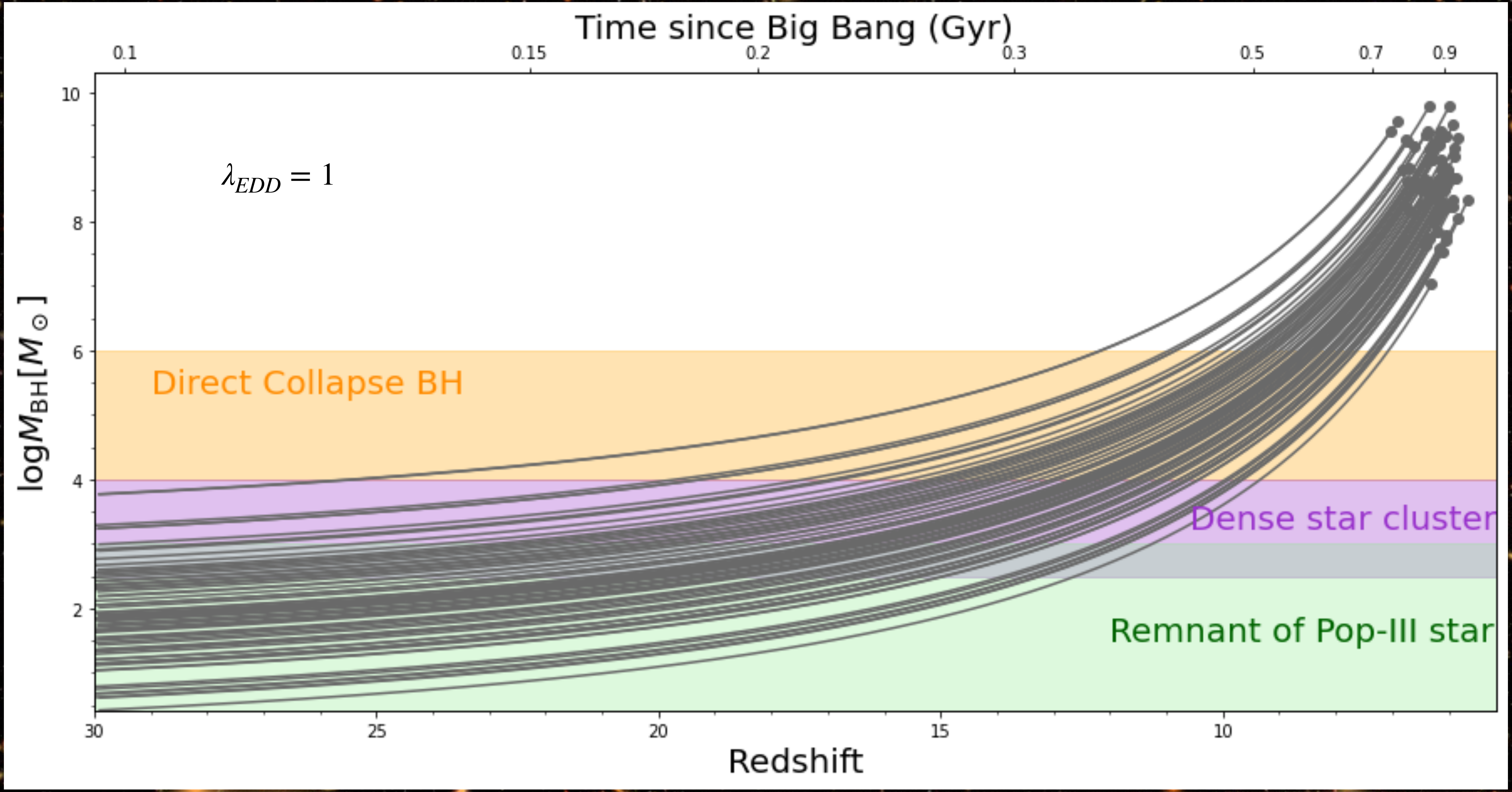
Super-λ_{Edd} candidates in SHELLQs sample



Estimated growth history of SHELLQs quasars

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

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

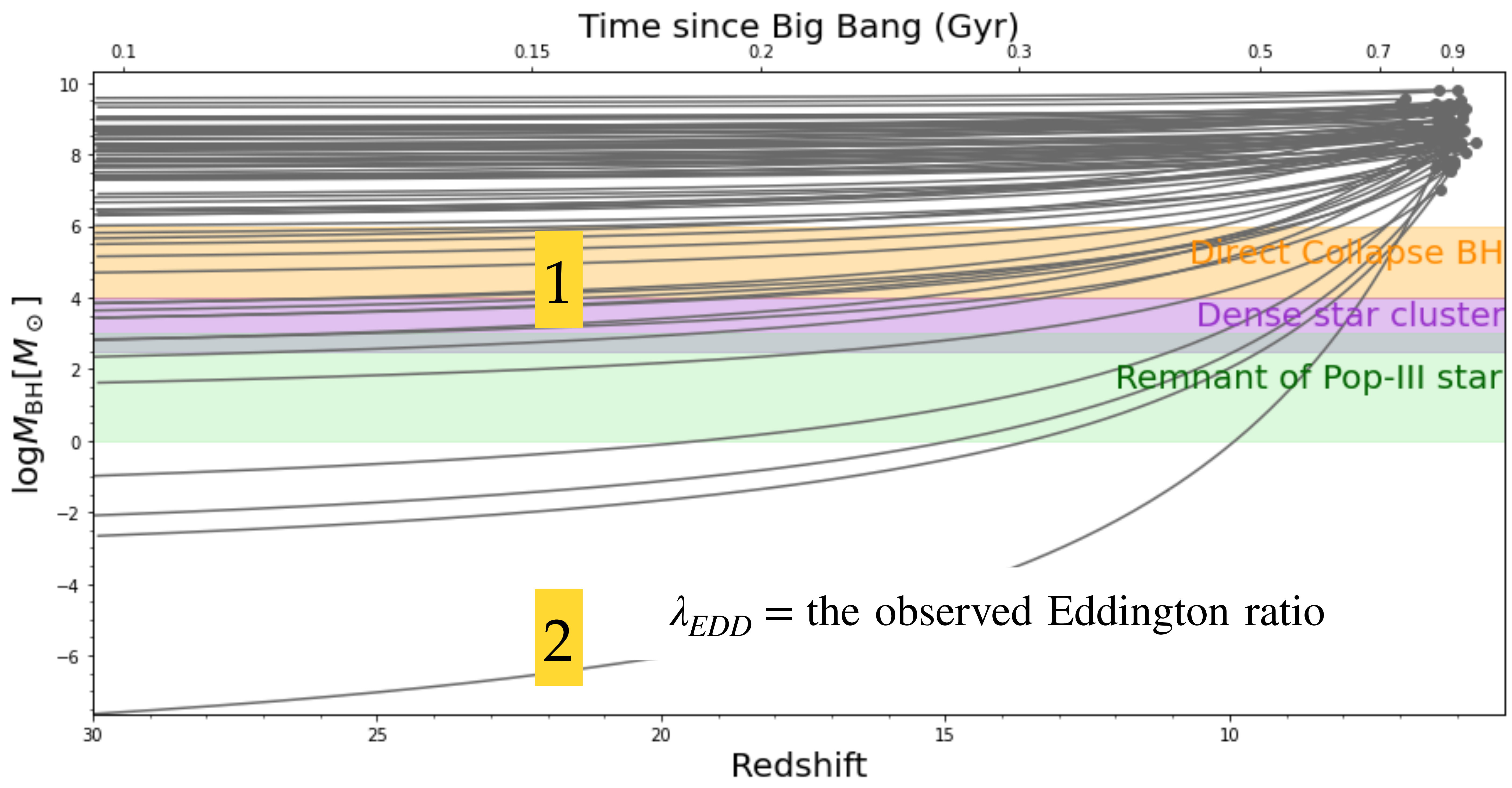


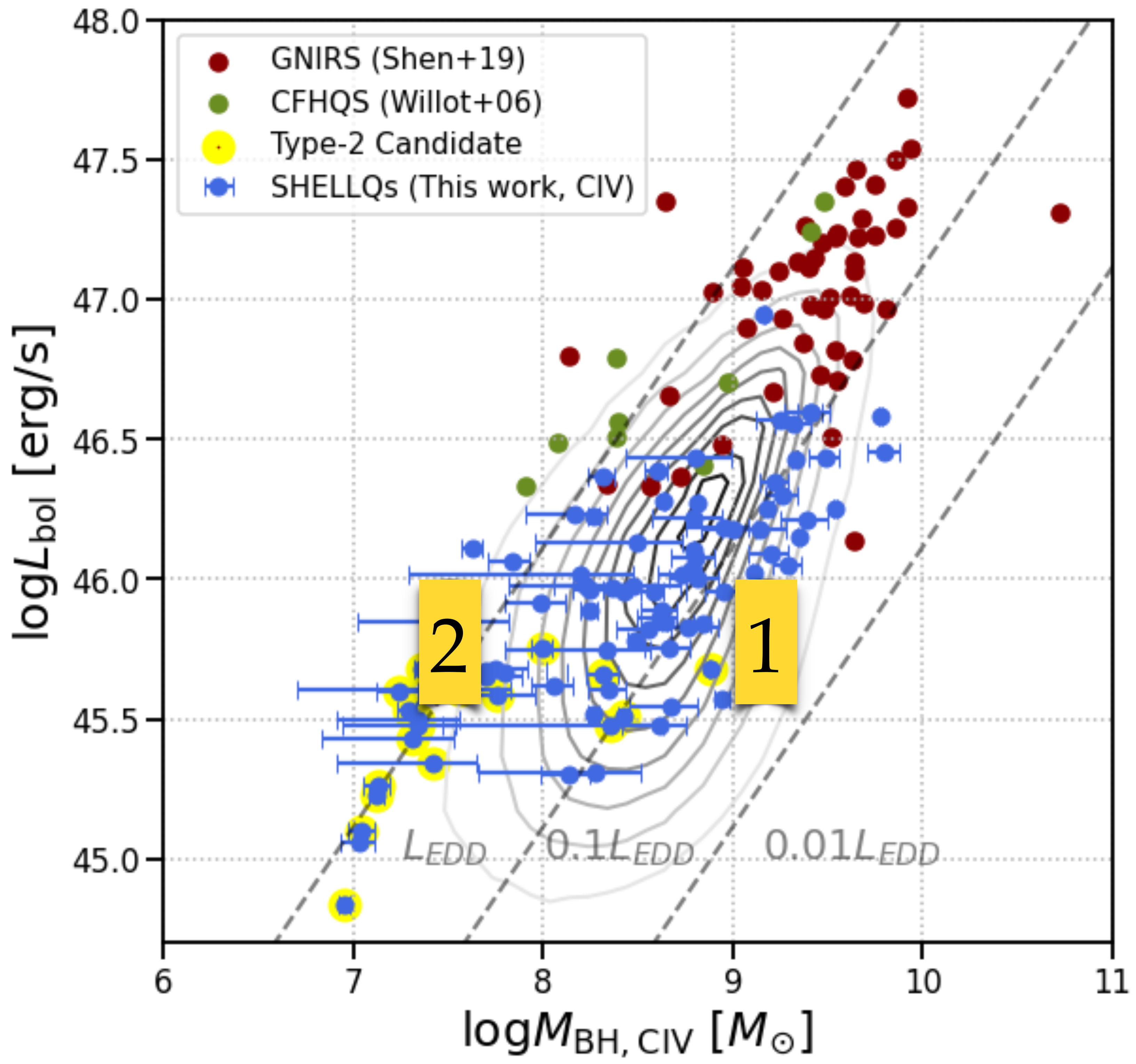
Most of seed are in the Pop-III remnants

Estimated growth history of SHELLQs quasars

L_{EDD}/L_{BOL} = each observed values

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





High-z & typical quasars are divided into different activity phases

1. In the less active phase. These should have a growth path with higher Eddington ratios in the past from z= 30 to z~6.
2. In the young, active phase. Some of these should have a growth path with lower Eddington ratios from z= 30 to z ~6

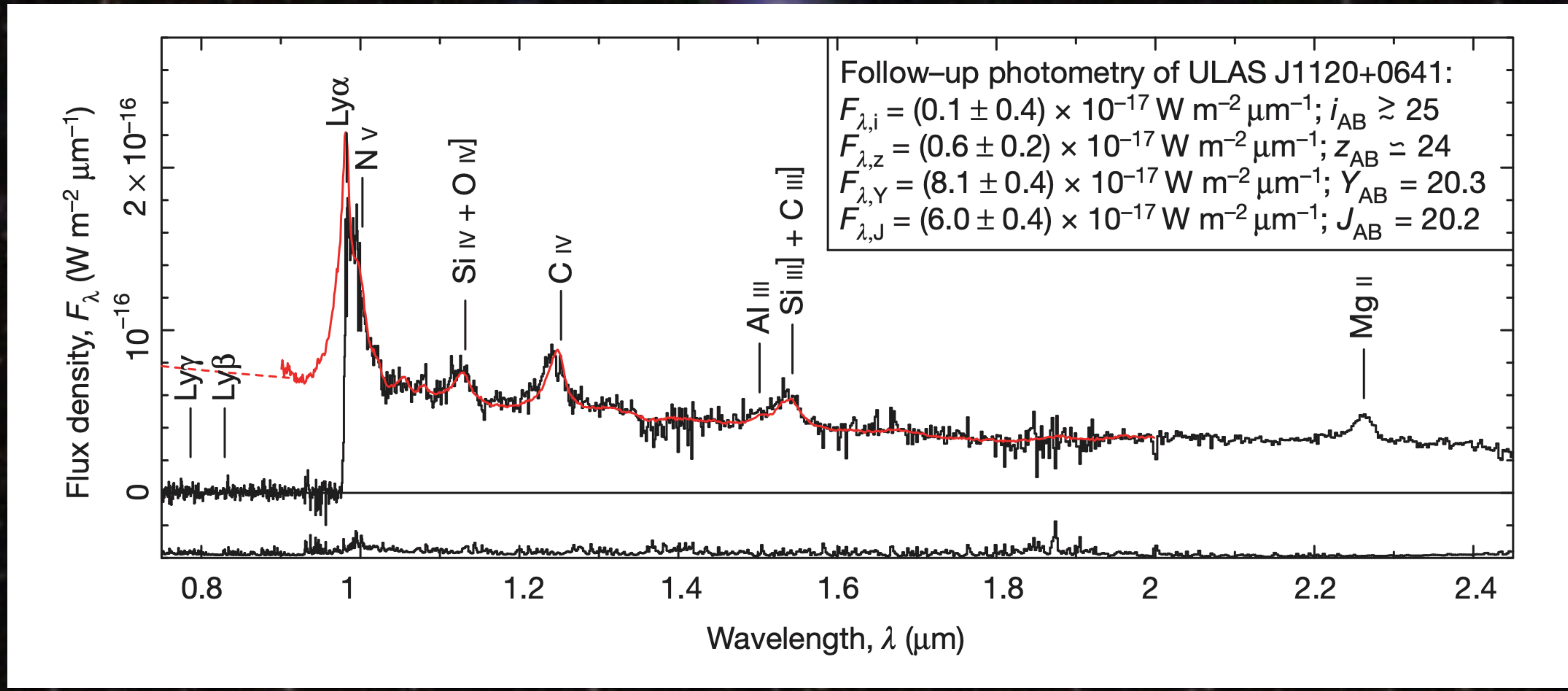
What is the spectral properties of typical quasars at high-z ?

Comparison of high-z QSOs and low-z QSOs

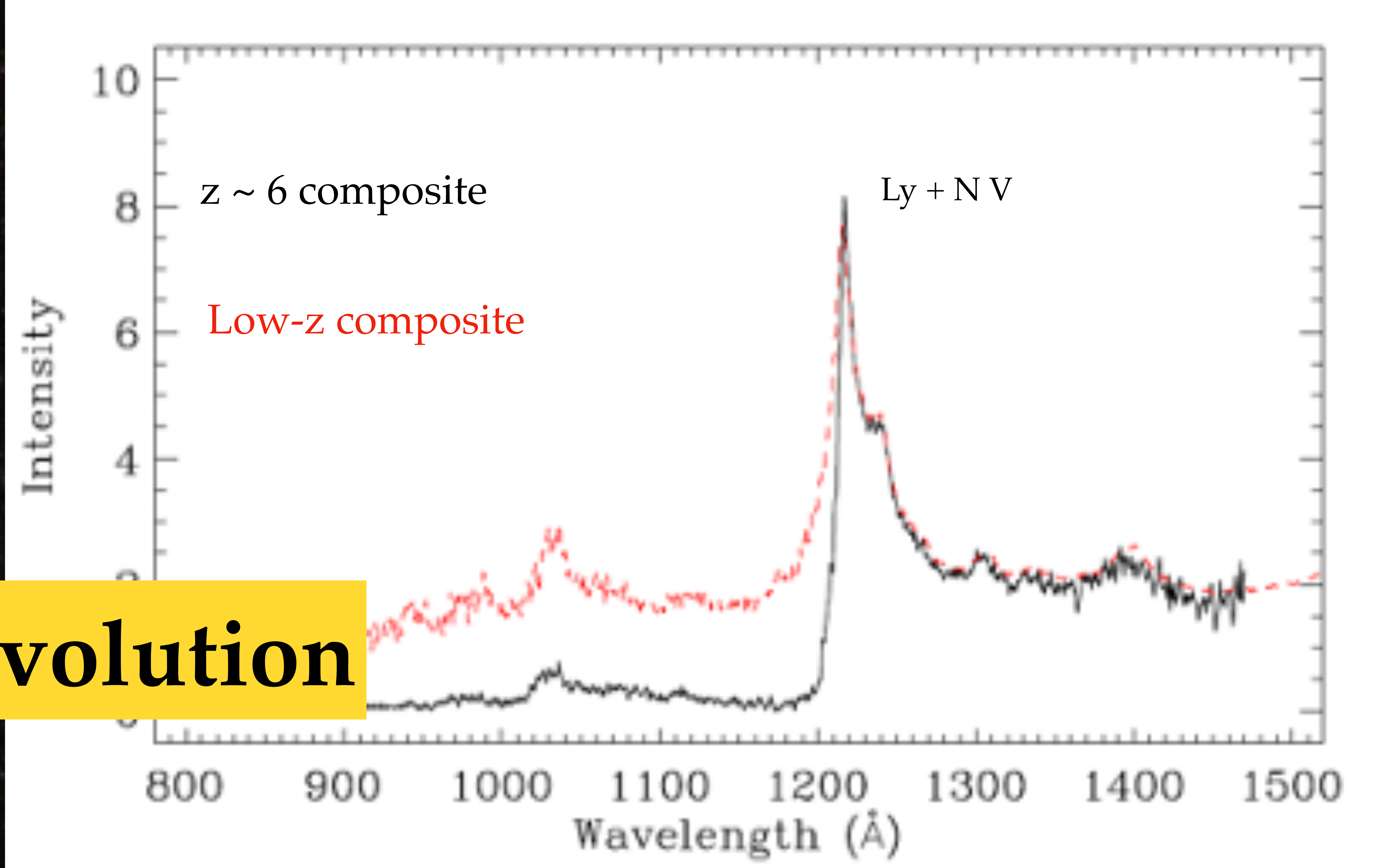
-Previous studies-

z = 7.1 quasar
z ~ 2 composite

Mortlock+11

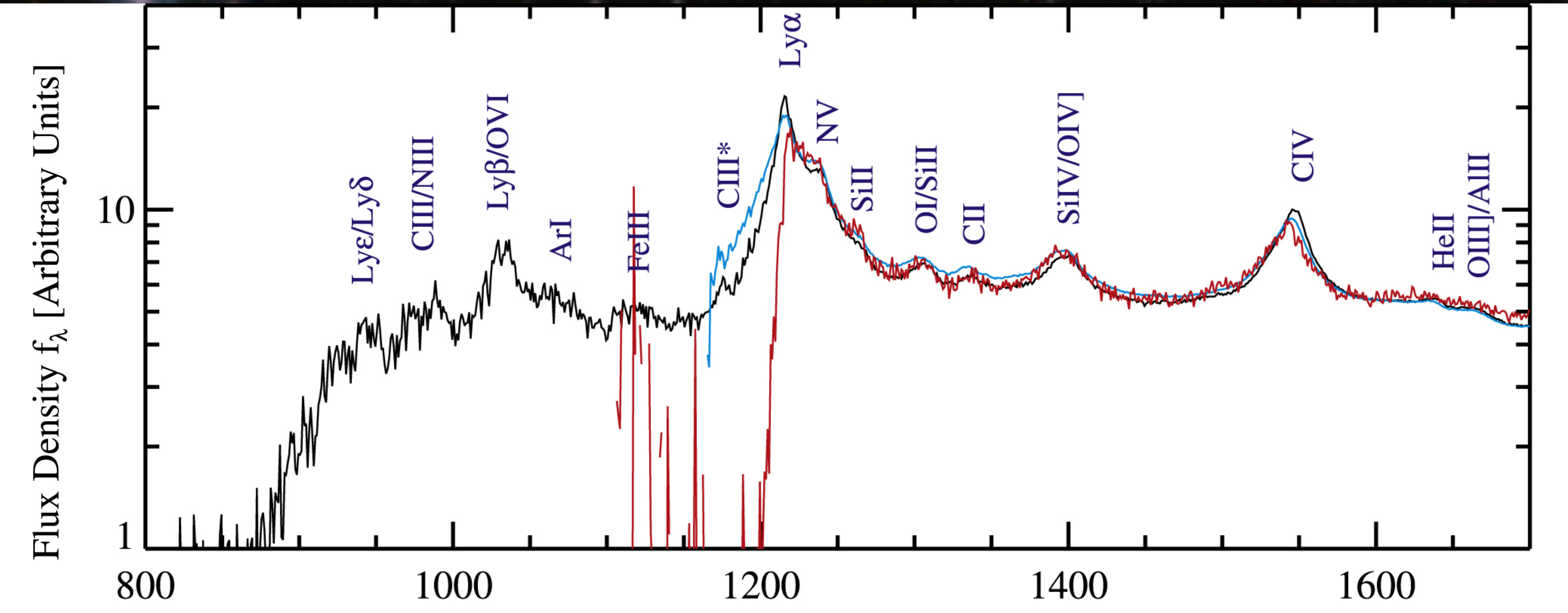


C: Fan-san's slide (Fan+10)



No redshift evolution

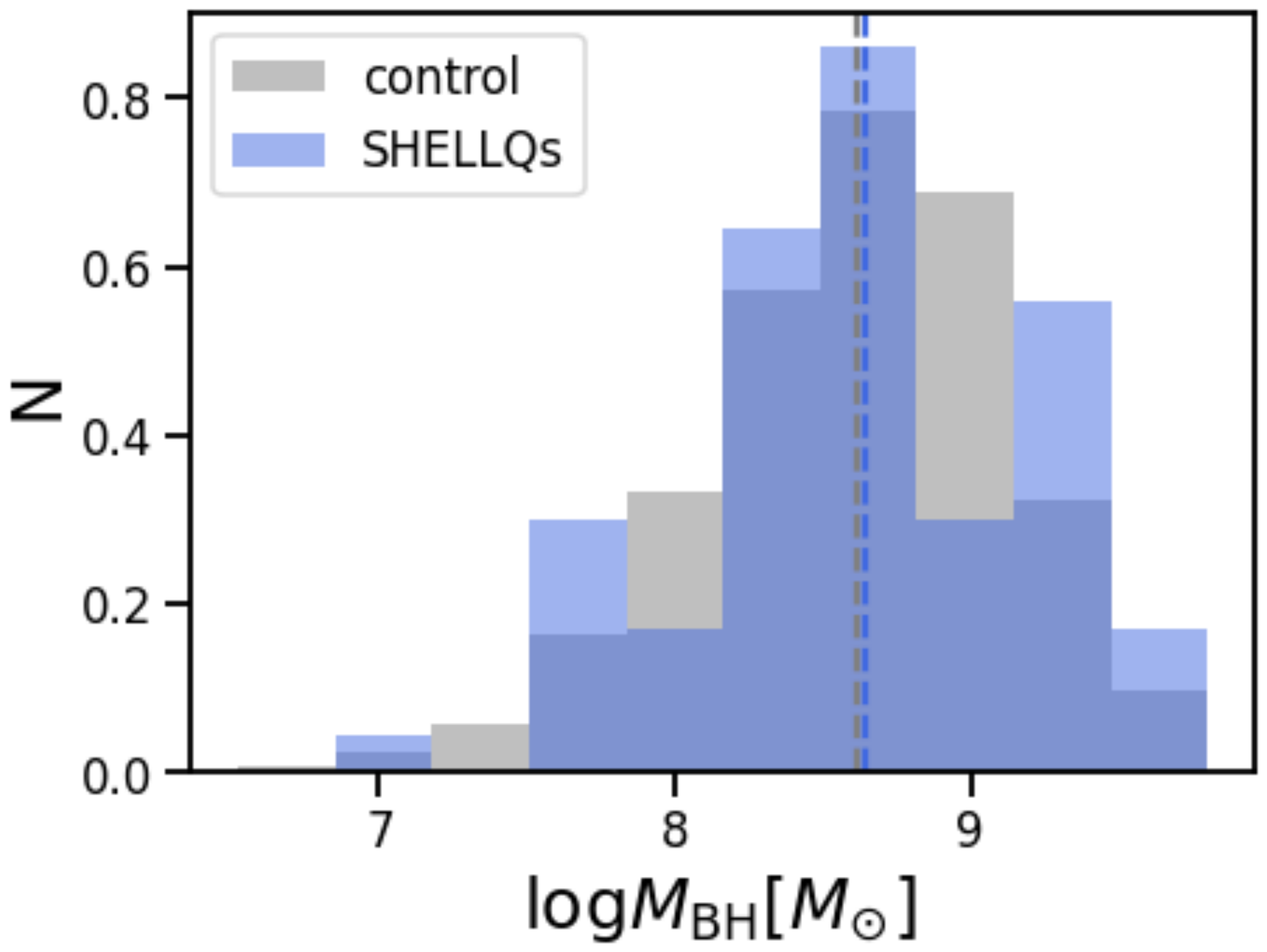
z ~ 6 quasars
Low-z luminosity-matched quasars
The sample in Vanden Berk+01

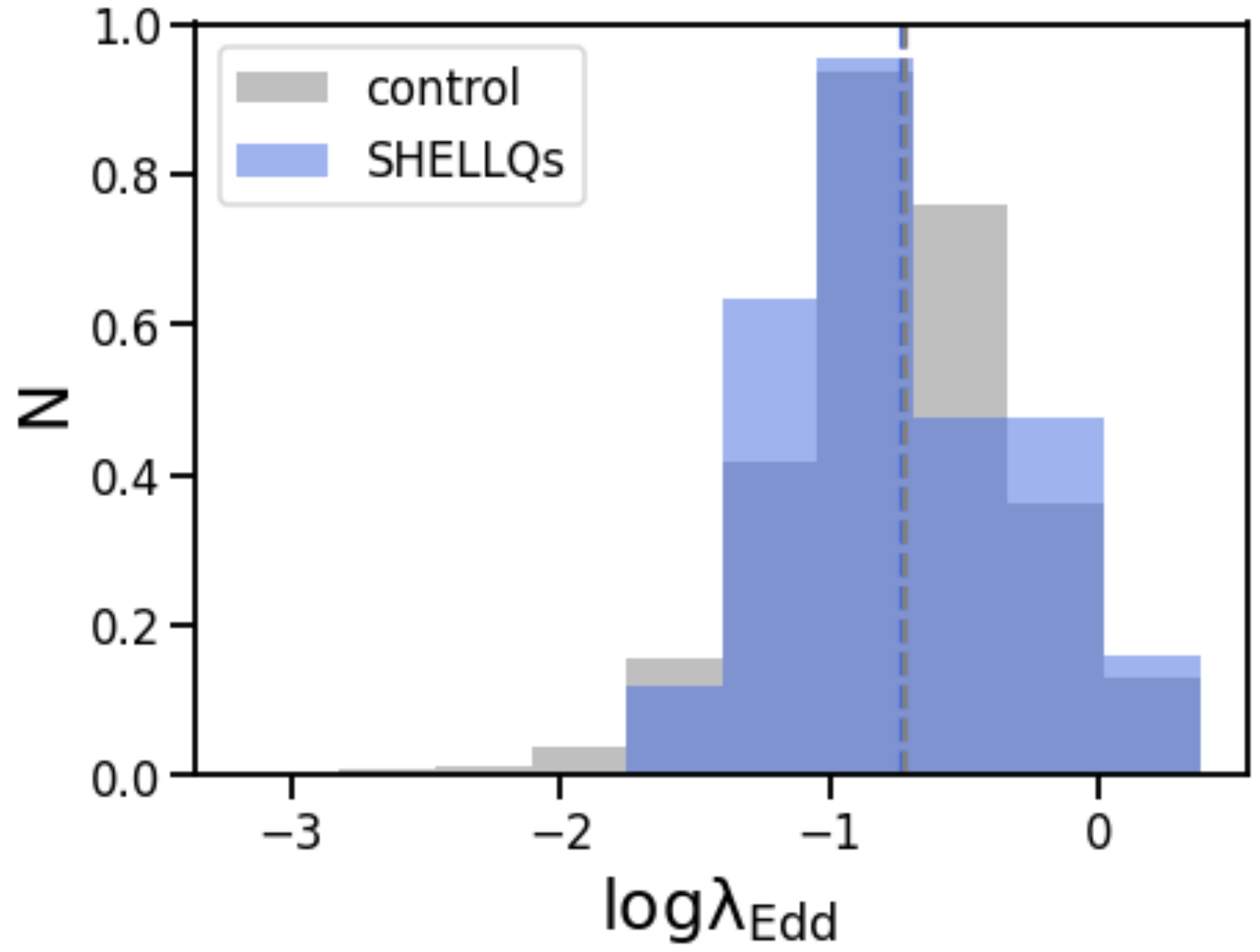


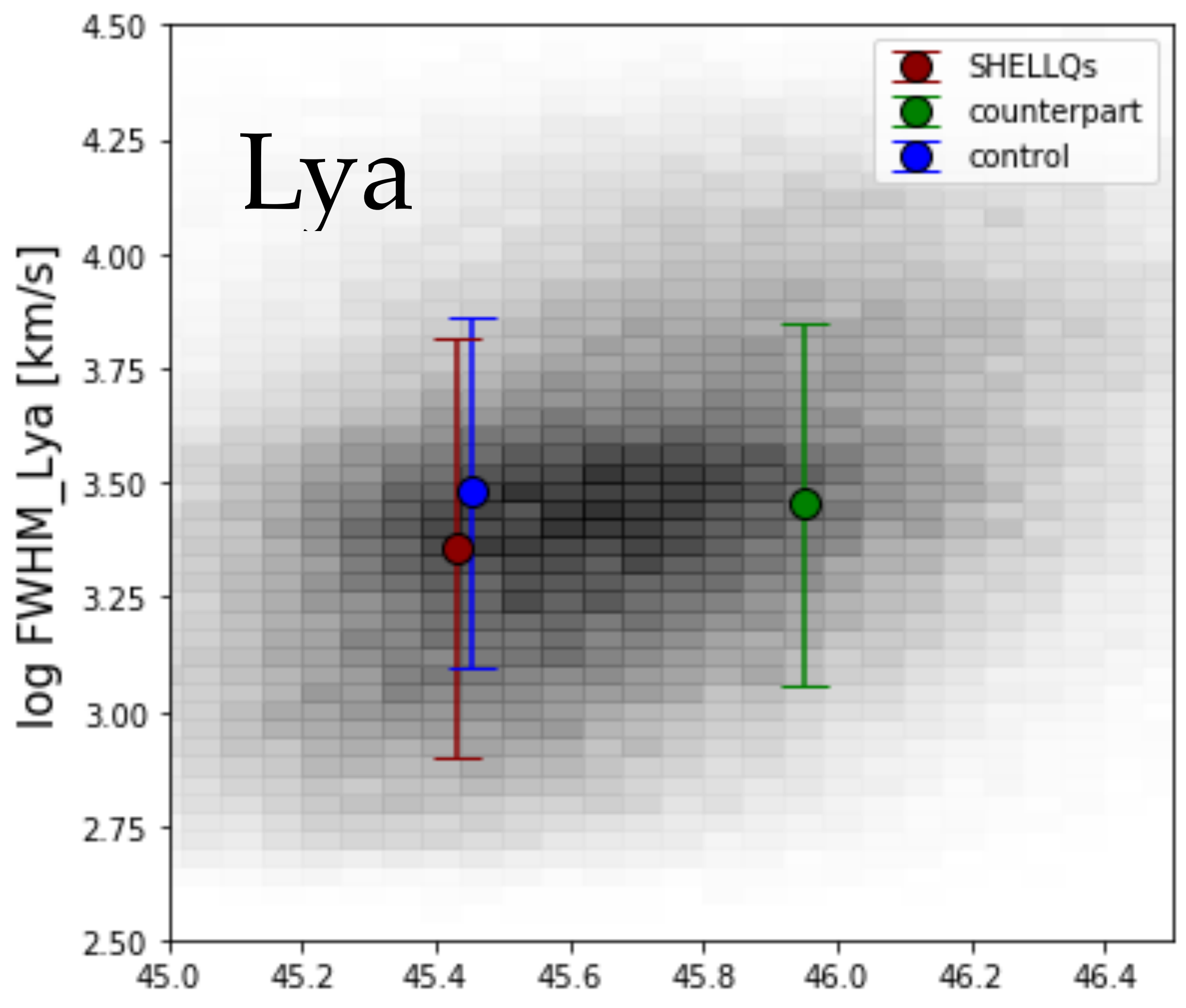
Many of high-z quasar studies show results that there is no redshift evolution of quasars in the rest-UV spectra.

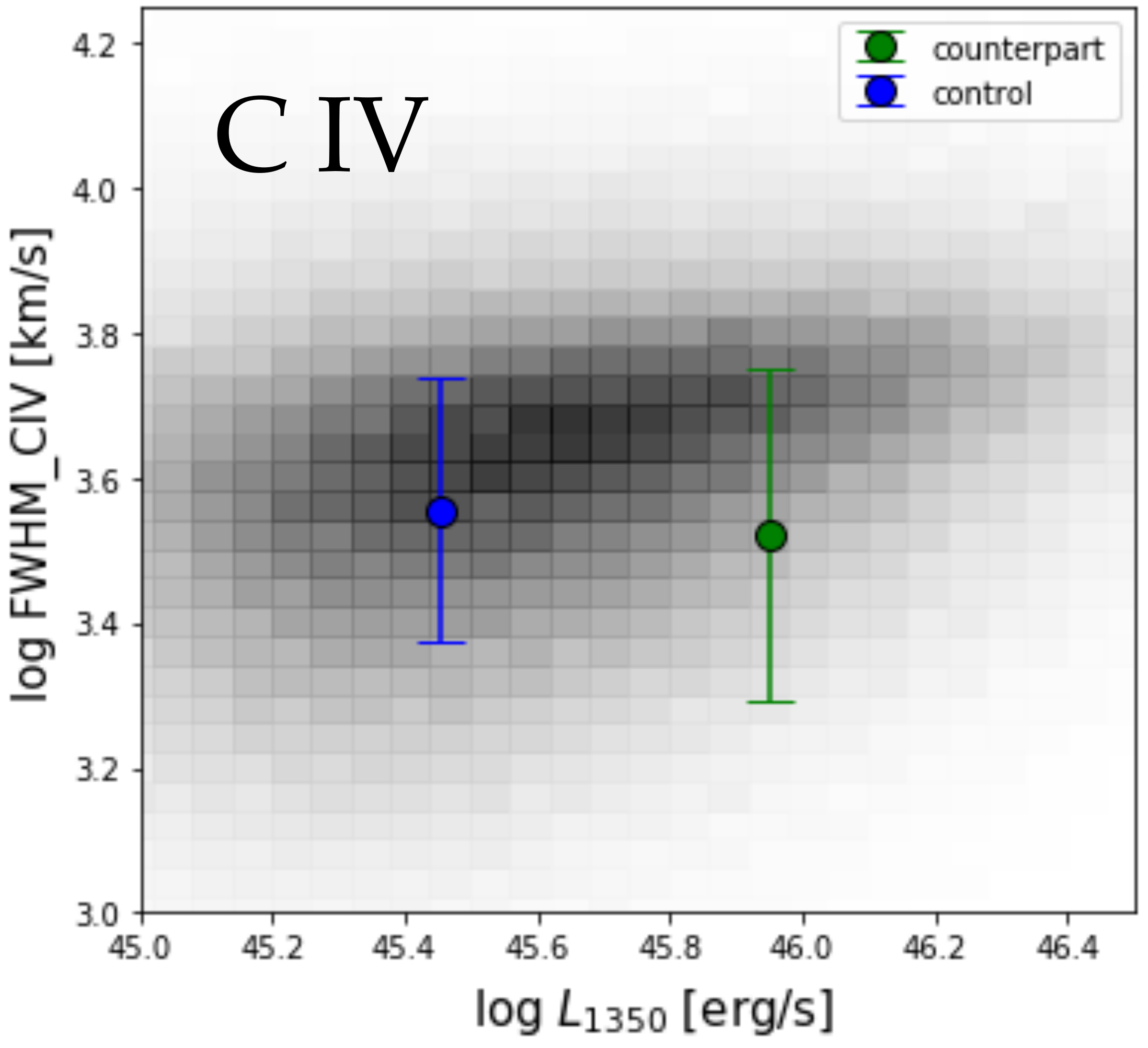
Comparison of high-z QSOs and low-z QSOs/Emission profiles

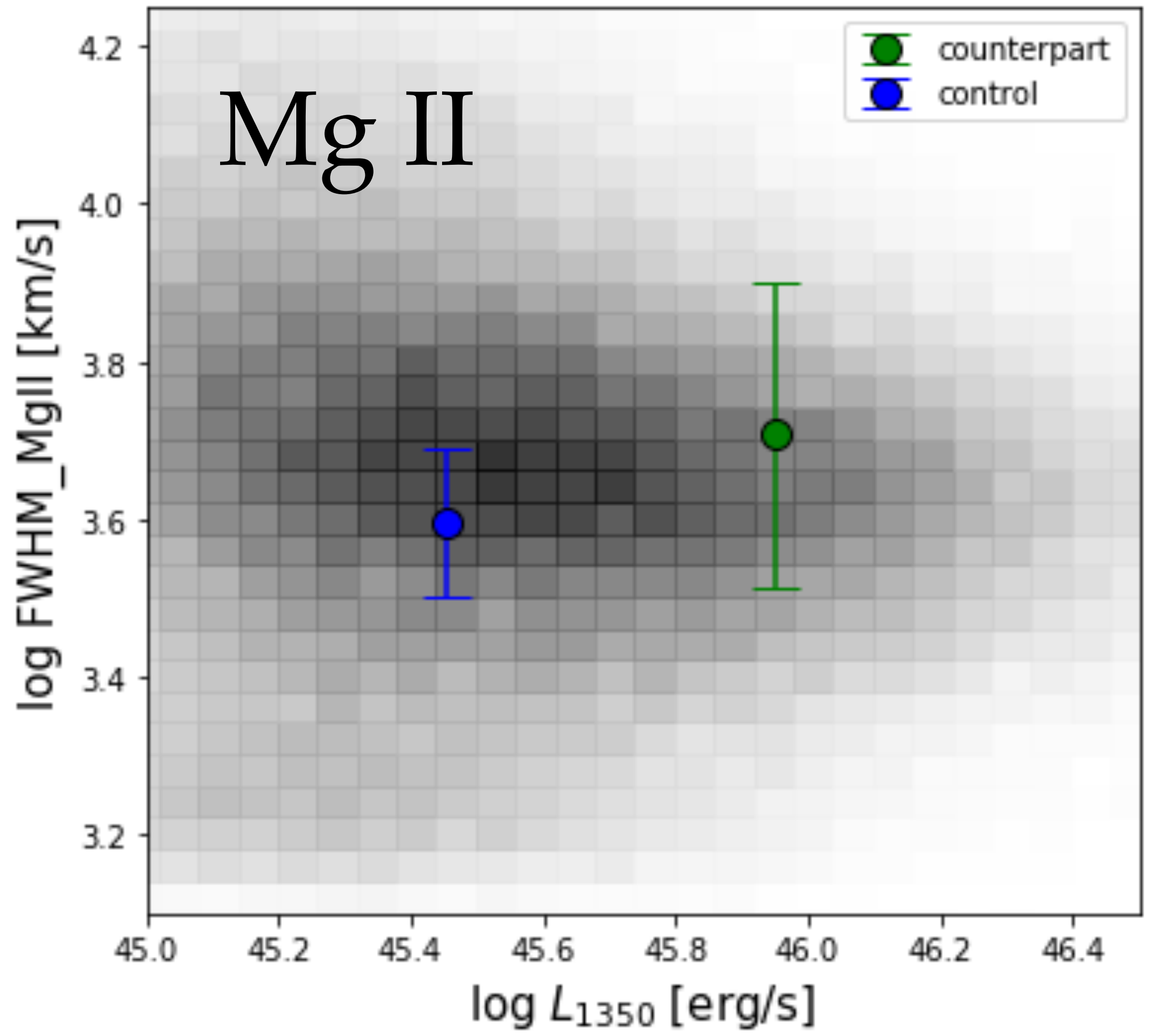
- Create luminosity-matched low-z QSOs (control) sample with SHELLQs sample
- Create composite spectra of three samples (SHELLQs, counterparts, control)











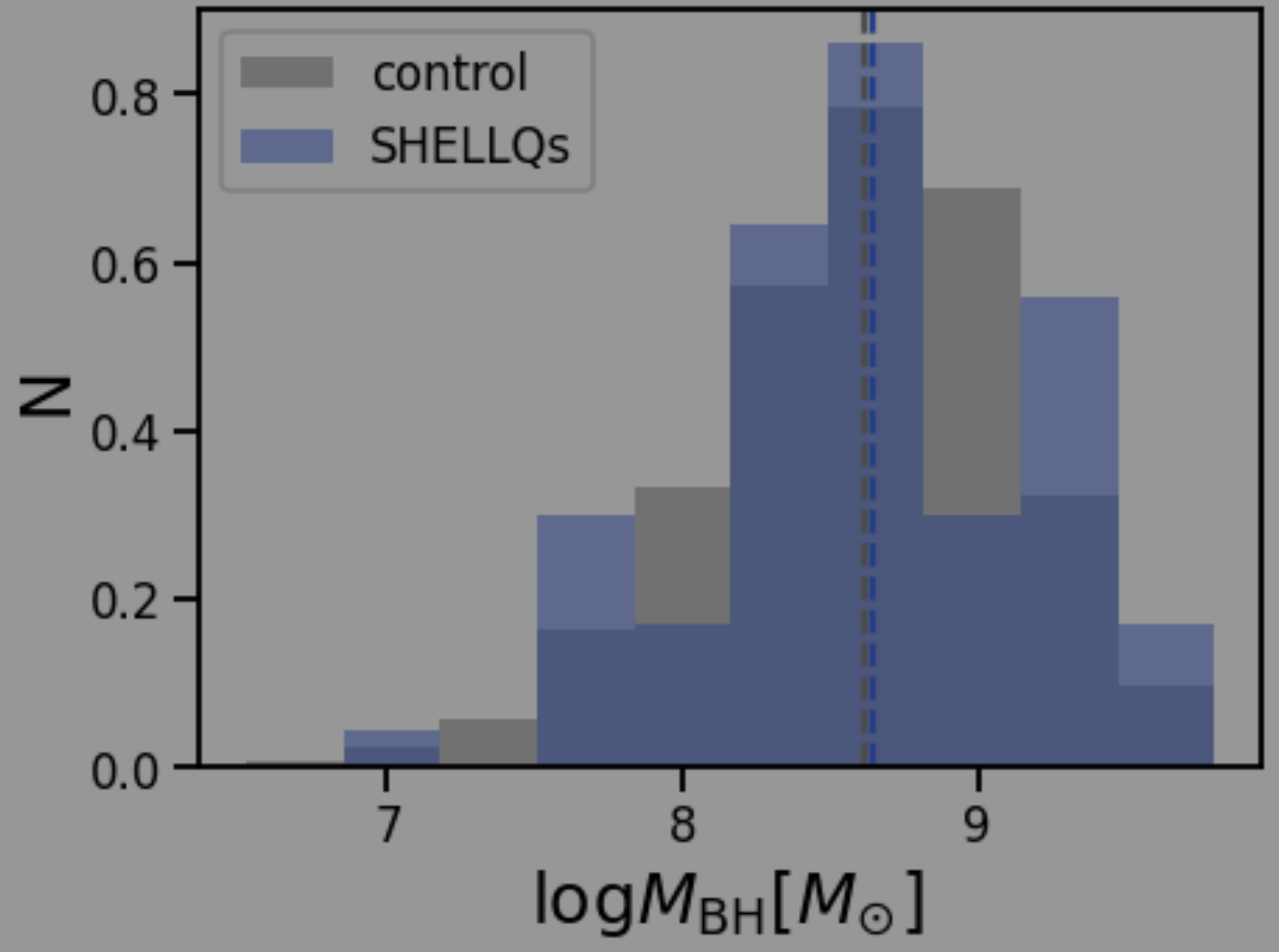
No difference!

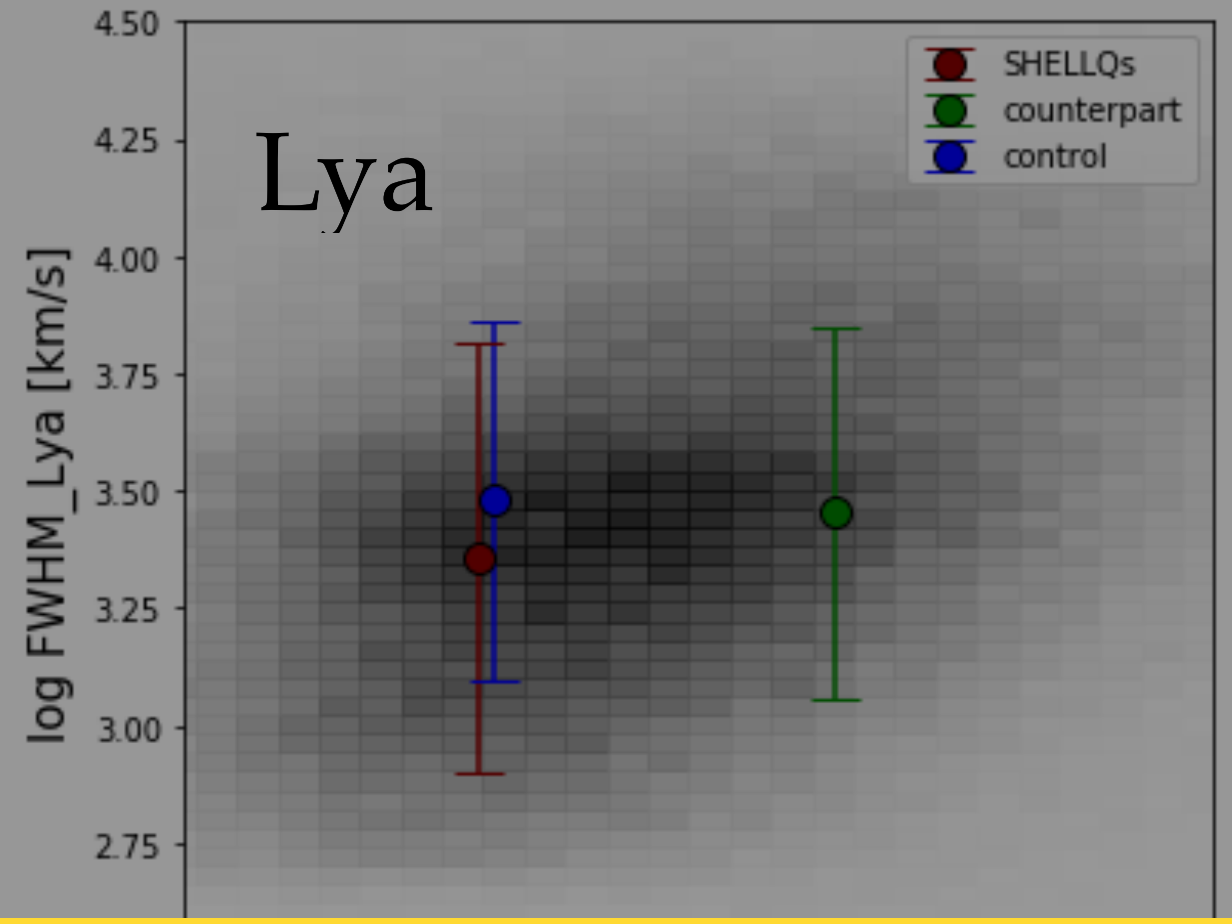
They are consistent within 1σ uncertainty with each other.

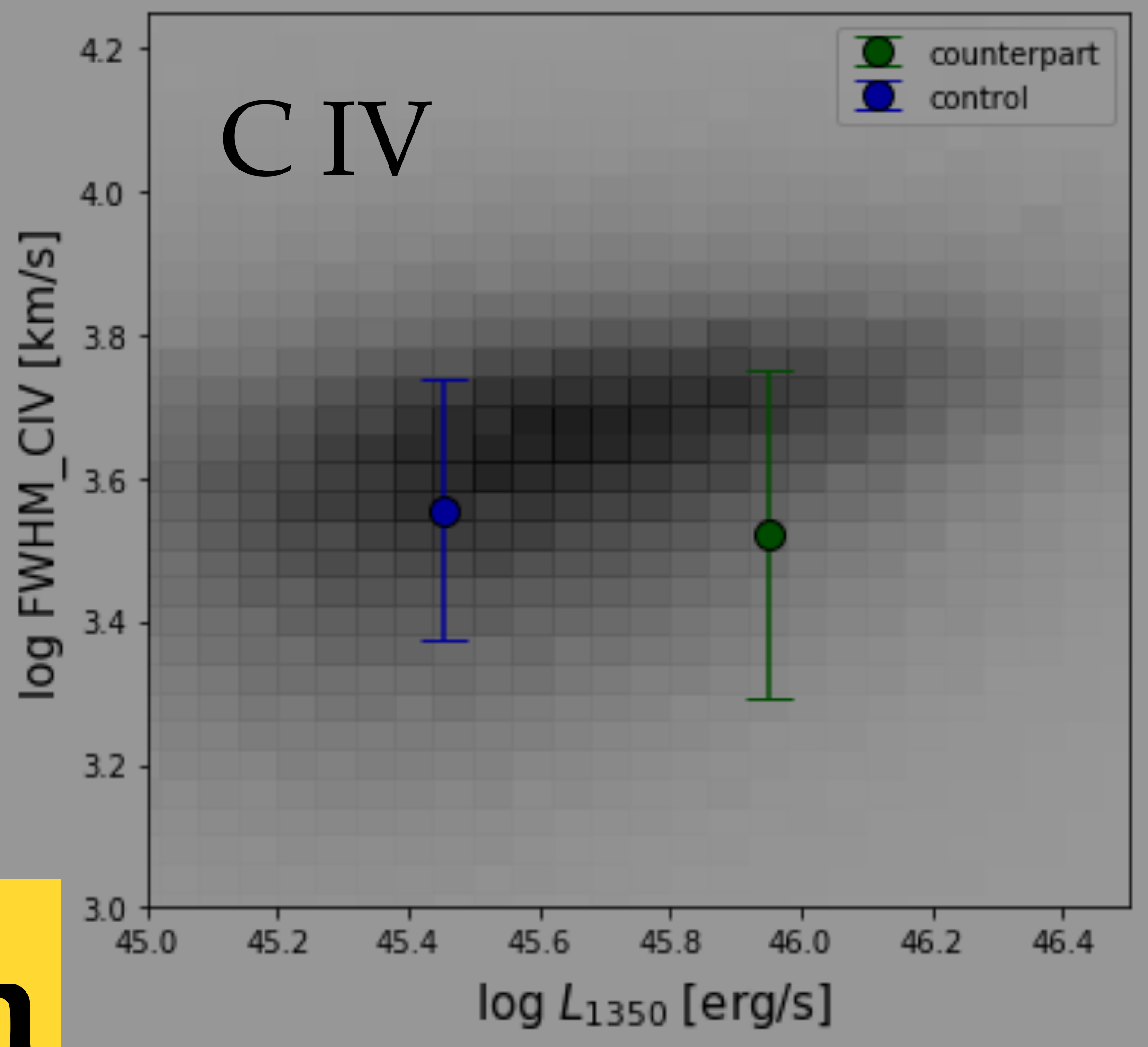
This means there is no significant difference between high-z and low-z quasars, which is consistent with the previous studies.

Comparison of high-z QSOs and low-z QSOs/Emission profiles

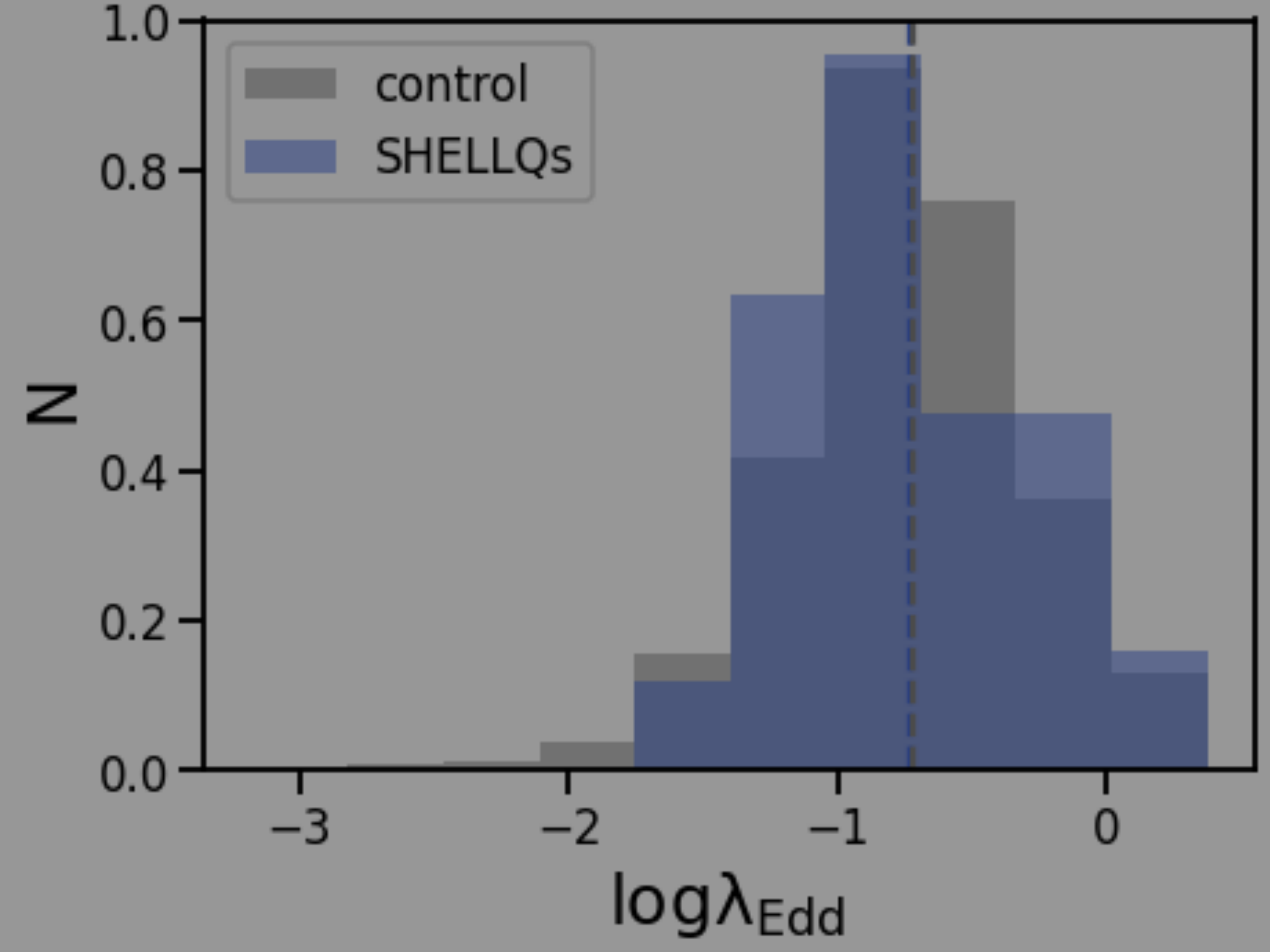
- Create luminosity-matched low-z QSOs (control) sample with SHELLQs sample
- Create composite spectra of three samples (SHELLQs, counterparts, control)

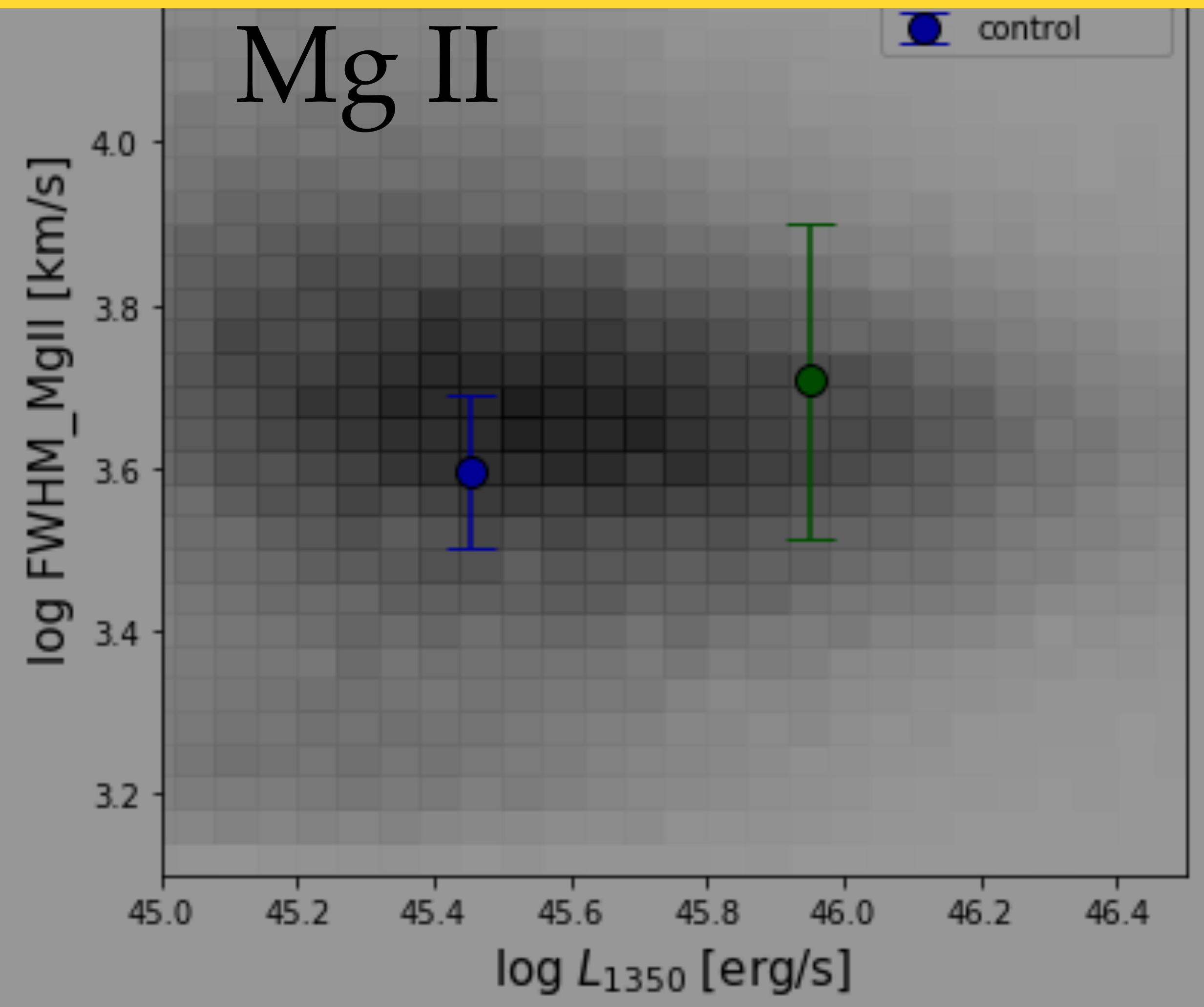






No redshift evolution





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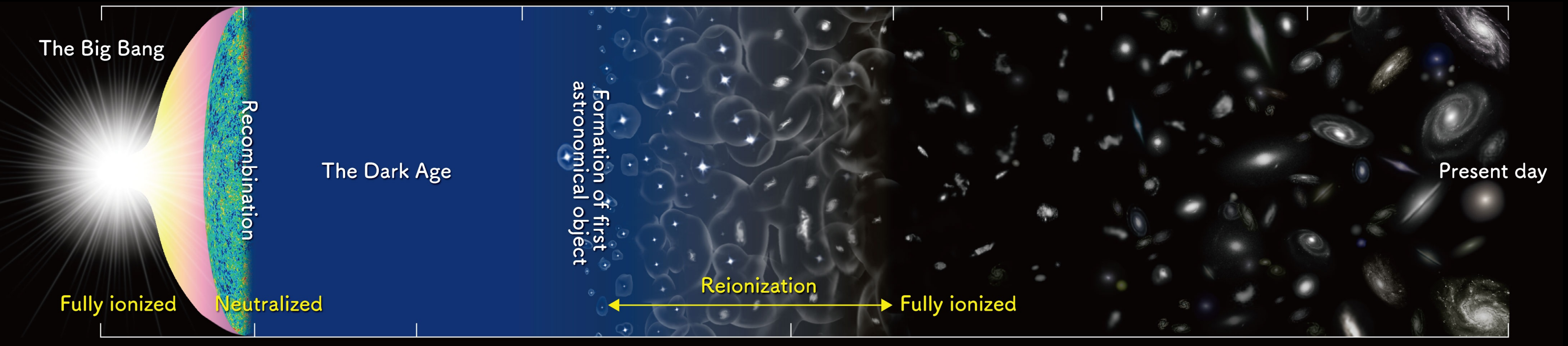
FUTURE PROSPECTS



- Confirm the predicted properties of our sample with the actual NIR-spec (especially the lowest candidate!)
- Investigate host properties of quasars at the low-mass side of the MBH distribution (e.g., the distribution of gas, outflow, and halo masses)

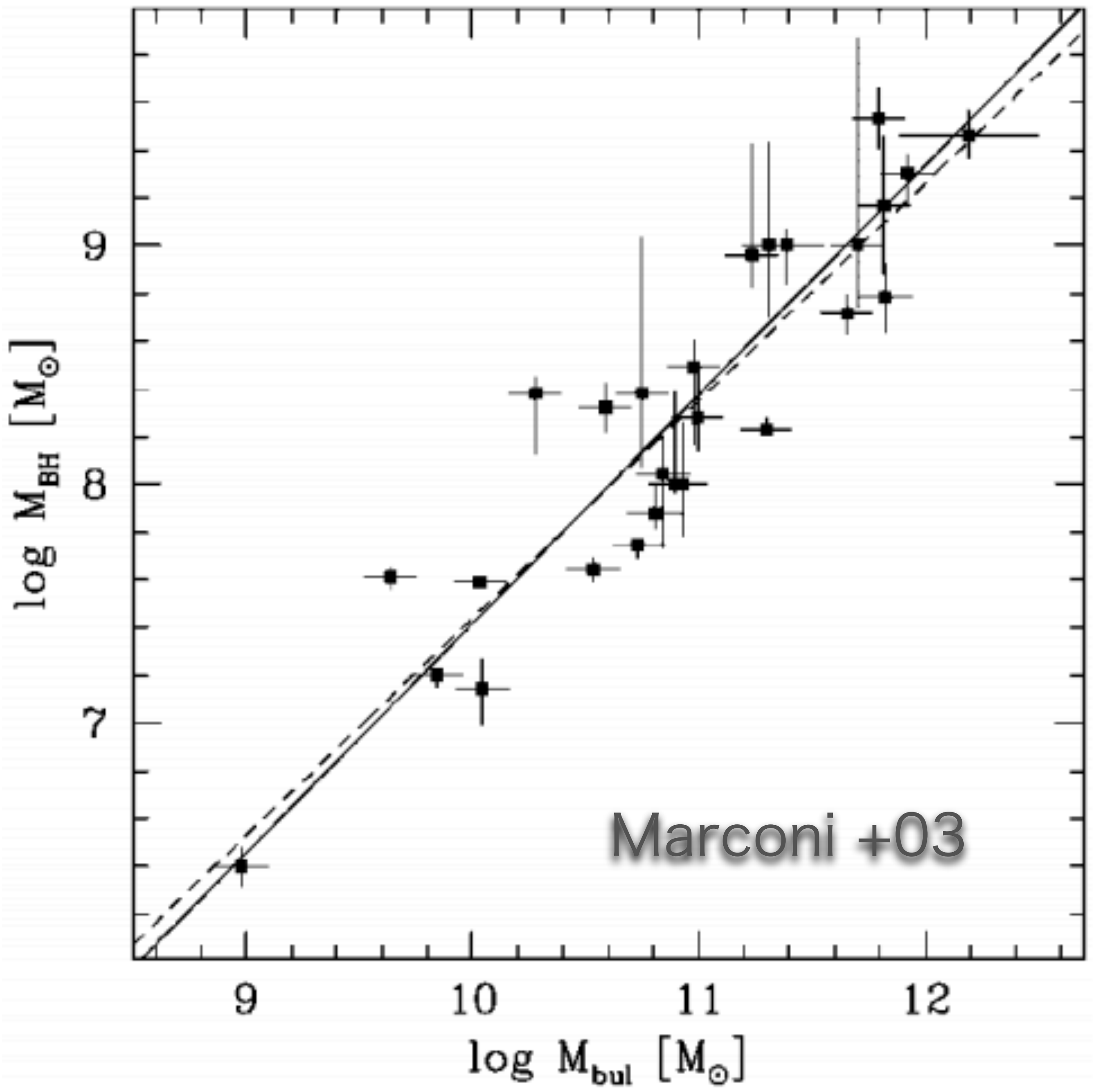
Additional reports

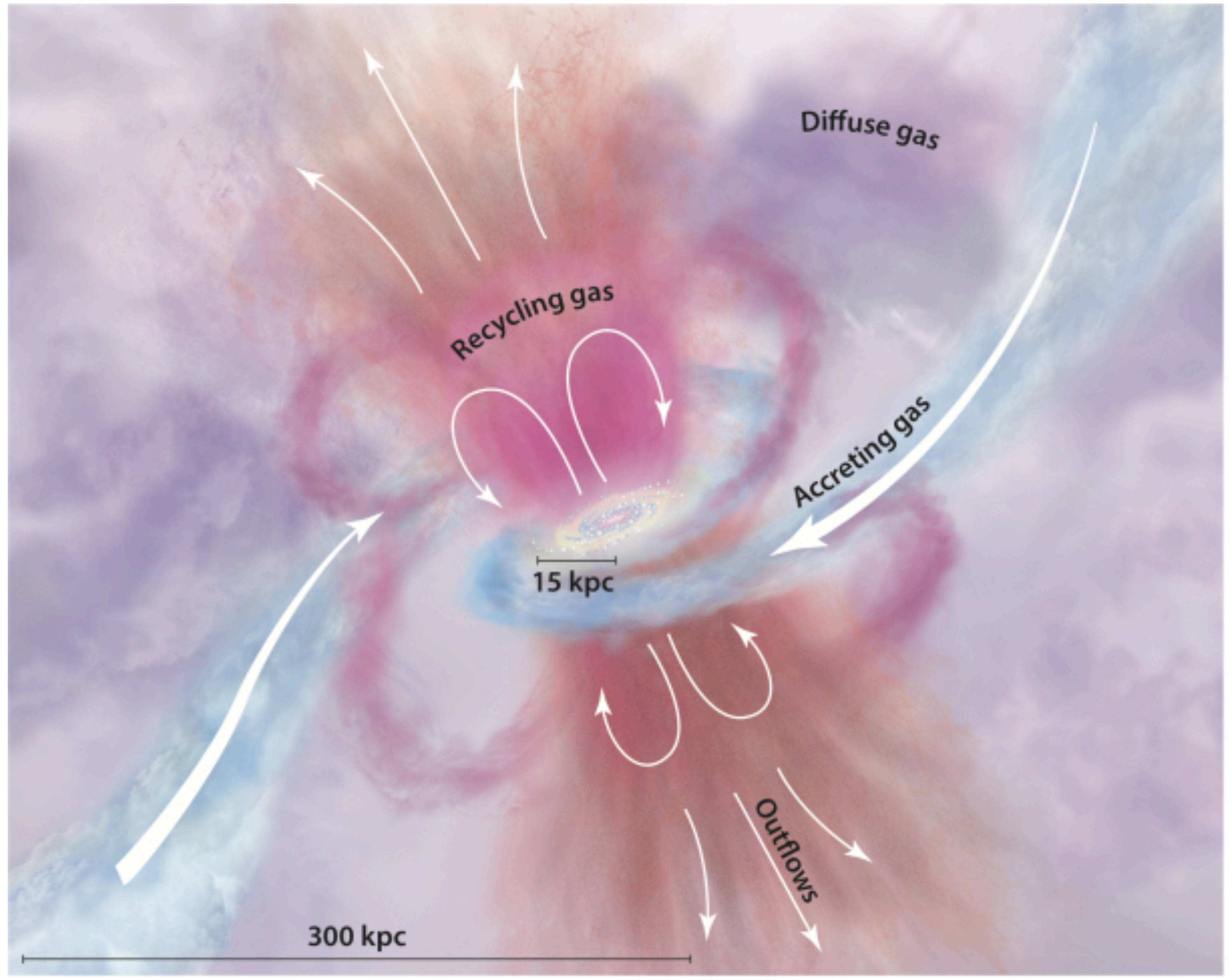
-Study of BAL quasars-

Quasar Outflow gas have arisen Broad Absorption Lines in quasar spectra

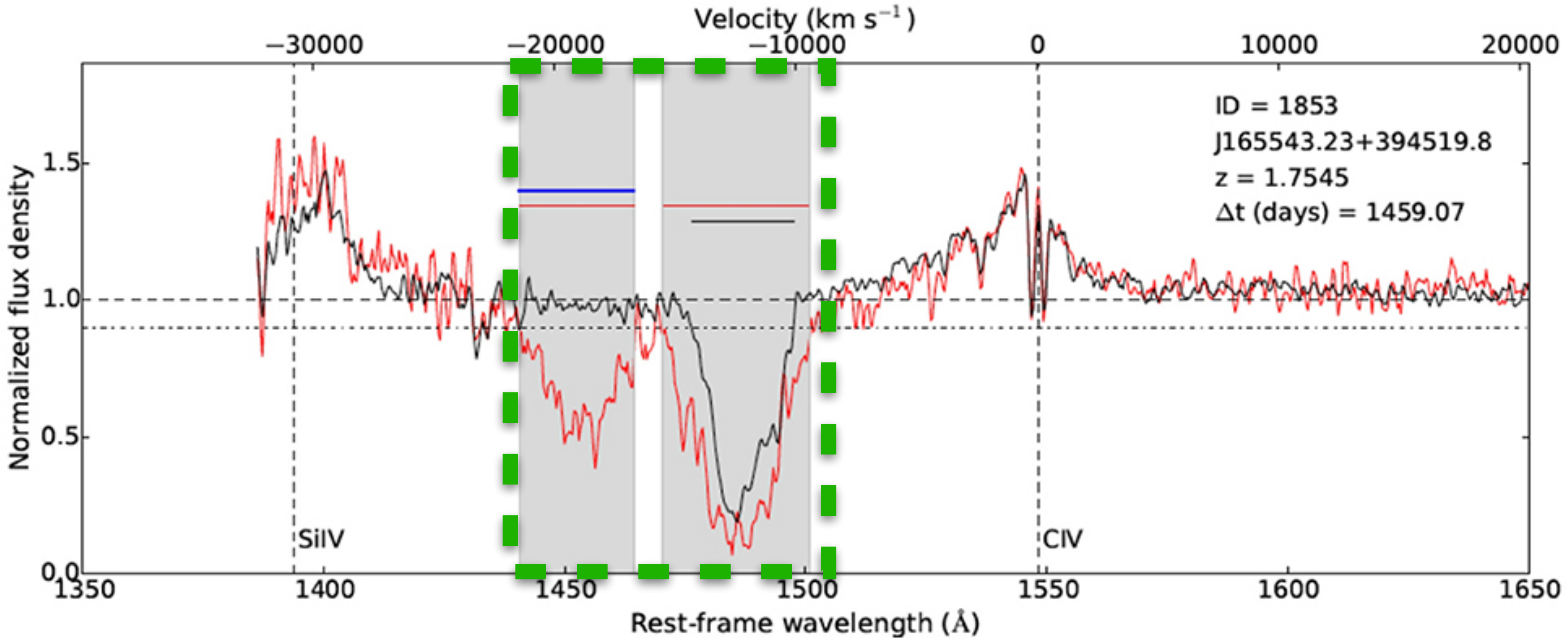
FWHM > 2000 km s^{-1}

BAL trough





Peeples & Werk (ARA&A 2017)



Broad-absorption troughs are present in spectra of about 15-40% of optically selected quasars

(e.g., Weymann et al. 1991; Knigge et al. 2008; Allen et al. 2011)

Why do we care about BAL features?

✦There are the possible that BALs are related to very high velocity gas outflow

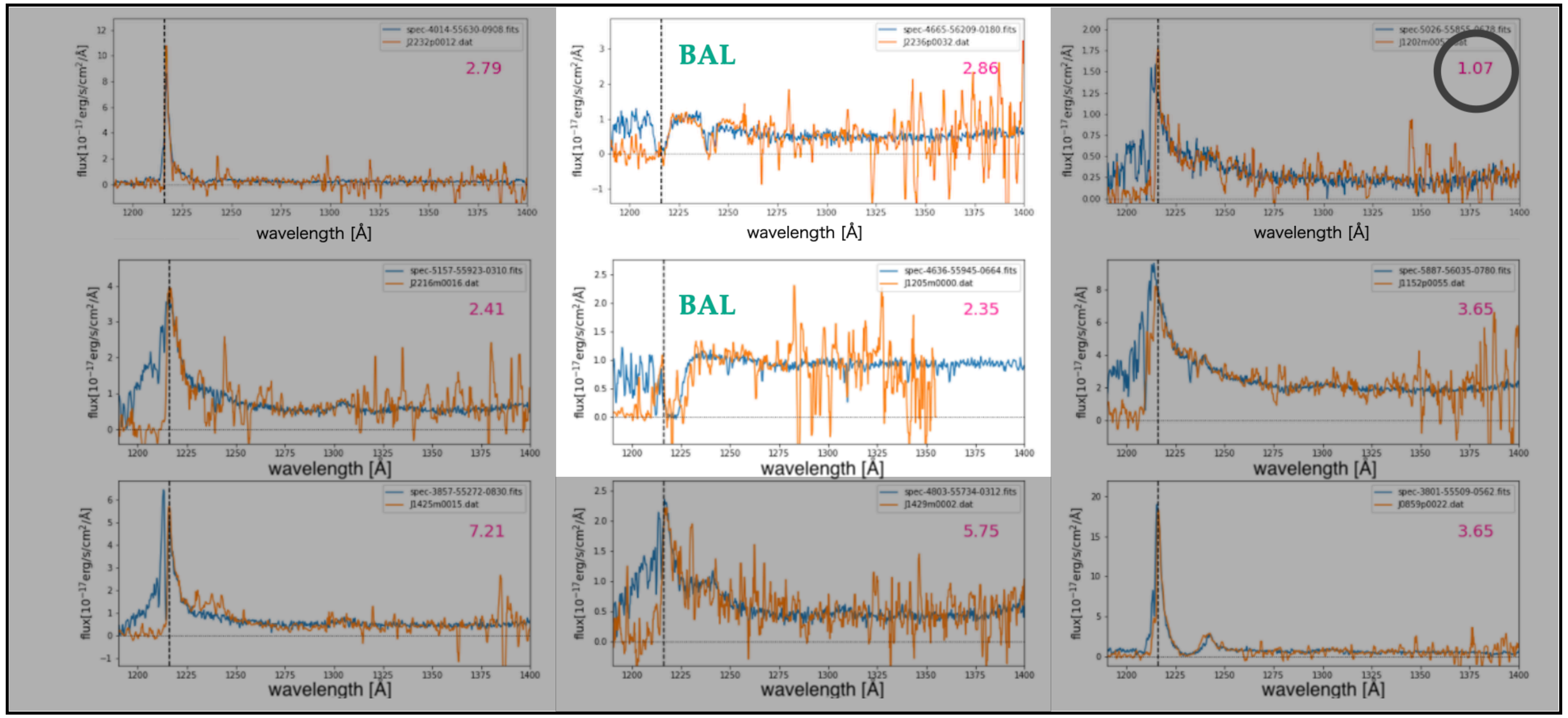
✦Outflow likely effect the accretion process onto SMBH, as well as galaxy evolution

✦BAL quasars could represent an early stage in the lifetime of the quasar.

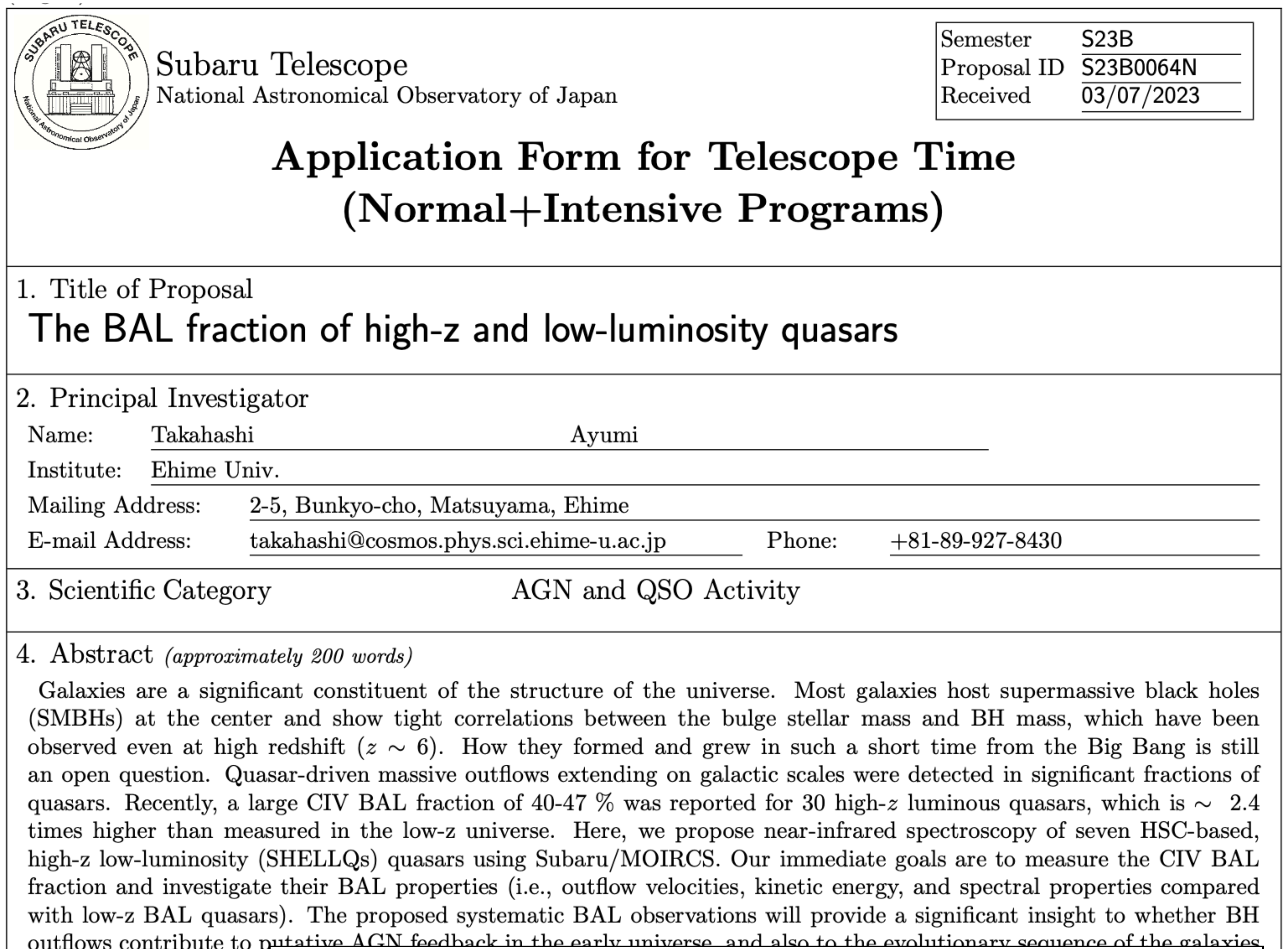
Proposal: **BAL study in SHELLQs sample (pilot study)**

-The temporal BAL fraction is less than 20 % in visual inspect with Lya and Nv

- Red QSOs (Kato et al. 2020), radiation boost efficiency (Costa +18)



We submitted BAL proposal in this semester!



Subaru Telescope
National Astronomical Observatory of Japan

Semester	S23B
Proposal ID	S23B0064N
Received	03/07/2023

Application Form for Telescope Time
(Normal+Intensive Programs)

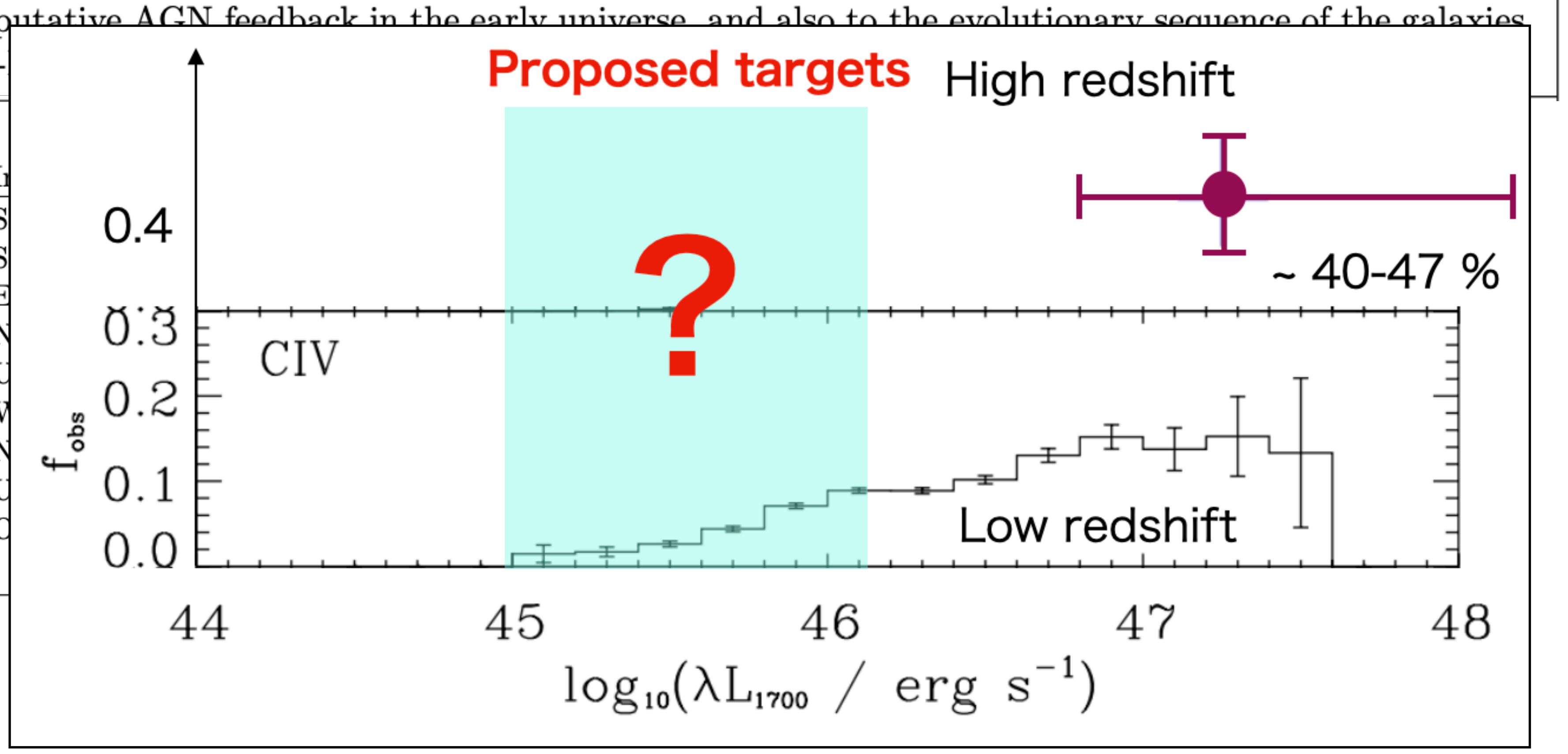
1. Title of Proposal
The BAL fraction of high-z and low-luminosity quasars

2. Principal Investigator
Name: Takahashi Ayumi
Institute: Ehime Univ.
Mailing Address: 2-5, Bunkyo-cho, Matsuyama, Ehime
E-mail Address: takahashi@cosmos.phys.sci.ehime-u.ac.jp Phone: +81-89-927-8430

3. Scientific Category AGN and QSO Activity

4. Abstract *(approximately 200 words)*
Galaxies are a significant constituent of the structure of the universe. Most galaxies host supermassive black holes (SMBHs) at the center and show tight correlations between the bulge stellar mass and BH mass, which have been observed even at high redshift ($z \sim 6$). How they formed and grew in such a short time from the Big Bang is still an open question. Quasar-driven massive outflows extending on galactic scales were detected in significant fractions of quasars. Recently, a large CIV BAL fraction of 40-47 % was reported for 30 high-z luminous quasars, which is $\sim$ 2.4 times higher than measured in the low-z universe. Here, we propose near-infrared spectroscopy of seven HSC-based, high-z low-luminosity (SHELLQs) quasars using Subaru/MOIRCS. Our immediate goals are to measure the CIV BAL fraction and investigate their BAL properties (i.e., outflow velocities, kinetic energy, and spectral properties compared with low-z BAL quasars). The proposed systematic BAL observations will provide a significant insight to whether BH outflows contribute to putative AGN feedback in the early universe, and also to the evolutionary sequence of the galaxies hosting high-z and low-

5. Co-Investigators
Name
Akatoki Noboriguchi
Toru Misawa
Yoshiki Matsuoka
Kentaro Aoki
Nobunari Kashikawa
Chien-Hsiu Lee
Masatoshi Imanishi
Kazushi Iwasawa
Toshihiro Kawaguchi



Aims

- ✦ Measurement BAL fraction of SHELLQs sample
- ✦ Investigation whether the SMBHs of our sample influence their host galaxies through energy exchange or not
- ✦ Investigation what's the difference in BAL properties btw low-z and high-z

SUMMARY

- ✦ Investigated the properties of high-z and low-luminosity quasars statistically
- ✦ High-z quasar BH masses can be predicted by low-z quasars spectra
- ✦ There is the tight correlation of FWHM between Lya and CIV.
- ✦ We find the lowest SMBH candidate with high Eddington accretion
- ✦ Black holes can grow up to SMBH from the Pop-III star remnants in the assumption of constant Eddington accretion
- ✦ We propose NIR-observation to find lowest-mass SMBHs and to confirm our method.
- ✦ We started a statistical investigation SHELLQs × BAL