Subaru Intensive Searches for the Most Distant Quasars

Progress Report of S18B-011I

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on behalf of the SHELLQs collaboration

High-z quasars - Unique probe of the early Universe

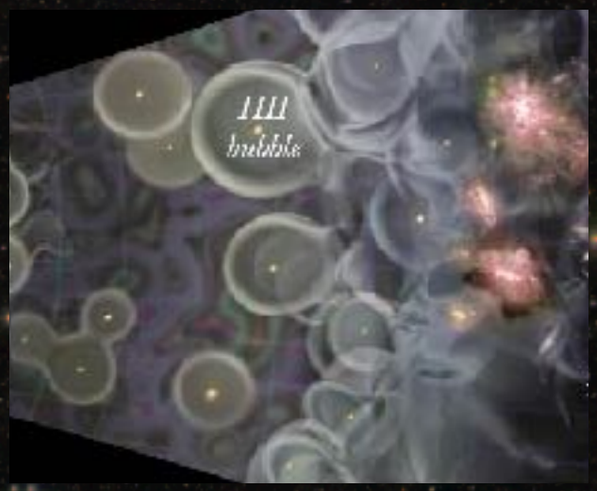
Fundamental questions we aim to answer:

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?

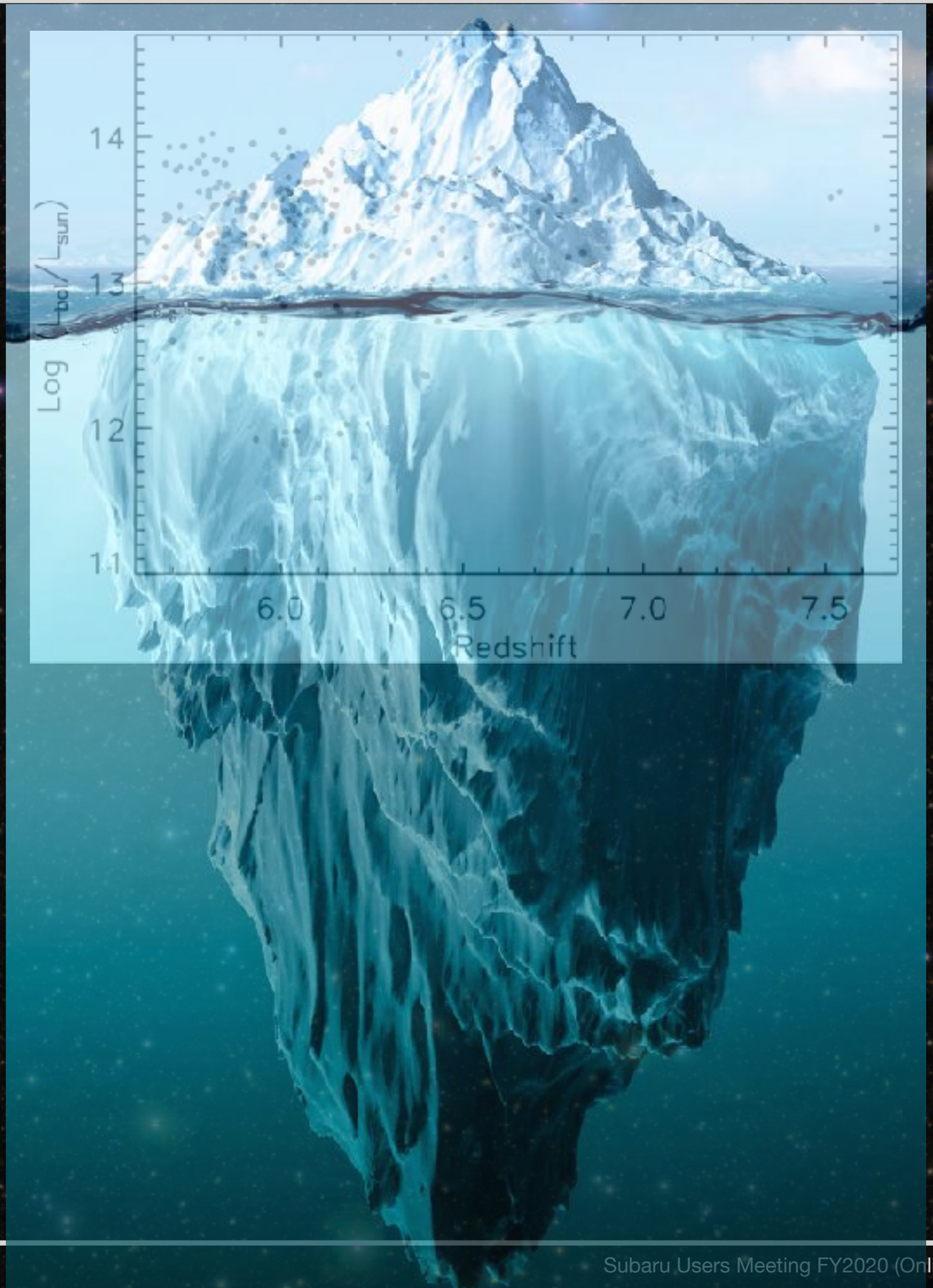
✶ When and how did the first stellar-mass assembly happen?
✶ Did SMBHs impact the host galaxy evolution? If so, how?
✶ Do they mark the highest density peaks of the DM distribution?



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!



Eddington luminosity at the mass of…

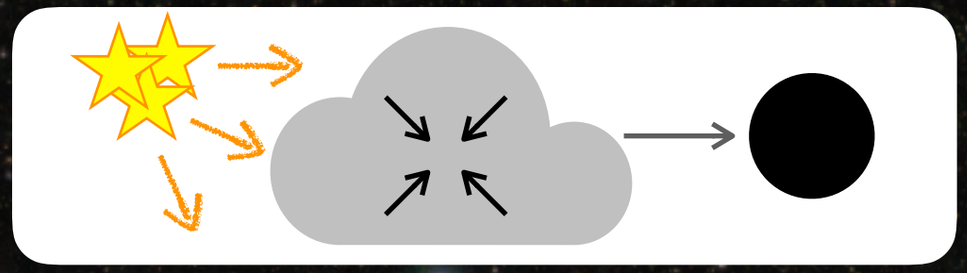
← $M_{BH} = 10^9\ M_{sun}$

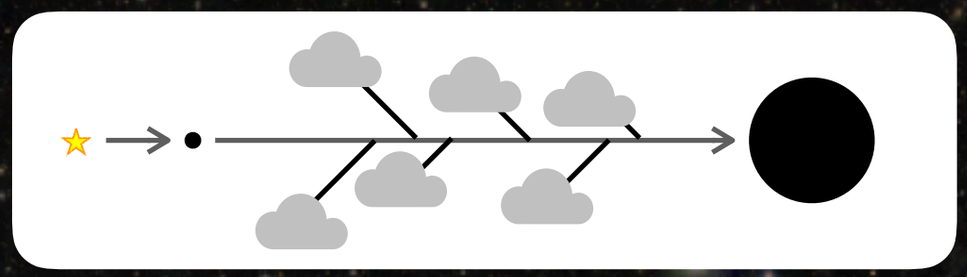
← $M_{BH} = 10^8\ M_{sun}$

← $M_{BH} = 10^7\ M_{sun}$

← SMBH in the Milky Way

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

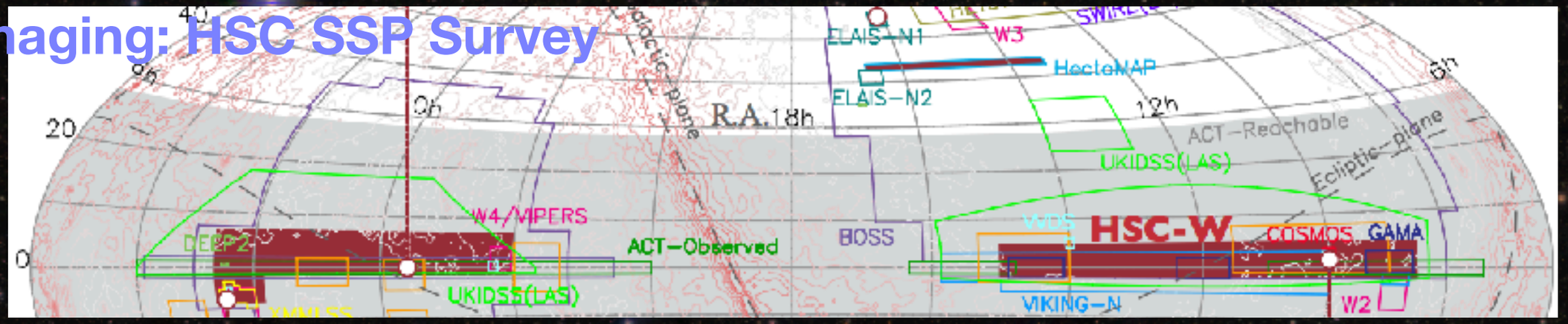




← "Light seeds" ($\leq 10^2\ M_{sun}$?)

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

✶ Imaging: HSC SSP Survey



✶ 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

✶ Immediate Objectives:

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

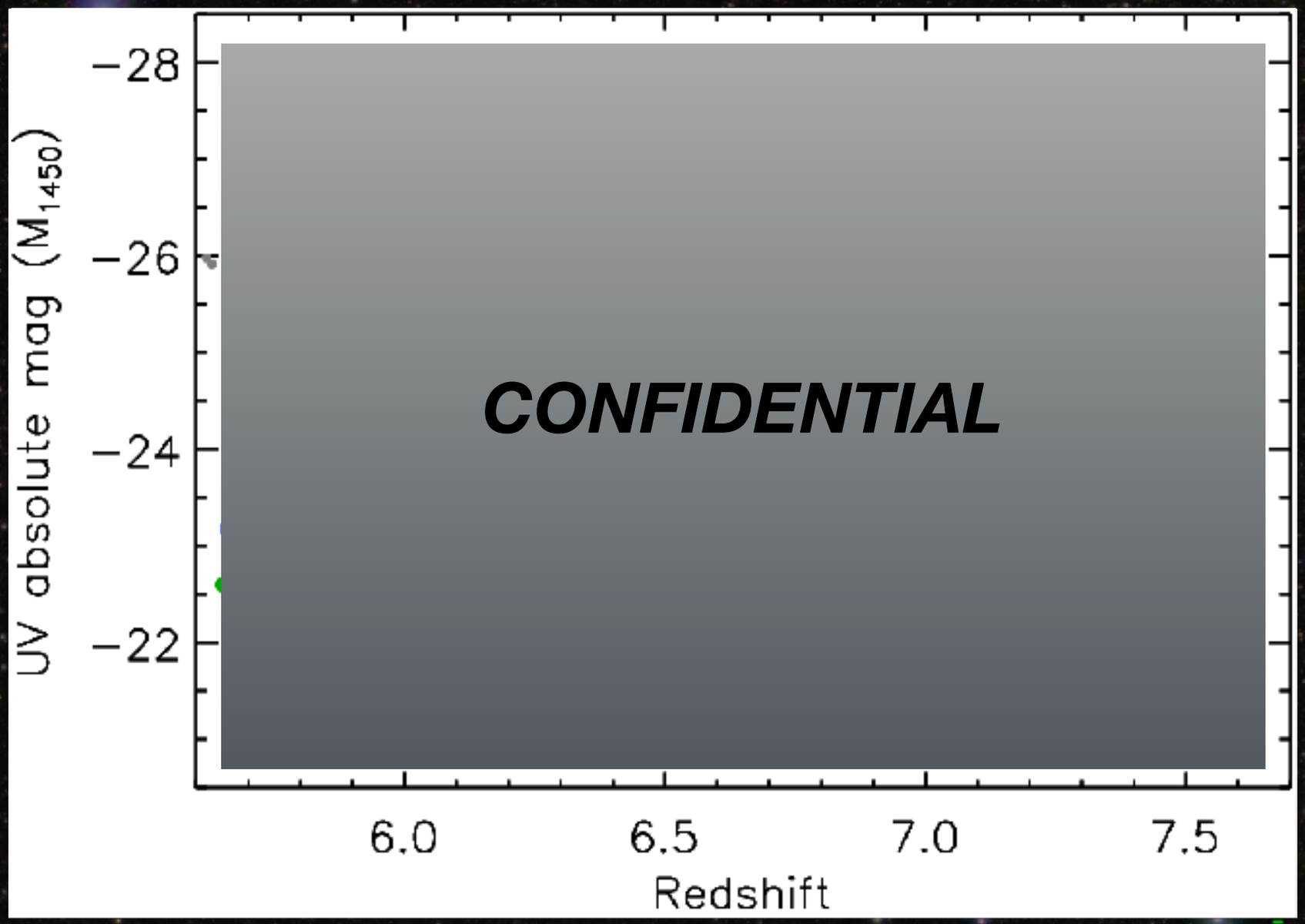
✓ To establish quasar luminosity function at z = 7

★ Observing progress of S18B-011I

- ✓ Sep 2018 (3 nights) … cancel due to UPS trouble (following electric power outage)
- ✓ Oct 2018 (2 nights) … no usable data due to FOCAS damage (water leakage)
- ✓ Mar 2019 (1 night) … cancel due to FOCAS repair work
- ✓ Apr 2019 (2.5 nights) … ~60% clear
- ✓ May 2019 (1.5 nights) … 100% clear
- ✓ Jun 2019 (1 night; compensation of the Mar run) … cancel due to AG system failure
- ✓ Oct 2019 (2 nights) … 100% clear
- ✓ Nov 2019 (3 nights) … cancel due to an earthquake
- ✓ Mar 2020 (0.5 night) … 0% clear
- ✓ Apr 2020 (4.5 nights) … cancel due to COVID-19
- ✓ Dec 2020 (2 nights) … 100% clear
- ✓ Jan 2021 (3 nights) … 100% clear
- ✓ Feb 2021 (4 nights) … ~60% clear
- ✓ Mar 2021 (1 night) … today & tomorrow

→ Relatively low success rate (~50%), due mostly to non-weather factors…

Discoveries so far



✓ 30 (150) quasars at z > 6.5 (5.8) ↔ 50 quasars needed for LF constraints
… fewer than originally expected over a given area, already suggesting an accelerating decline in number density toward higher redshift

✓ Unobserved candidates still distribute more or less sparsely on the sky, which must be covered in the remaining nights to make the final ***complete*** sample

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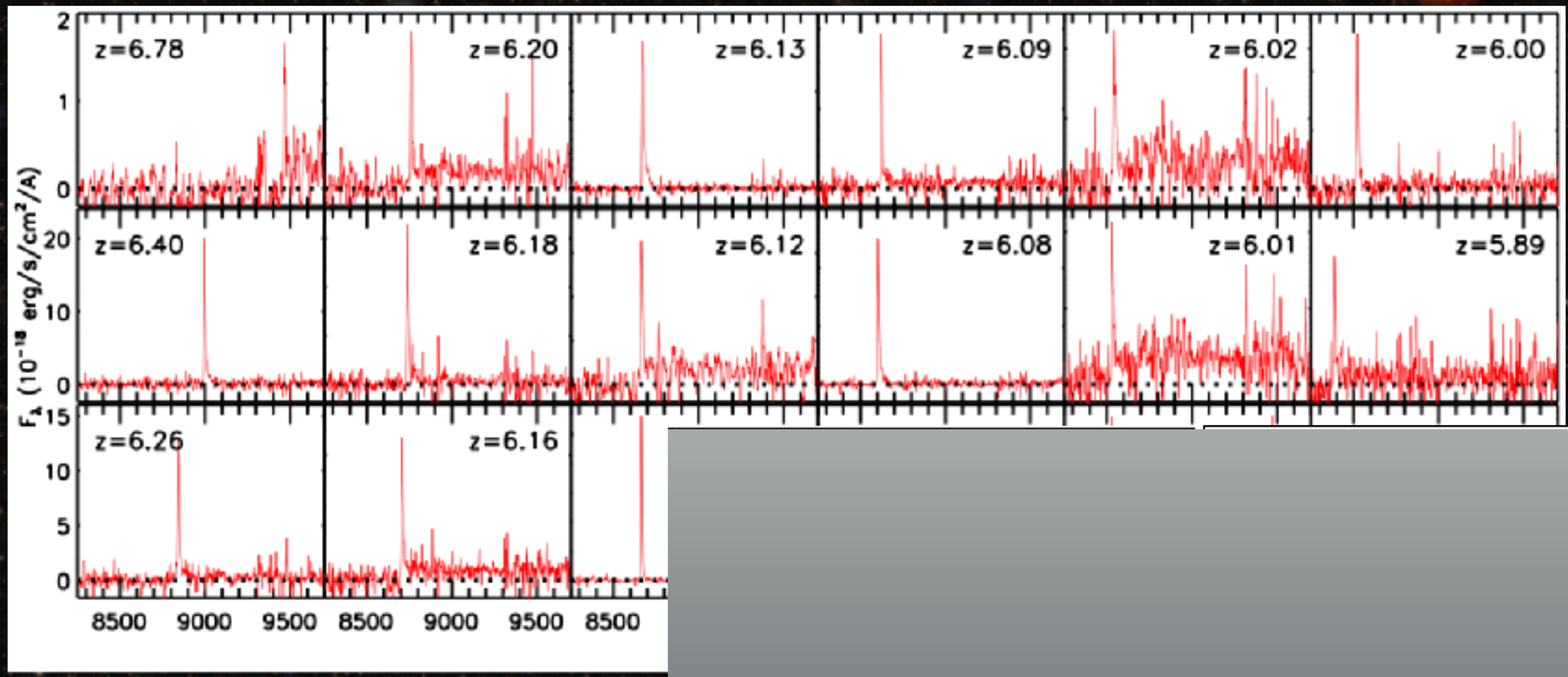
We are opening up a new frontier…

✓ **Type-II quasar candidates** with very luminous Ly α emission (> 10^{43} erg/s), which are not common among "normal" Ly α emitters.

✓ **Keck/MOSFIRE** follow-up → strong CIV-doublet detected, indicating the AGN nature?



Onoue et al. (in prep.)

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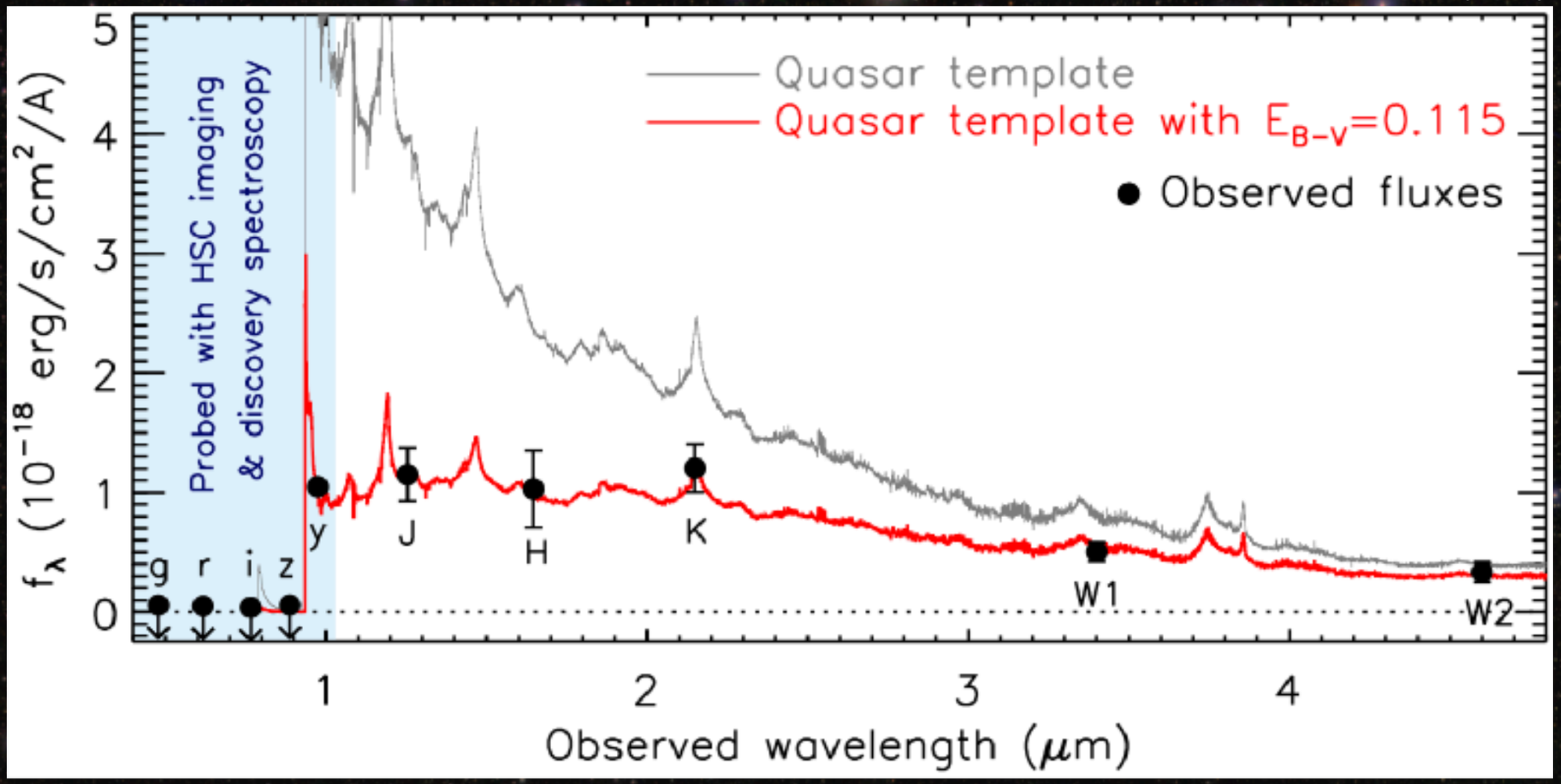
We are opening up a new frontier…

✓ **Red quasars** with a significant dust extinction

Kato et al. (2020)



This quasar, HSC J1205-0000 at z = 6.70 (y_{AB} = 22.6 mag), would have been ~2 mag brighter in the y-band and detectable in past imaging surveys, if there were no dust extinction.

→ Systematic NIR imaging survey toward all the confirmed (and published) quasars

★ **Gemini/NIRI** 2020B (35.6 hours) & 2021A (13.3 hours in Band-3)

★ **GTC/EMIR** 2020B (12.1 hours) & 2021A (15.0 hours)

We are opening up a new frontier…

✓ **ALMA** observations have revealed diverse nature of the host galaxies, sometimes with complex extended morphology, powerful outflows, and/or ULIRG-class star formation.

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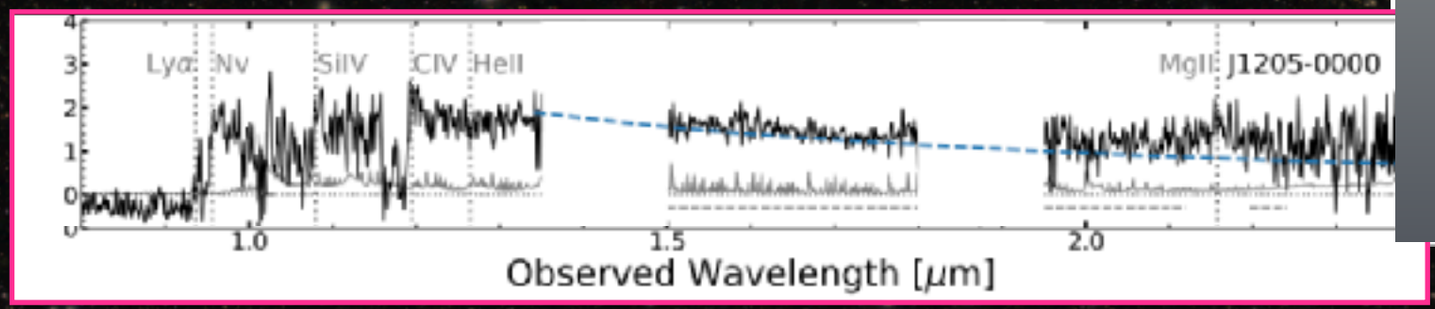
Izumi et al. (in prep.)

✓ M_{BH} - M_{host} relation consistent with that measured in the local universe?

✓ M_{BH} coming from NIR spectroscopy at Subaru/MOIRCS, VLT/X-shooter, and Gemini/GNIRS.



Onoue et al. (2019)

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Conclusions

- We are making good progress. We've discovered 30 (150) quasars at $z > 6.5$ (5.8), probing unprecedentedly low luminosity and thus enabling significant discoveries on the early Universe.
- We will finish follow-up spectroscopy of the remaining candidates and make a complete sample for various statistical analyses, luminosity function in particular, in the remaining nights.