Subaru Intensive Searches for the Most Distant Quasars

Progress reports of S16B-071I & S18B-011I

Masafusa Onoue (MPIA)

Slides prepared by **Yoshiki Matsuoka** (Ehime U; *observing at Subaru now…*)

on behalf of the SHELLQs collaboration

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cancelled…

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?

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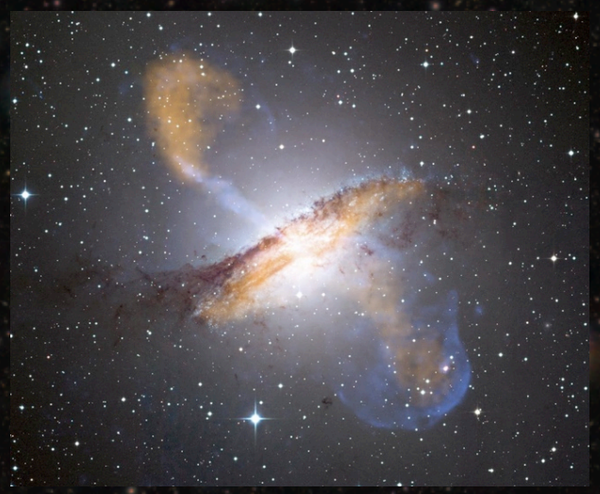

How did the host galaxies form and (co-)evolve?

✶ 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?

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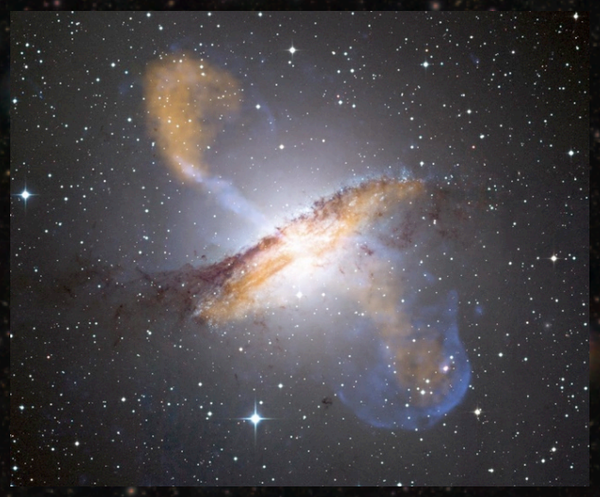

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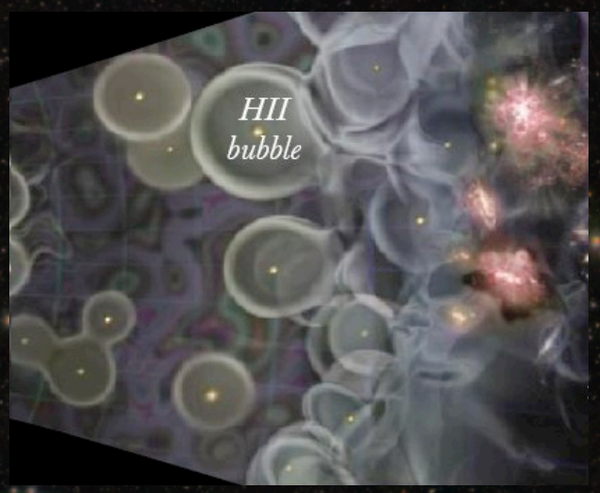
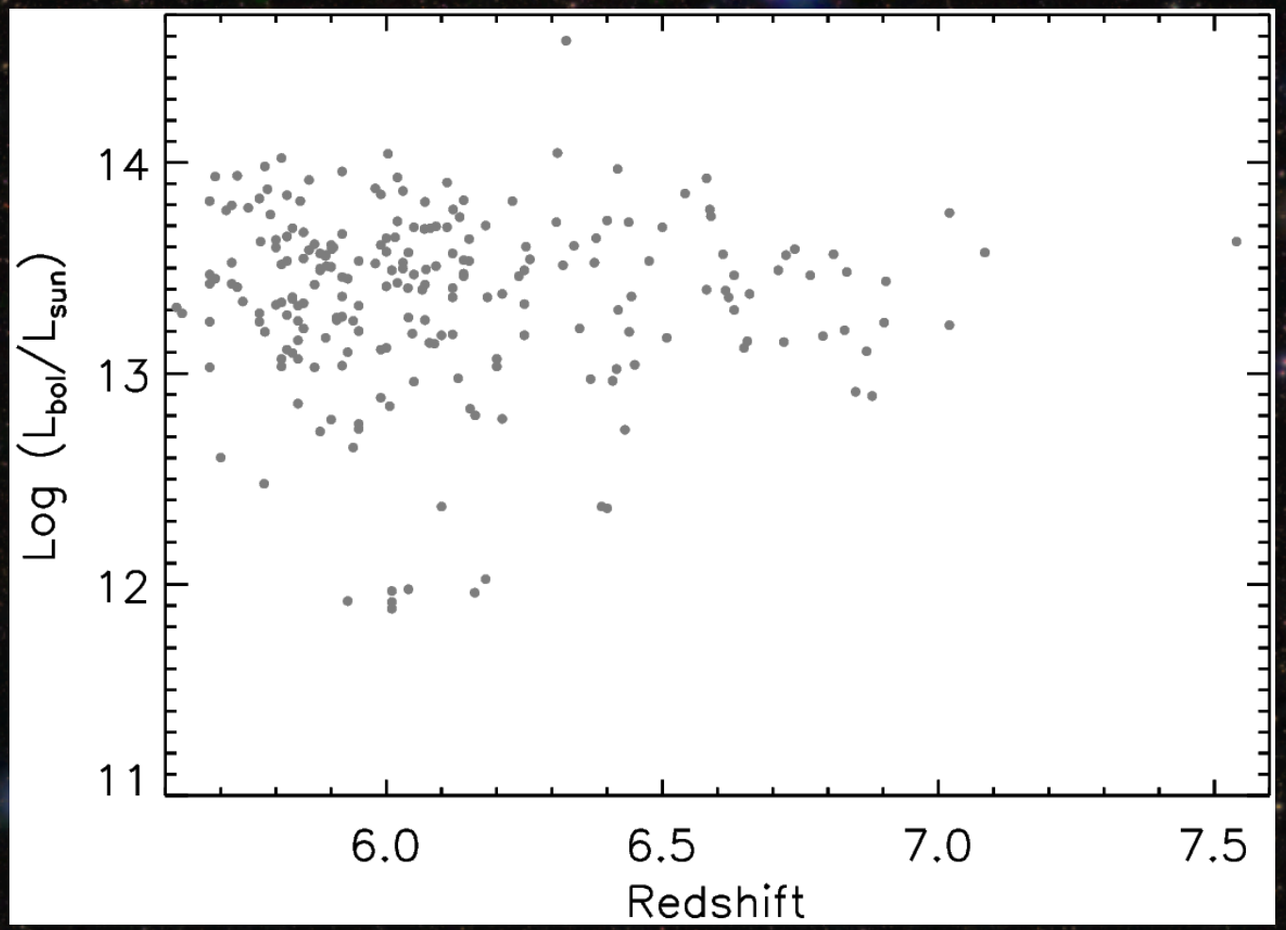
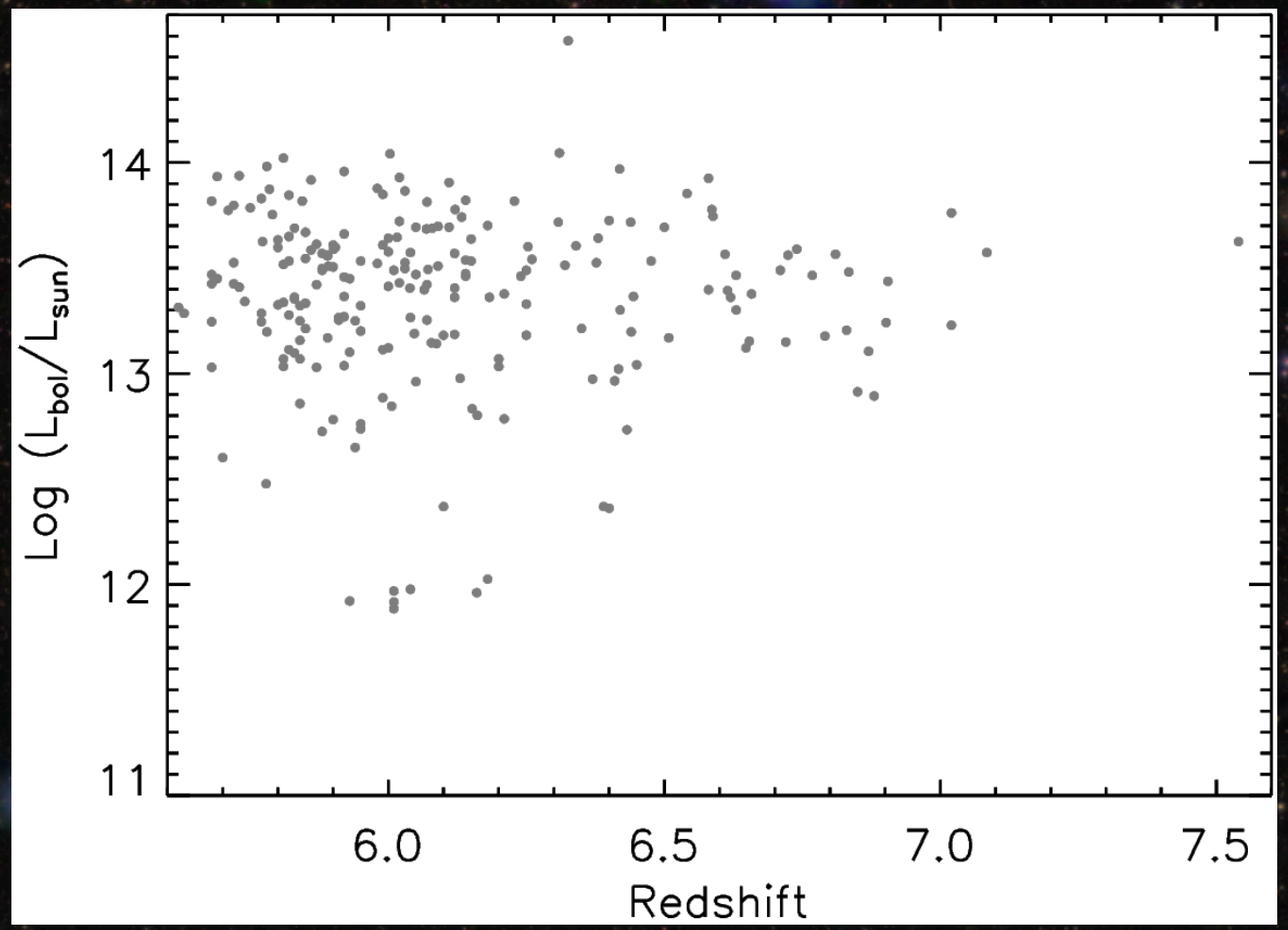


When and how was the Universe re-ionized?

✶ 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!


14
13
12
11
Log (L_{bol}/L_{sun})
6.0
6.5
7.0
7.5
Redshift



Eddington luminosity at the mass of…

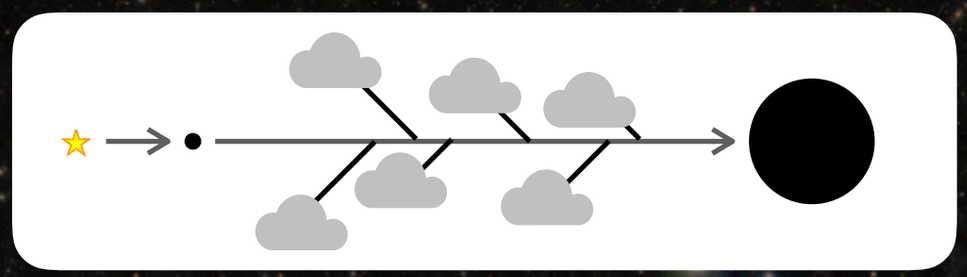
← $M_{BH} = 10^9\ M_{sun}$

← $M_{BH} = 10^8\ M_{sun}$

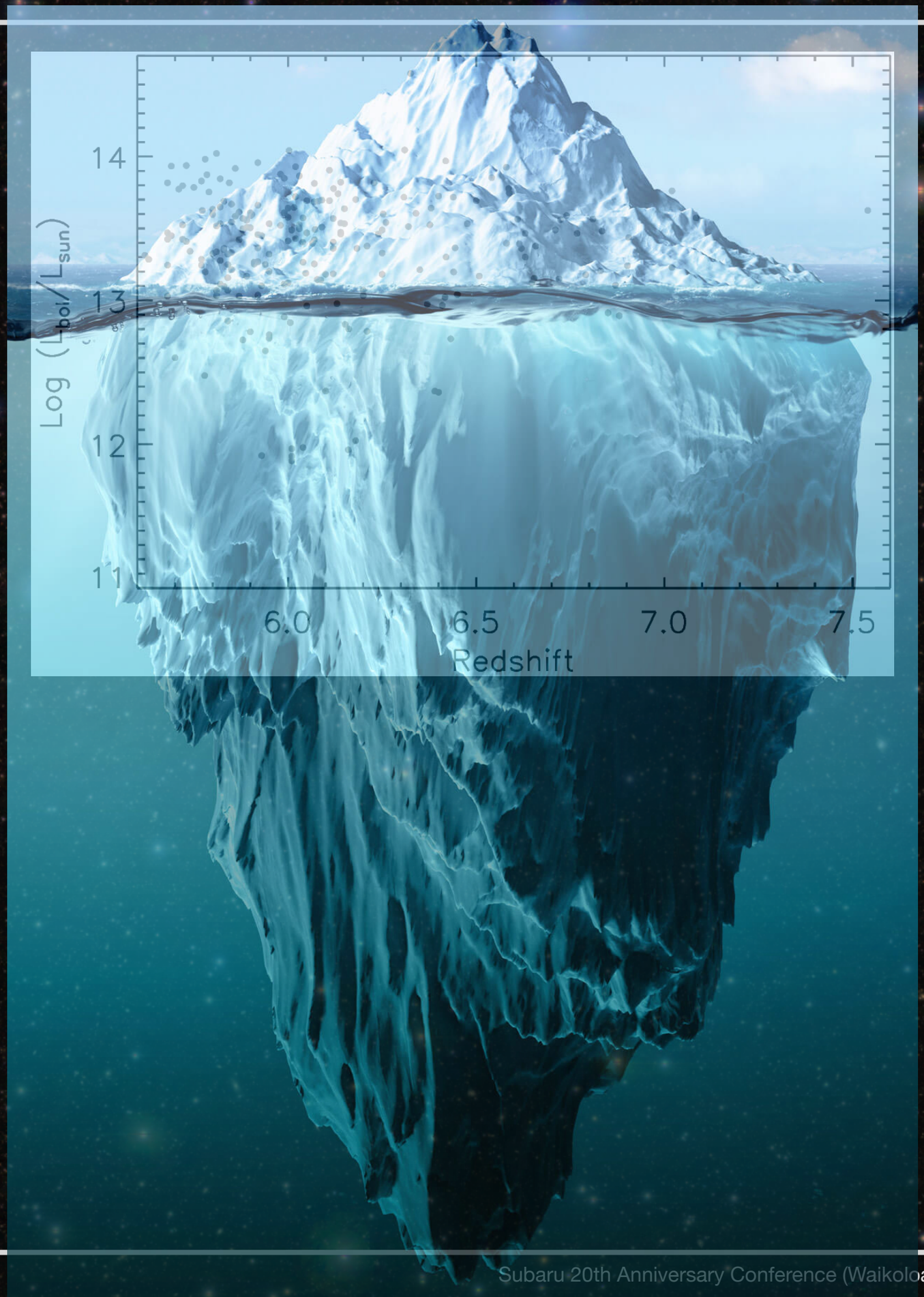
← $M_{BH} = 10^7\ M_{sun}$

← SMBH in the Milky Way

← "Heavy seeds" (10^5 - $10^6\ M_{sun}$?)



← "Light seeds" (≤ $10^2\ M_{sun}$?)



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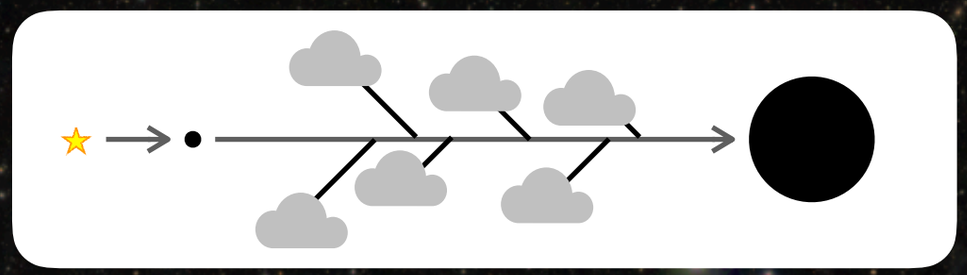


← "Light seeds" ($\leq 10^2\ M_{sun}$?)

Ionizing photon emissivity

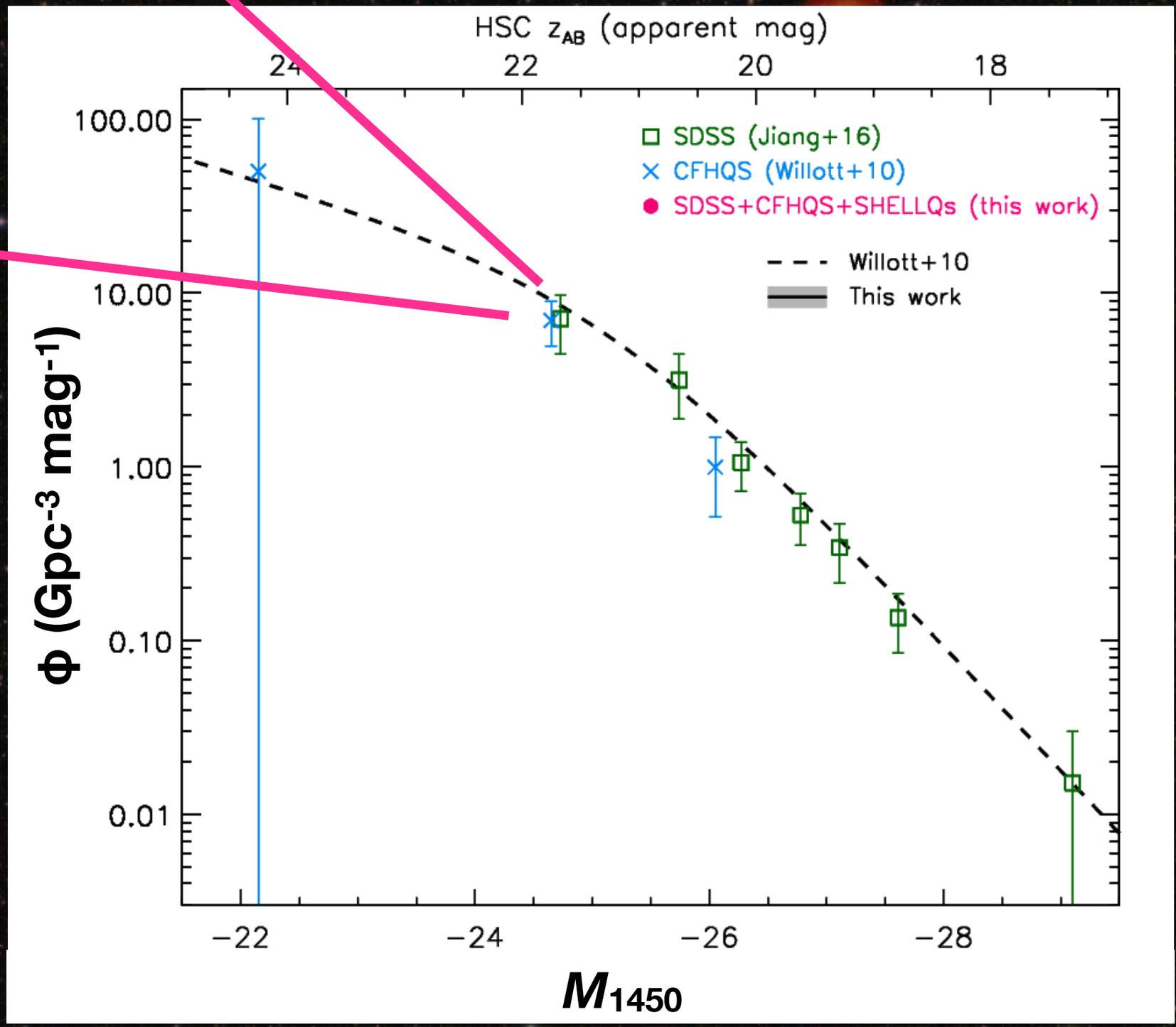
$dn_{ion}/dt > 10^{50}$ s^{-1} Mpc^{-3}

→ Quasars can sustain complete reionization

$dn_{ion}/dt << 10^{50}$ s^{-1} Mpc^{-3}

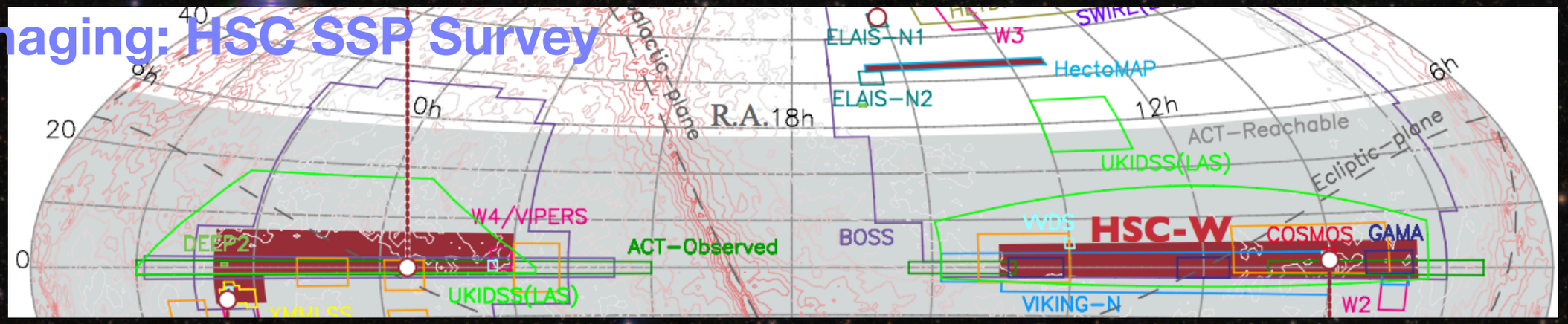
→ Quasars are a minor contributor to cosmic reionization

Matsuoka et al. (2018c)



"Subaru High-z Exploration of Low-Luminosity Quasars (SHELLQs)"

★ Imaging: HSC SSP Survey



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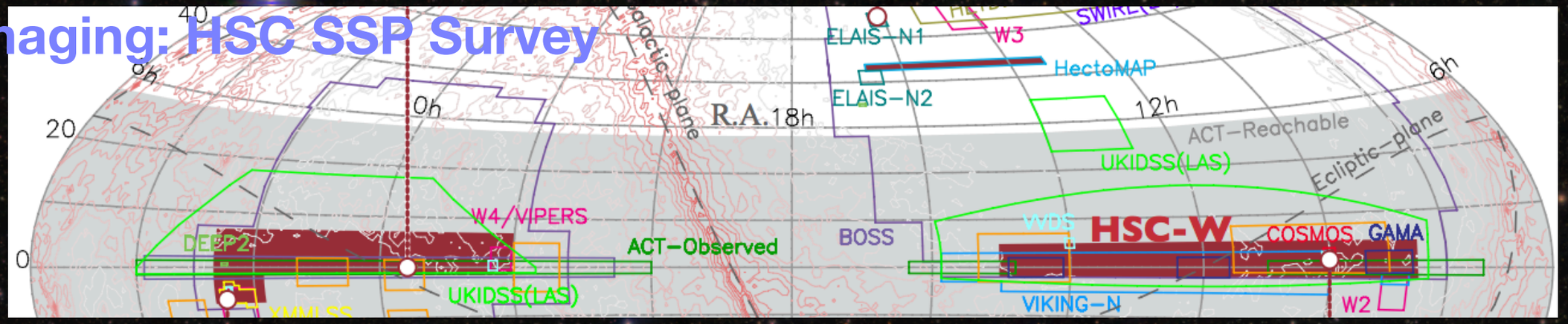


✶ Spectroscopy: 3 Normal + 2 Intensive Programs with ***FOCAS***

S15A-061 "Spectroscopy of HSC-SSP High-z Quasar Candidates" (1 FOCAS night)
S15B-070 "Spectroscopy of HSC-SSP High-z Quasar Candidates" (4 FOCAS nights)
S16A-076 "Spectroscopy of HSC-SSP High-z Quasar Candidates" (5 FOCAS nights)

S16B-071I *"Subaru High-z Exploration of Low-Luminosity Quasars"*

✶ 20 FOCAS nights in S16B - S18A

✶ Immediate Objectives:

✓ To discover 50 low-L (M_{1450} < -22 mag) quasars at 5.7 < z < 6.5

✓ To establish quasar luminosity function at z = 6

S18B-011I *"Subaru Complete Census of the Most Distant Quasars at z > 6.5"*

✶ 30 FOCAS nights in S18B - S21A (mid-term review after the first 20 nights)

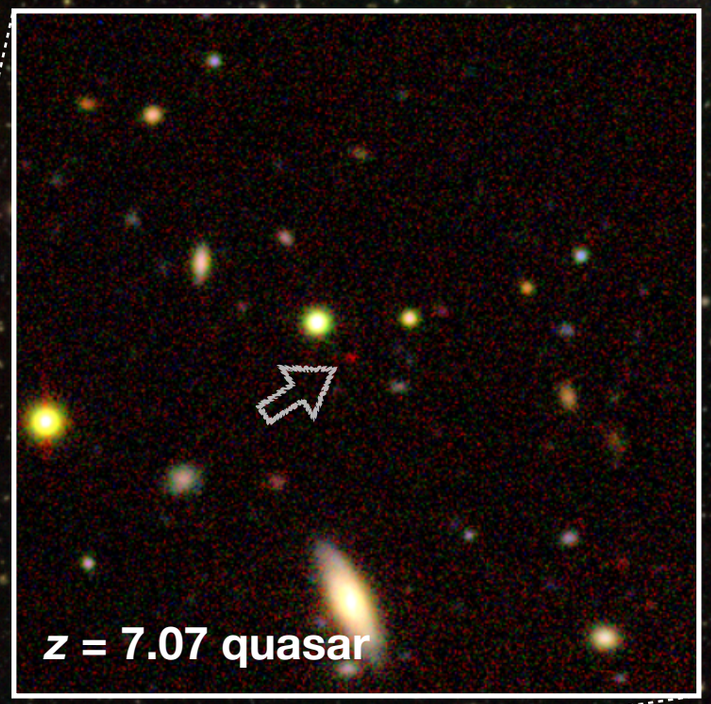
✶ Immediate Objectives:

✓ To discover 50 low-L (M_{1450} < -23 mag) quasars at 6.5 < z < 7.5

✓ To establish quasar luminosity function at z = 7

Quasar survey - outcome

93 (= 75 BL + 18 NL) quasars published, and more being discovered.



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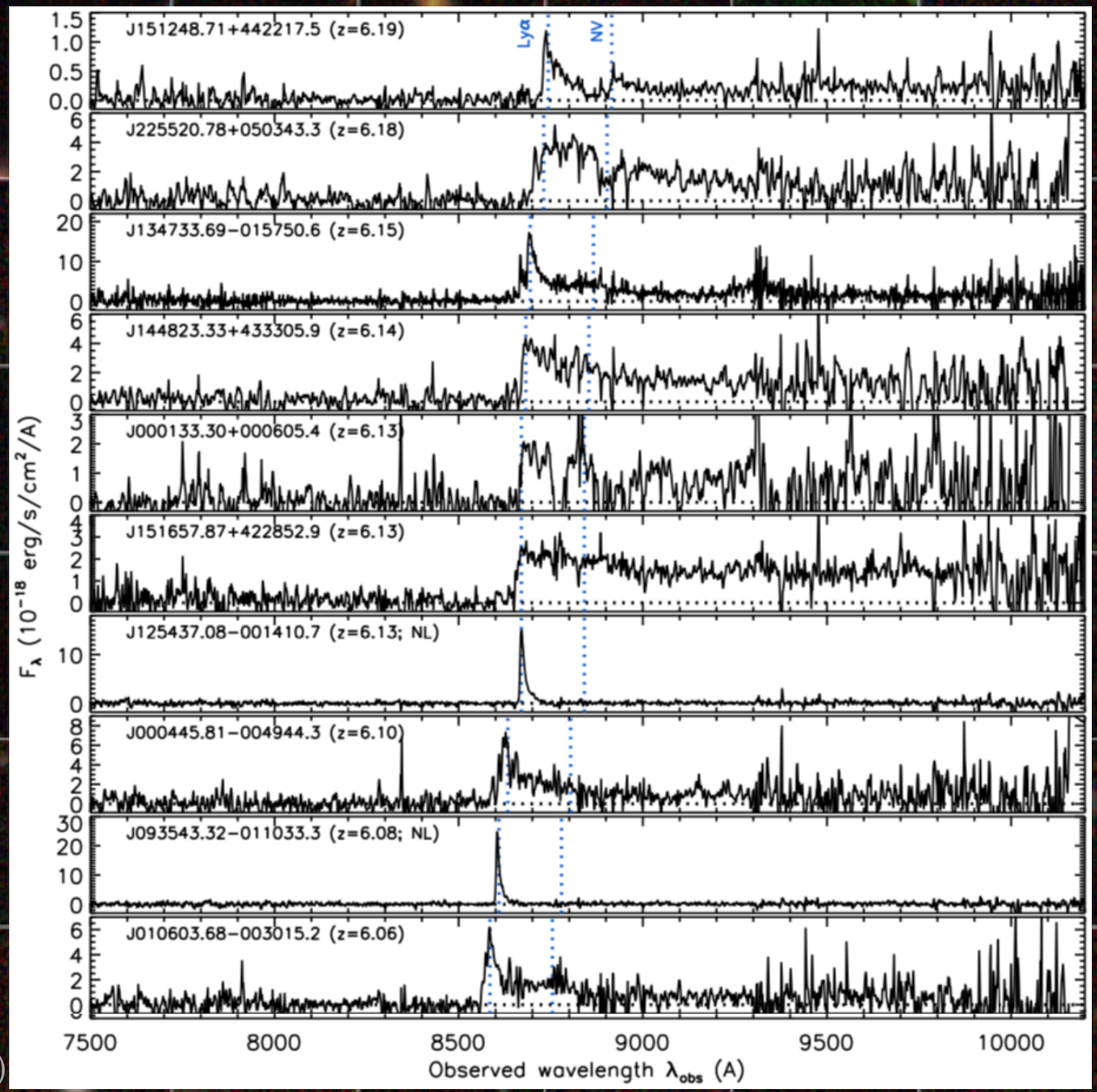

Matsuoka et al. (2019b)

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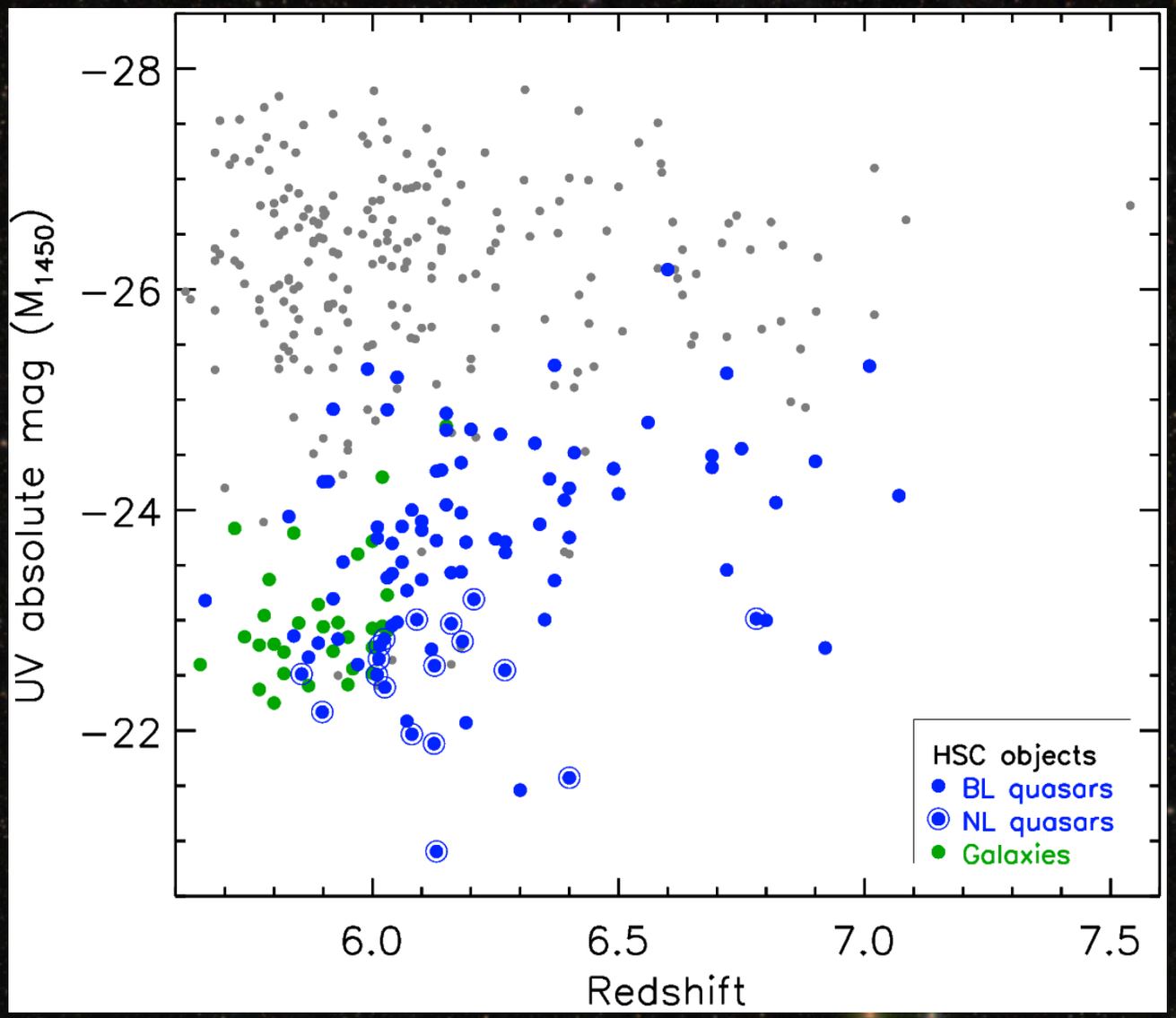

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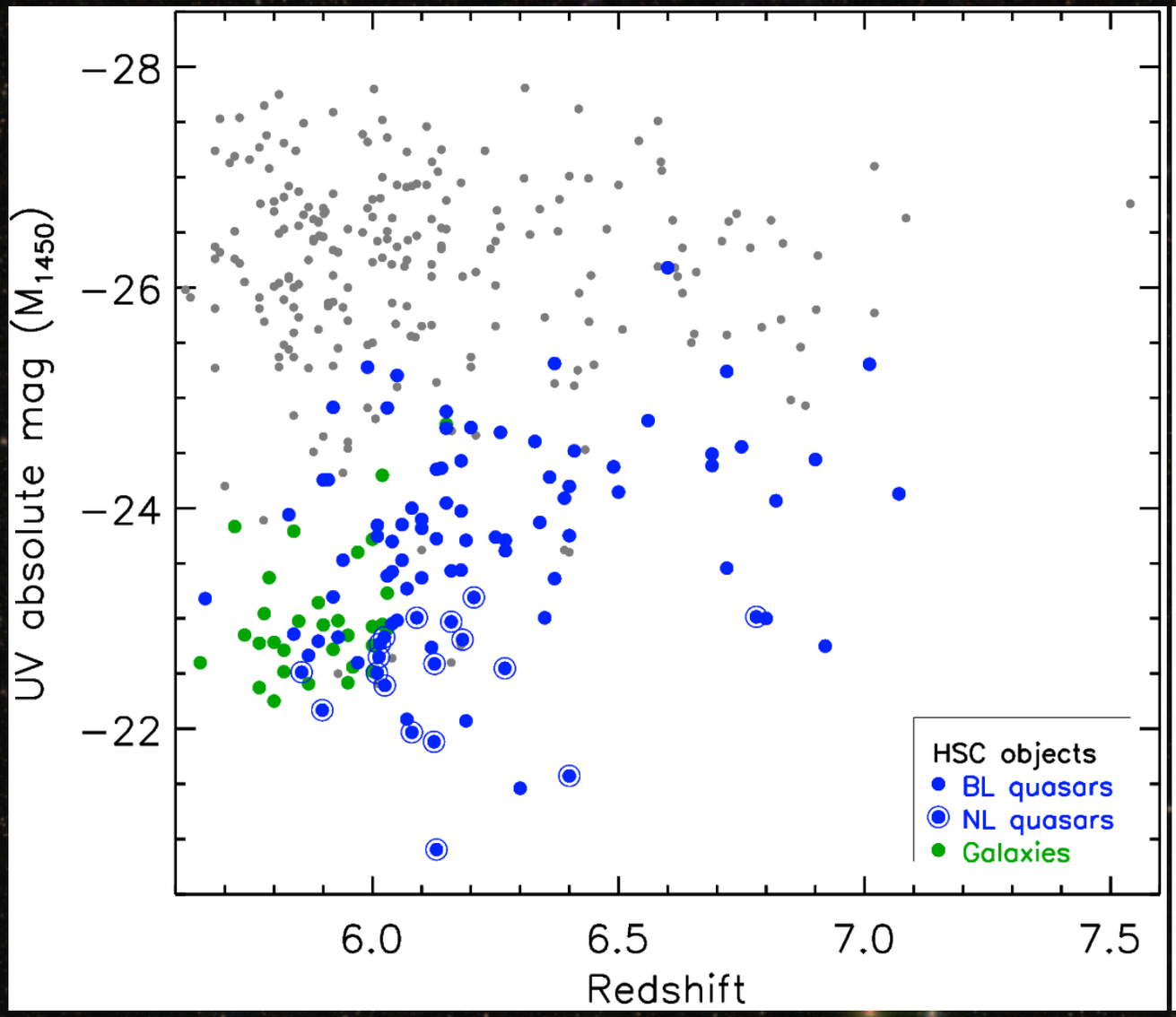
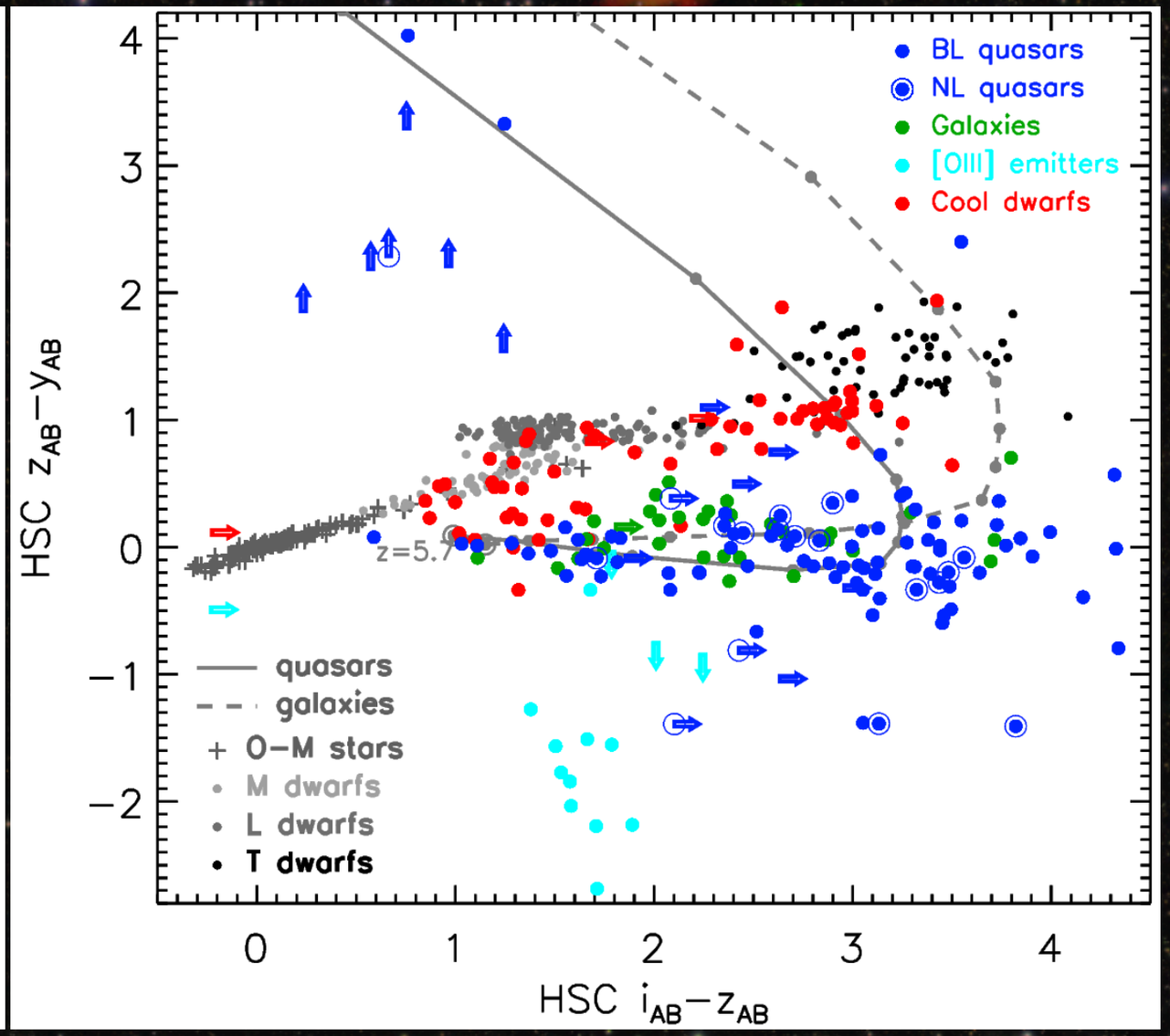
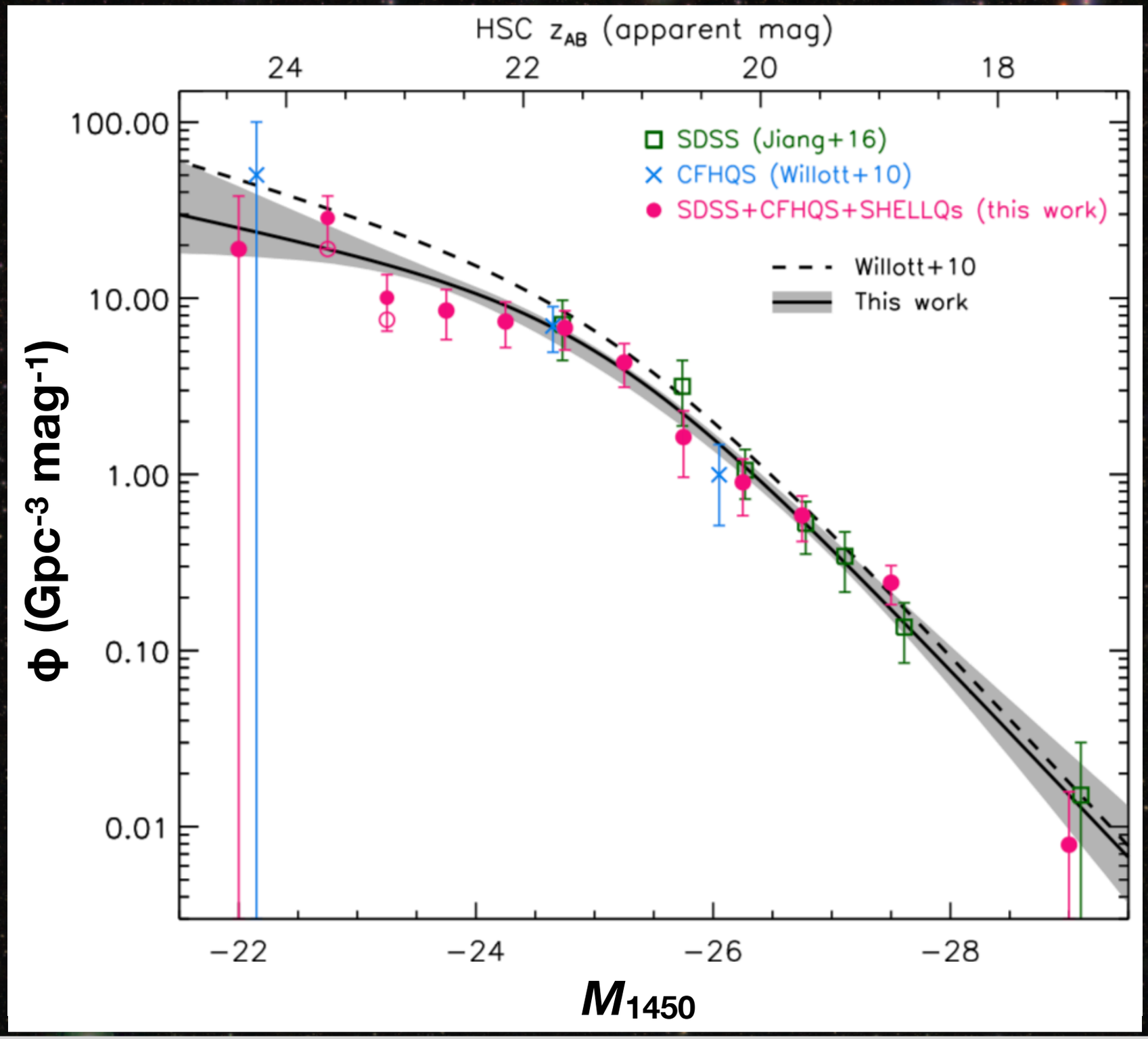




Quasar survey - outcome: z=6 Quasar LF

Quasars are a minor contributor to reionization



Matsuoka et al. (2018c)

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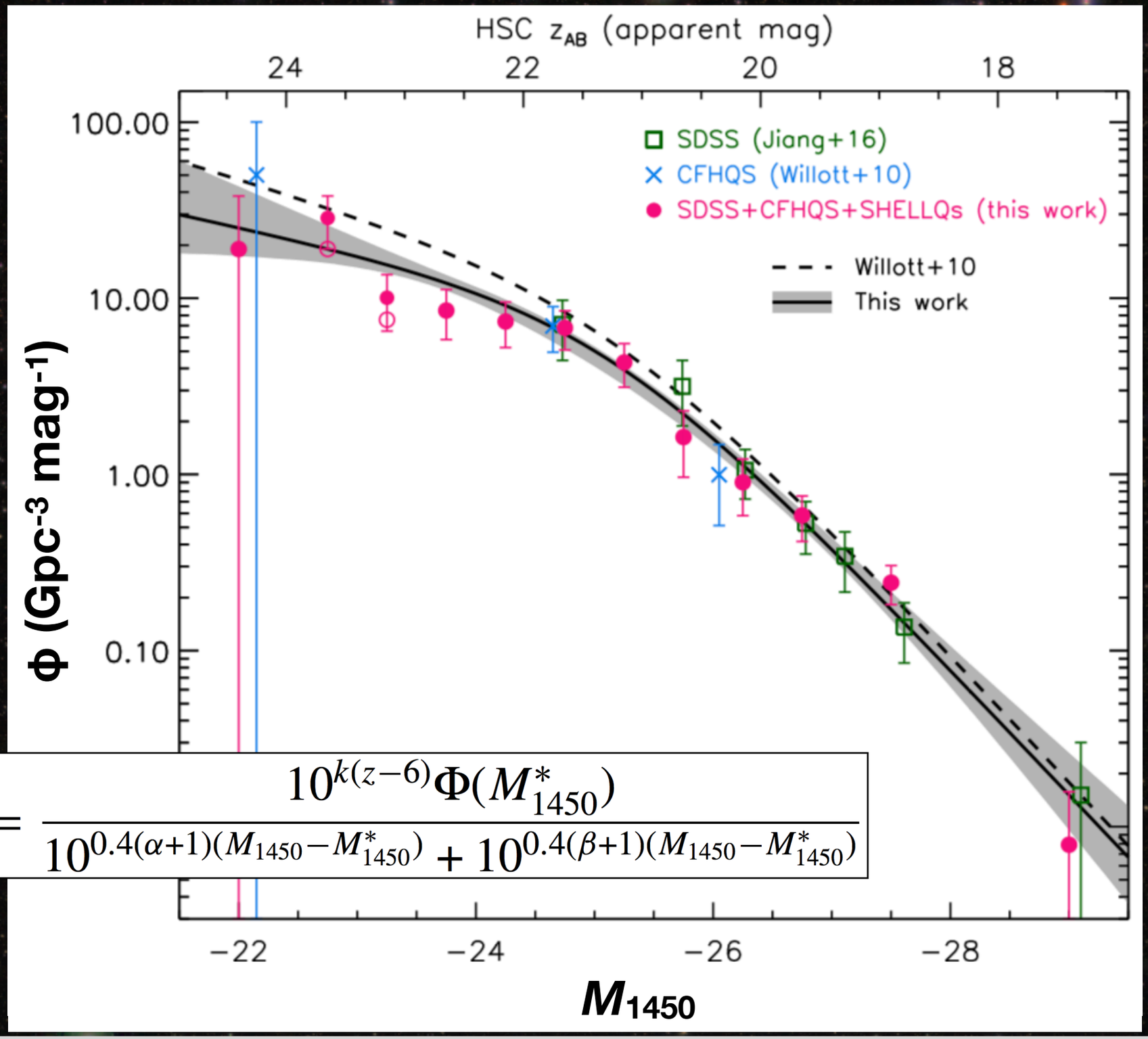

$$\Phi(M_{1450}, z) = \frac{10^{k(z-6)}\Phi(M^*_{1450})}{10^{0.4(\alpha+1)(M_{1450}-M^*_{1450})} + 10^{0.4(\beta+1)(M_{1450}-M^*_{1450})}}$$

Matsuoka et al. (2018c)

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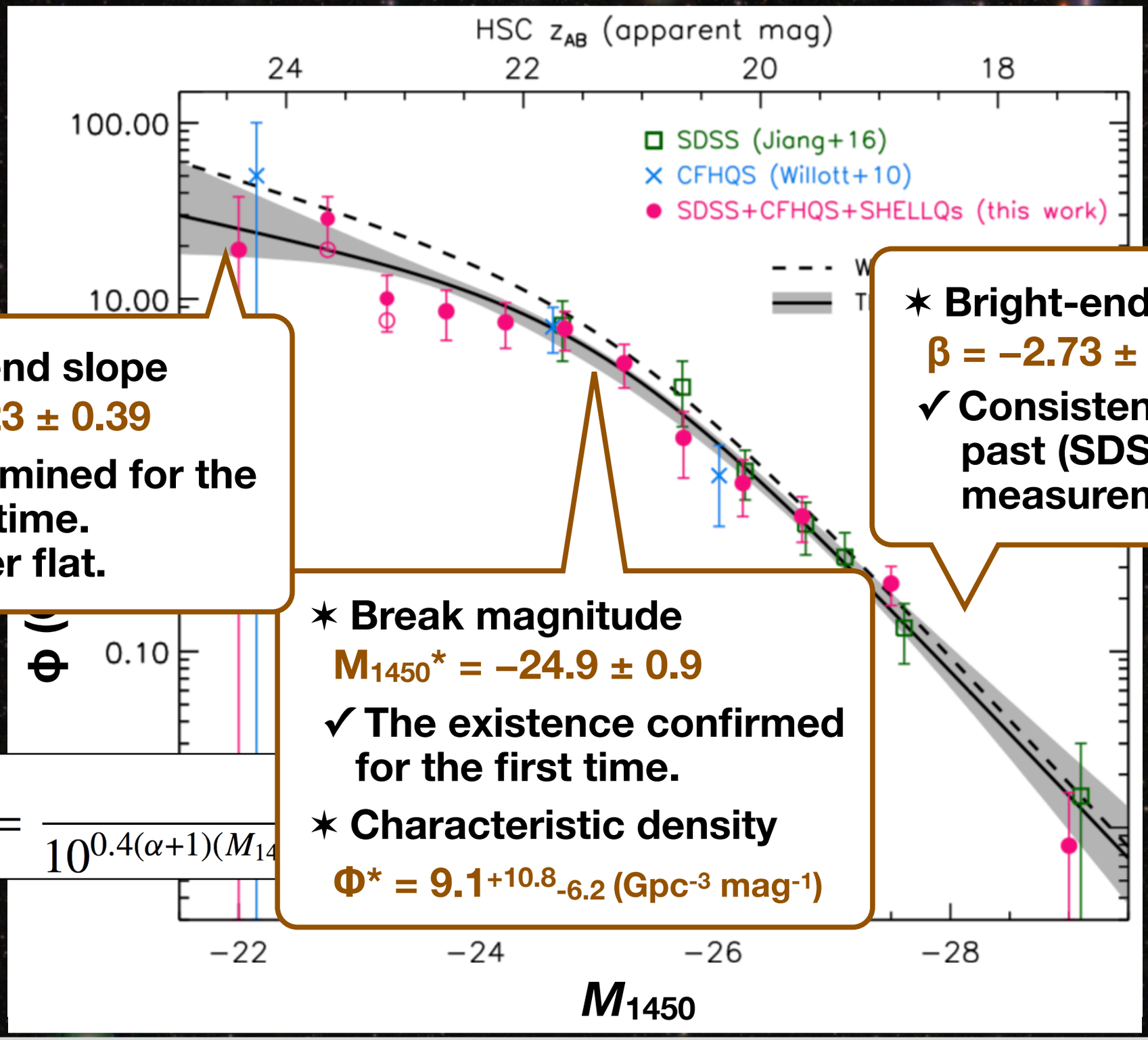


✶ **Faint-end slope**

α = –1.23 ± 0.39

✓ **Determined for the first time.**

✓ **Rather flat.**

✶ **Break magnitude**

M_{1450}^* = –24.9 ± 0.9

✓ **The existence confirmed for the first time.**

✶ **Characteristic density**

$\Phi^* = 9.1^{+10.8}_{-6.2}$ (Gpc^{-3} mag^{-1})

✶ **Bright-end slope**

β = –2.73 ± 0.27

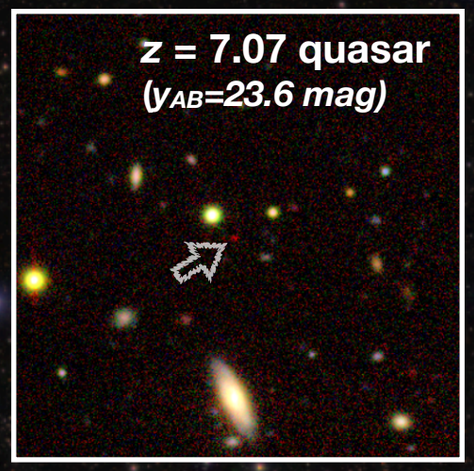
✓ **Consistent with the past (SDSS, CFHQS) measurements.**

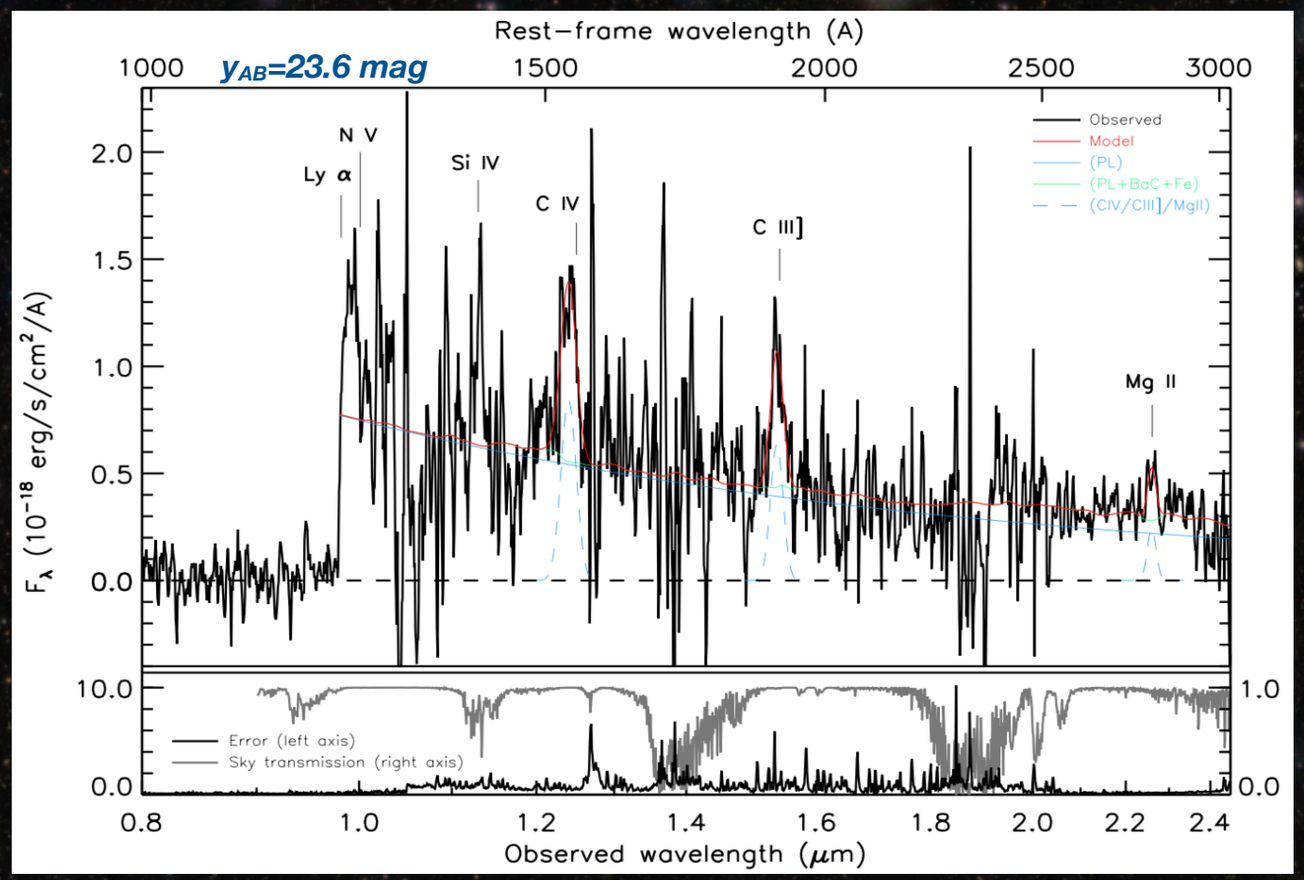
$$\Phi(M_{1450}, z) = \frac{}{10^{0.4(\alpha+1)(M_{14}}}$$

Matsuoka et al. (2018c)

Quasar survey - outcome

The first low-luminosity quasar at z > 7

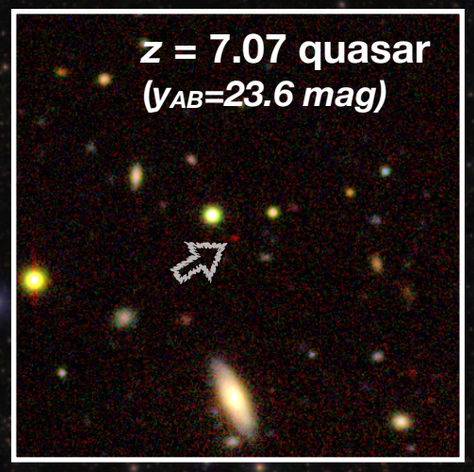


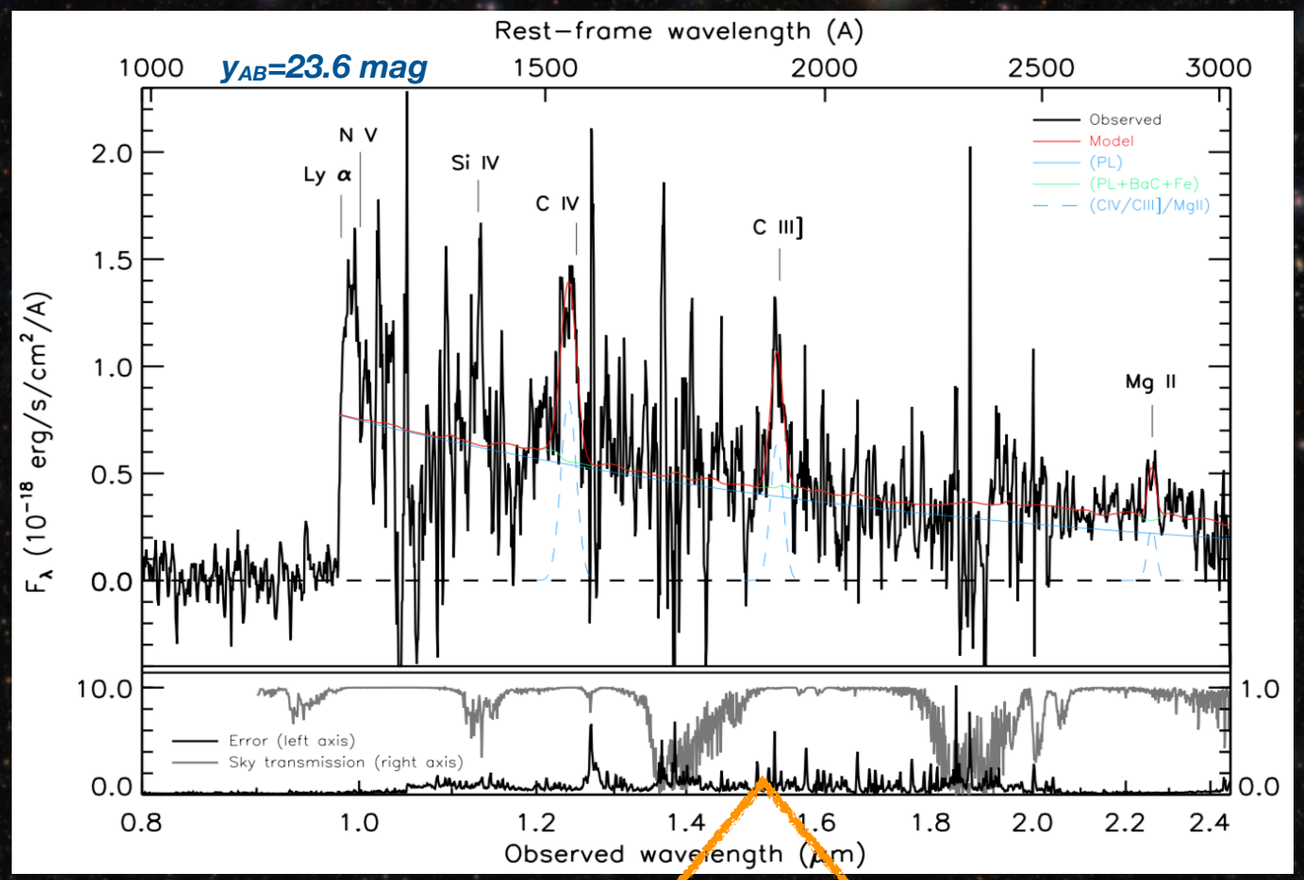


Matsuoka et al. (2019a)

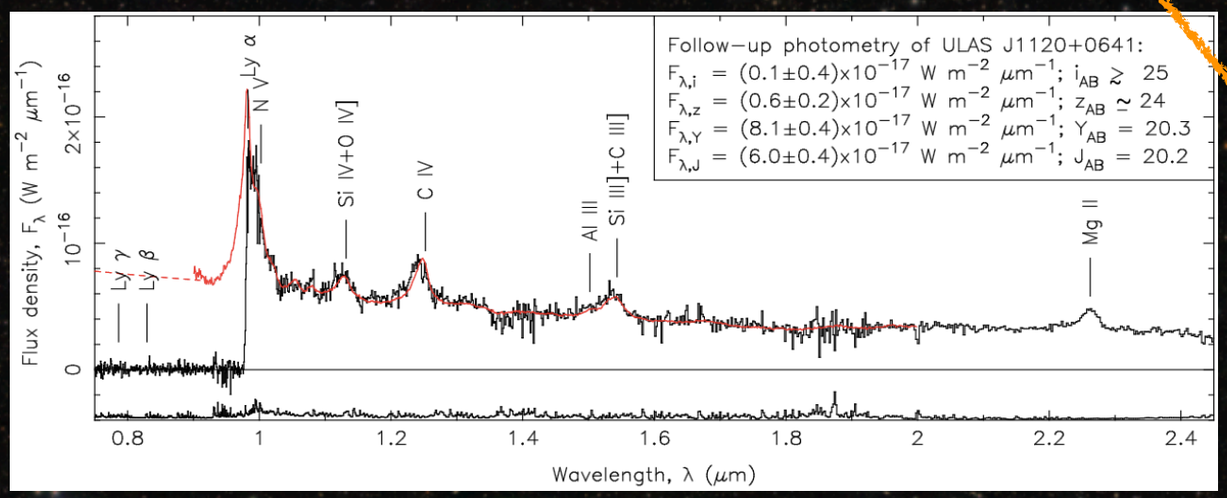
Quasar survey - outcome

The first low-luminosity quasar at z > 7

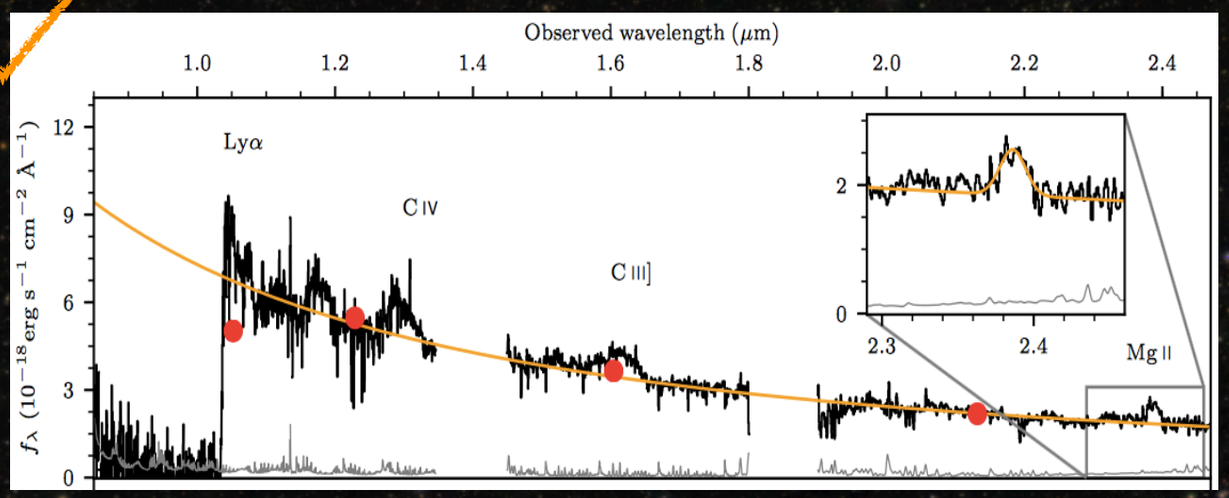




Matsuoka et al. (2019a)



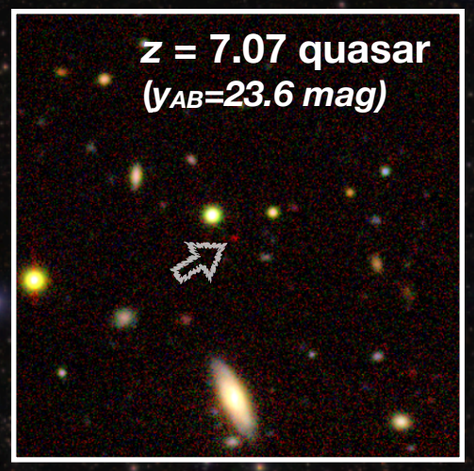
z = 7.085 (Mortlock et al. 2011)

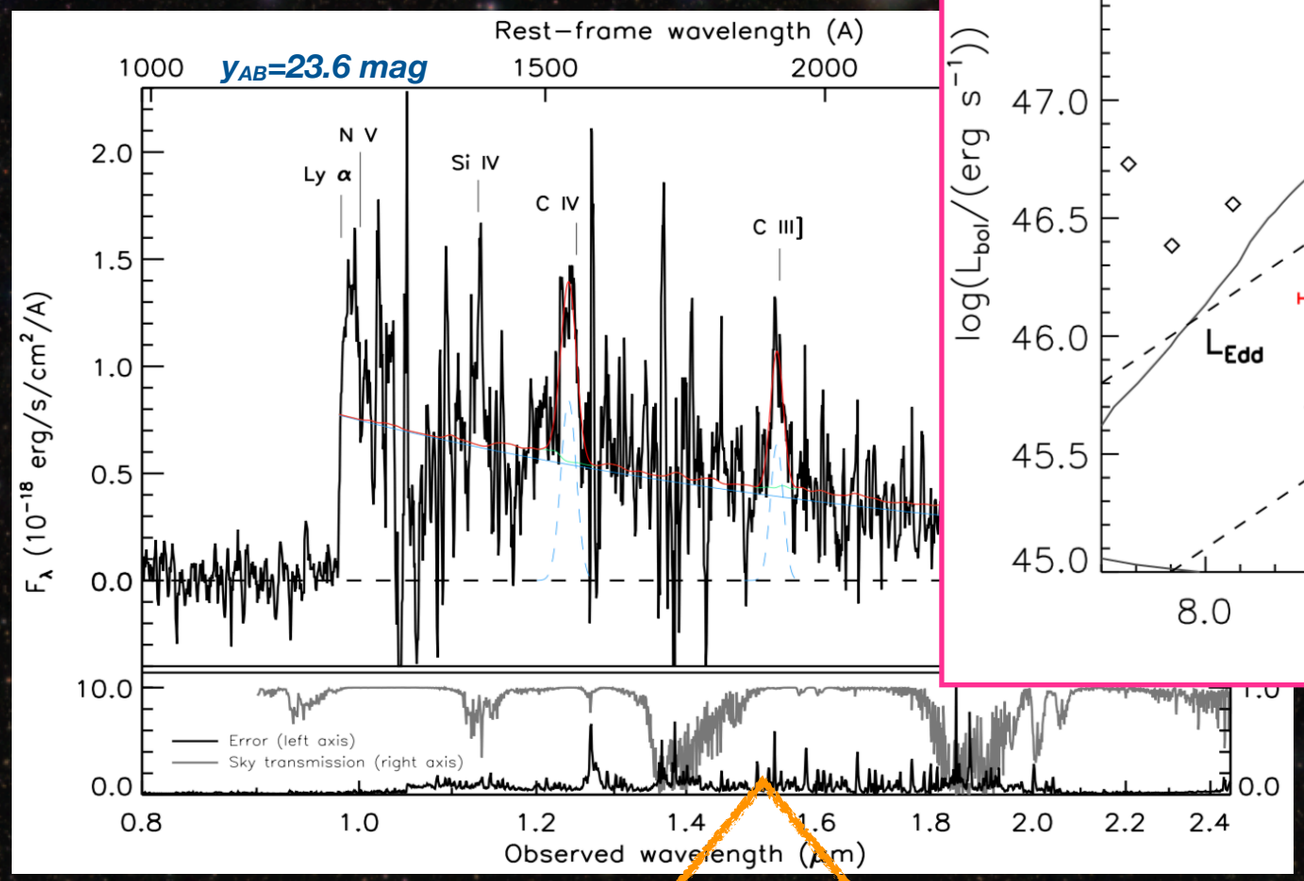


z = 7.54 (Banados et al. 2018)

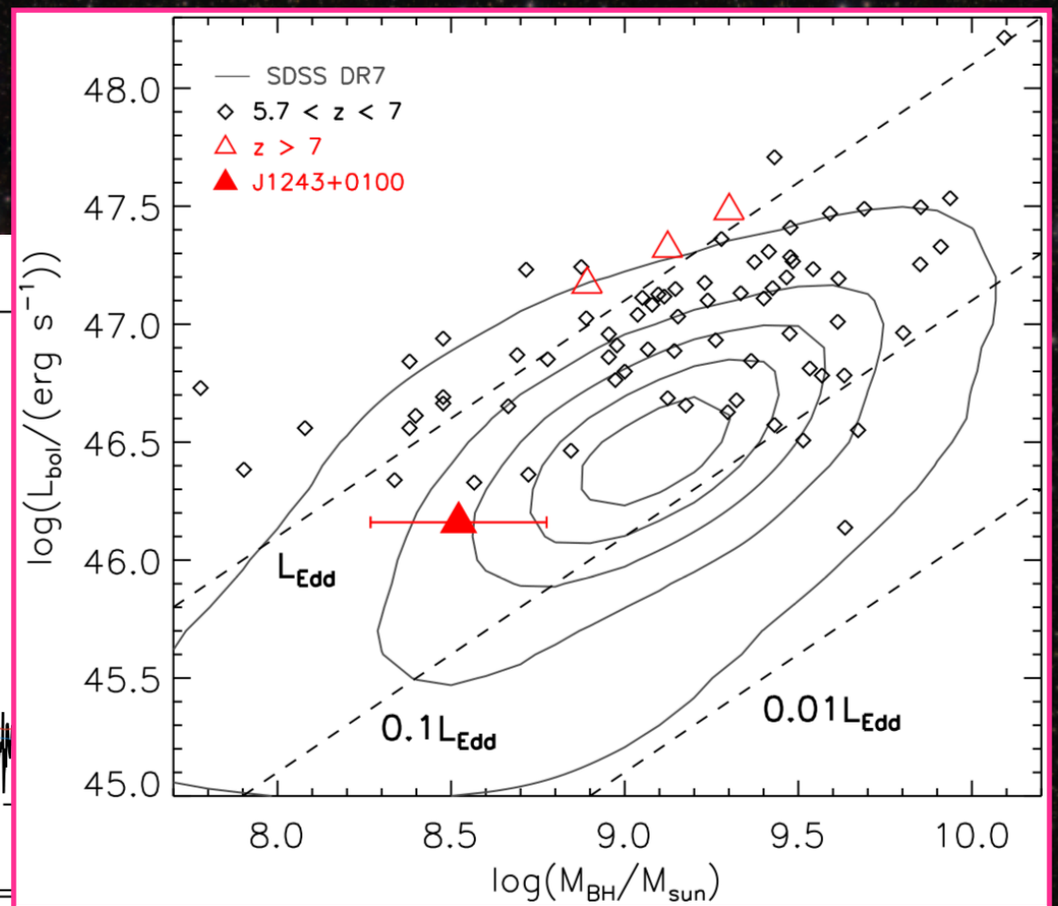
Quasar survey - outcome

The first low-luminosity quasar at z > 7

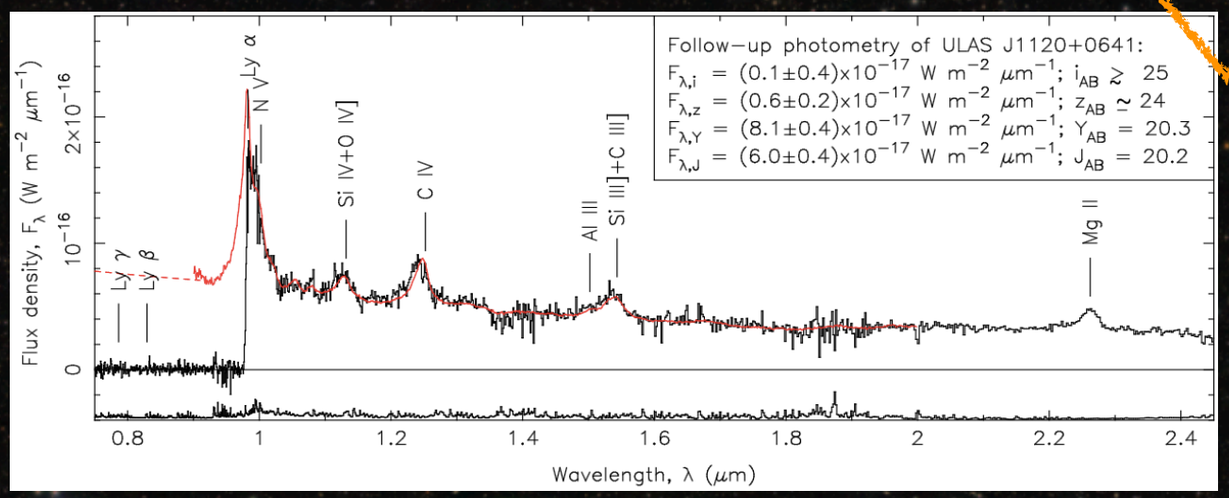




Matsuoka et al. (2019a)



- M_{BH} = 3.3 x 10^8 M_{sun}
- λ_{Edd} = 0.34



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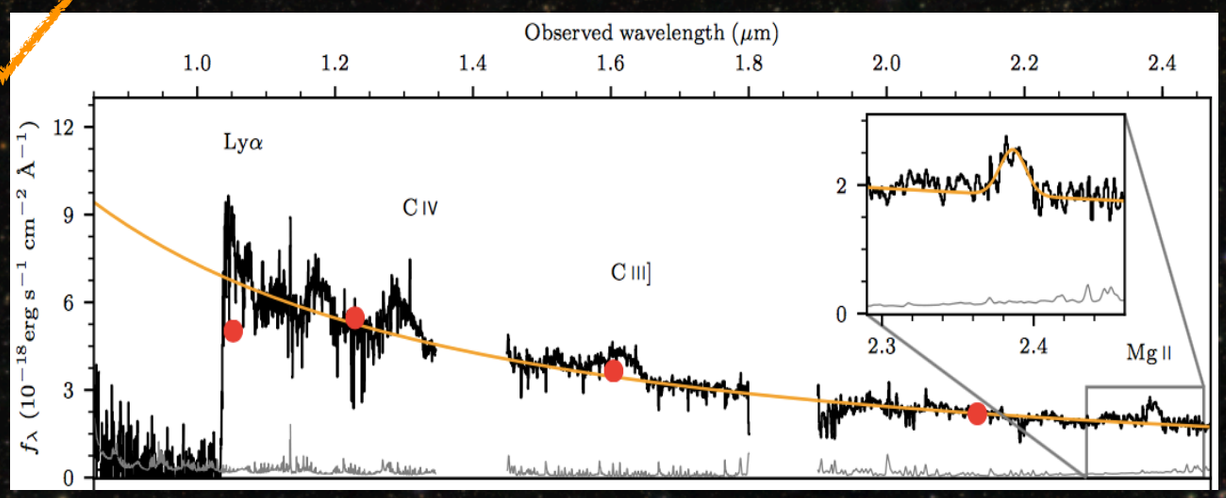
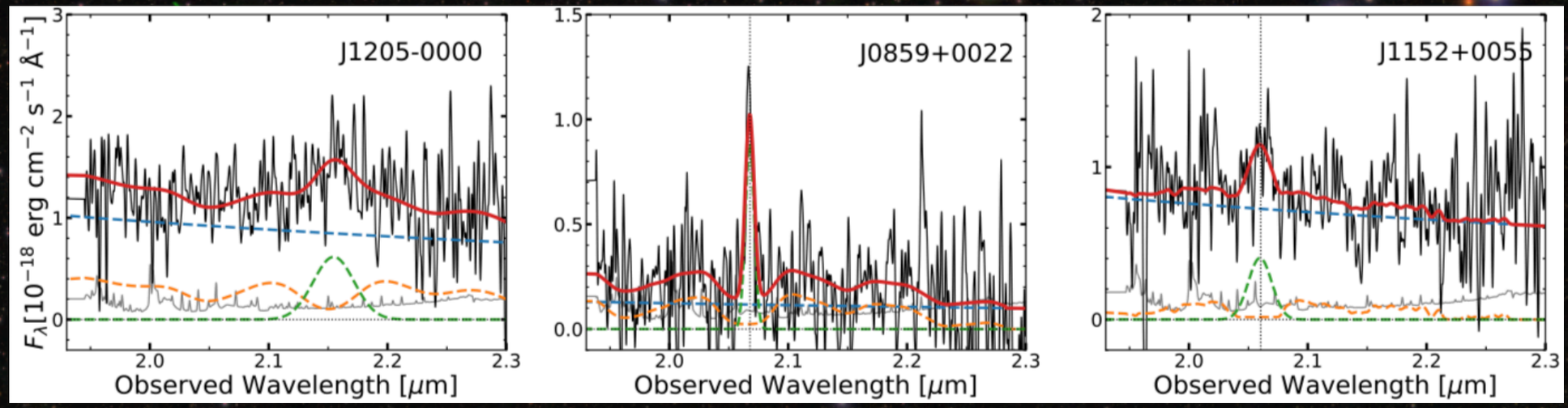


z = 7.54 (Banados et al. 2018)

Multi-wavelength follow-up

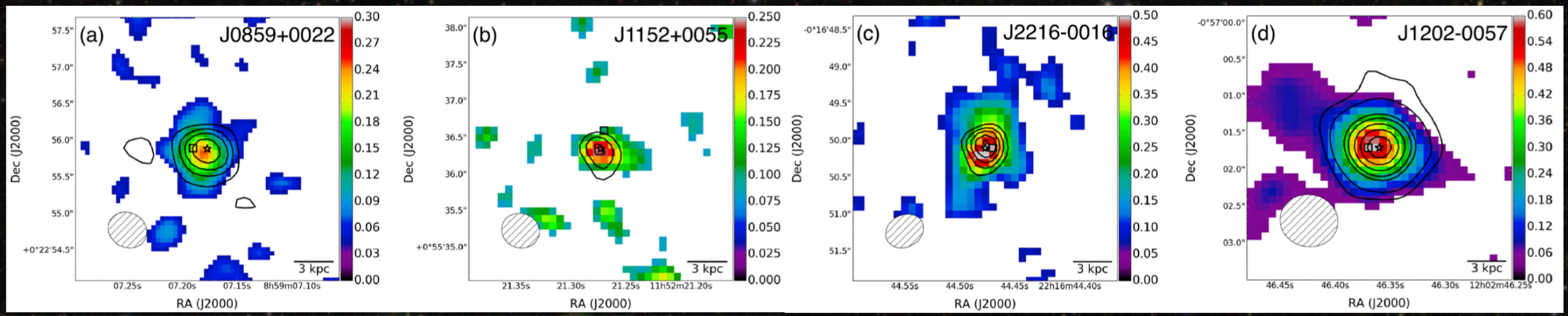
- BH mass measurements with NIR spectroscopy



Onoue et al. (2019)

→ Masafusa Onoue's talk on Thursday (SMBH session, Naupaka 7)

- Host galaxies probed with ALMA



Izumi et al. (2018, 2019)

- JVLA follow-up → Kianhong Lee's talk on Thursday
- Combination with WISE to look for red quasars → Nanako Kato's talk on Thursday

Conclusions

- We are making good progress! Approaching 100 new quasars at $z \geq 6$, which probe unprecedentedly low luminosity and thus enable significant discoveries on the early Universe.
- Our next milestone is to establish the quasar LF at $z = 7$. This is also the primary goal of the ongoing S18B-011I intensive program.