Subaru Intensive Searches for the Most Distant Quasars

Progress Report of S18B-011I

Yoshiki Matsuoka (Ehime University)
on behalf of the SHELLQs collaboration

High-z quasars - Unique probe of the early Universe

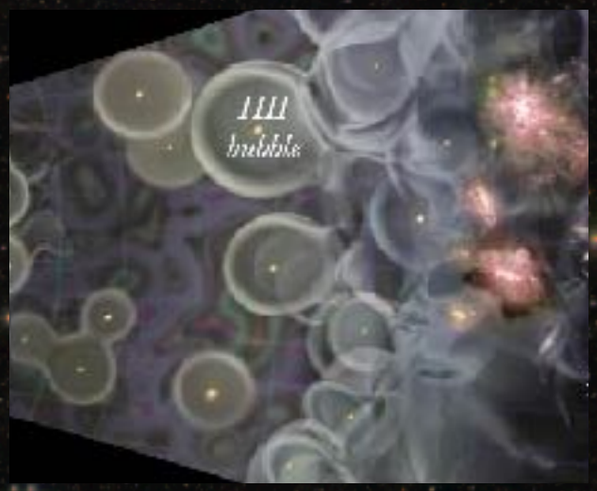
Fundamental questions we aim to answer:

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?



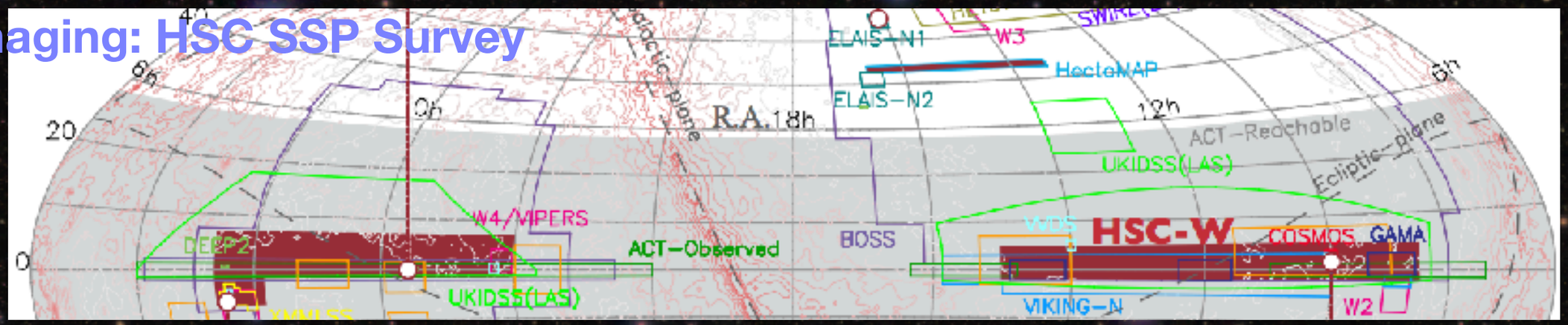
When and how was the Universe re-ionized?

✶ 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!

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

✶ Imaging: HSC SSP Survey



✶ Spectroscopy: 4 Normal + 2 Intensive Programs with ***FOCAS***

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

S16B-071I *"Subaru High-z Exploration of Low-Luminosity Quasars"*
- ✶ 20 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 nights in S18B - S21B
- ✶ Immediate Objectives:
  - ✓ To discover 50 low-L ($M_{1450} < -23$ mag) quasars at $6.5 < z < 7.5$
  - ✓ To establish quasar luminosity function at $z = 7$

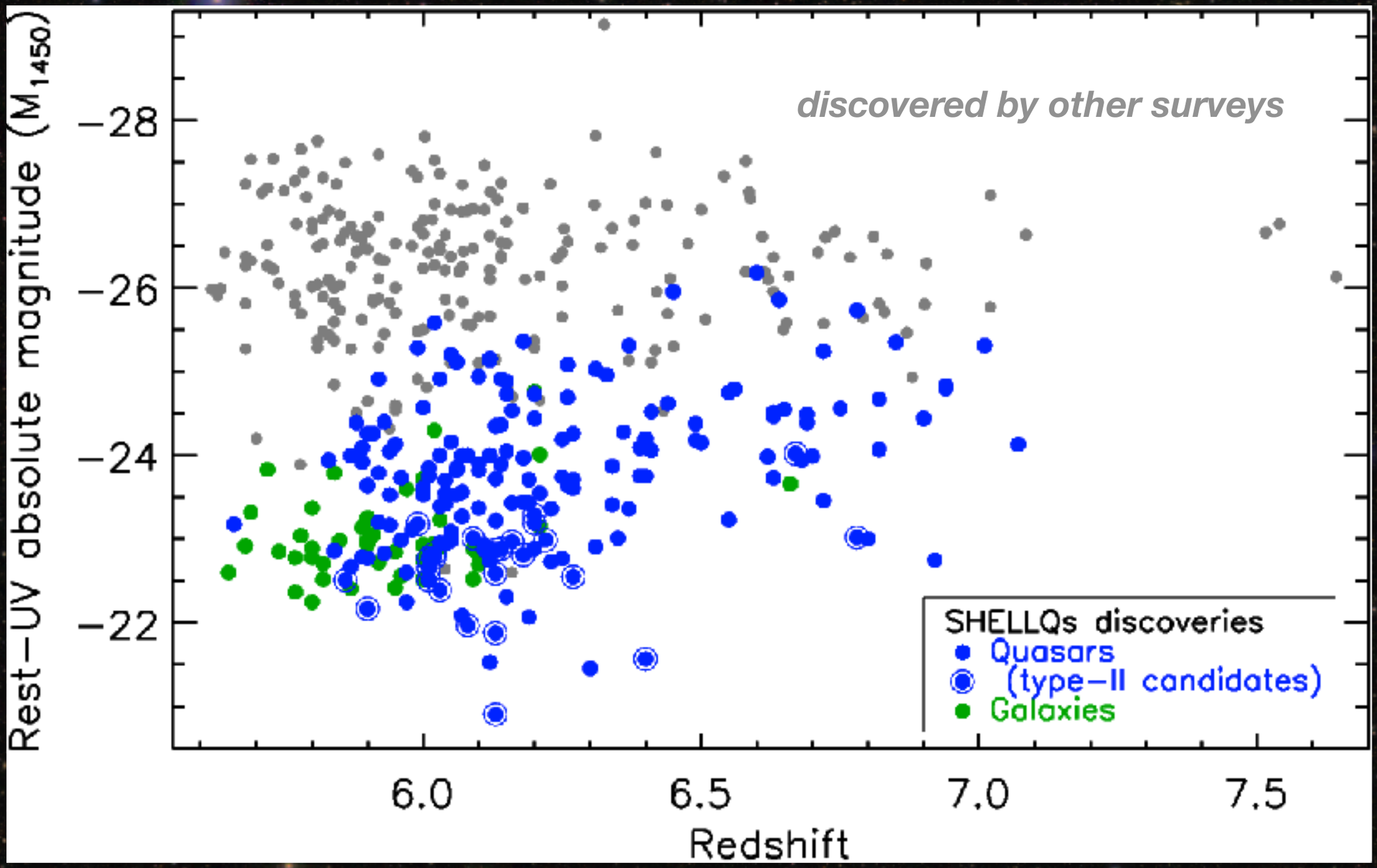
S22A-025 *"A Search for the Youngest Quasars in the Early Universe"* (1 night)

★ 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)
- ✓ Apr 2019 (2.5 nights) … 60% clear
- ✓ May 2019 (1.5 nights) … 100% clear
- ✓ Jun 2019 (1 night) … 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
- ✓ Dec 2020 (2 nights) … 100% clear
- ✓ Jan 2021 (3 nights) … 100% clear
- ✓ Feb 2021 (4 nights) … 60% clear
- ✓ Mar 2021 (1 night) … 100% clear
- ✓ Nov 2021 (2 nights) … 75% clear
- ✓ Dec 2021 (2.5 nights) … 60% clear → ***30 nights completed!***

In total, ~30% lost due to telescope/instrument/operational troubles,
~20% lost due to bad weather,
~50% observed successfully.

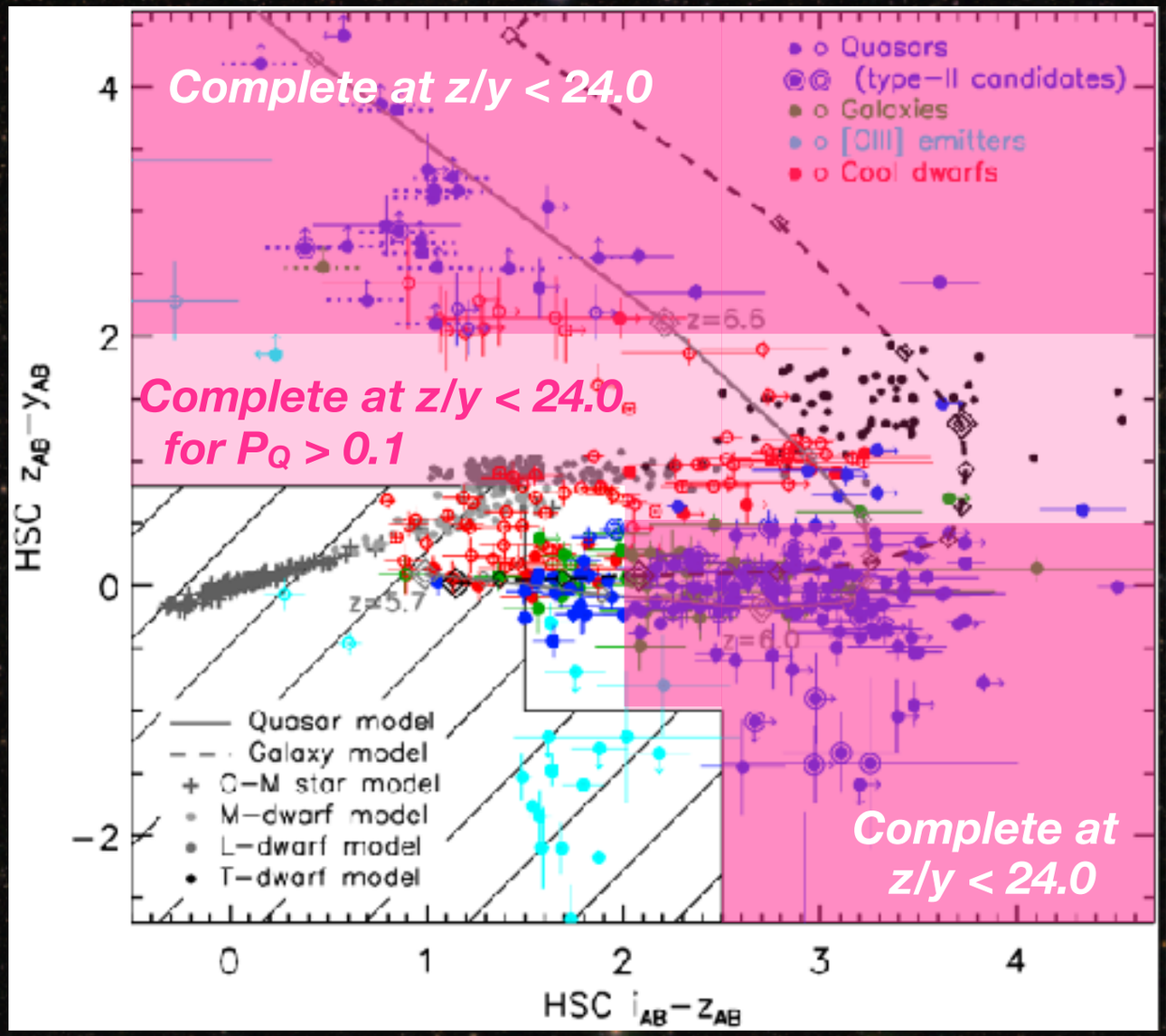
Discoveries so far

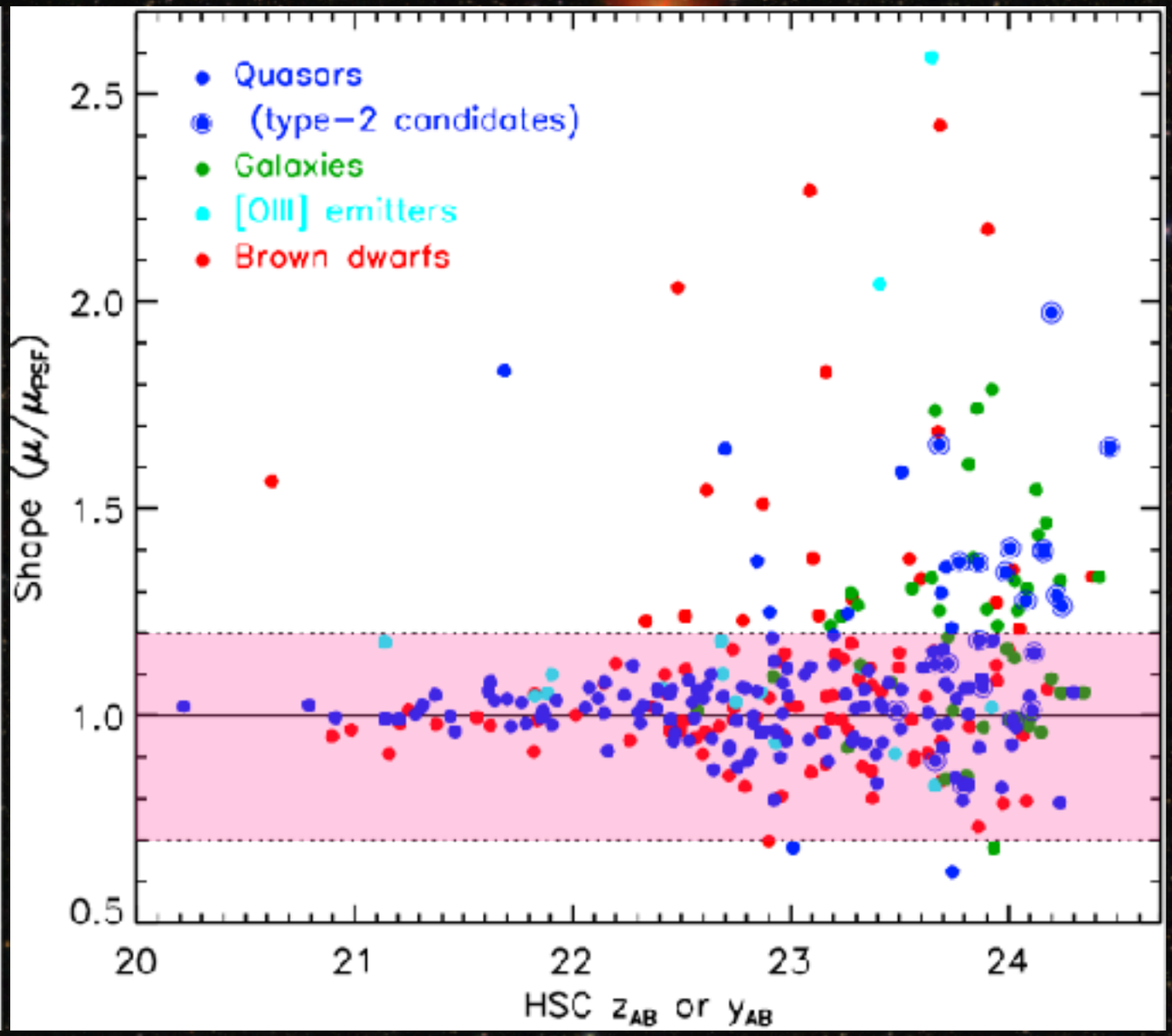


✓ 30 (175) quasars at $z > 6.5$ (5.8)

… fewer than originally expected (50 at $z > 6.5$) over the entire survey area, suggesting an accelerating decline in number density toward higher redshift

How is it complete?

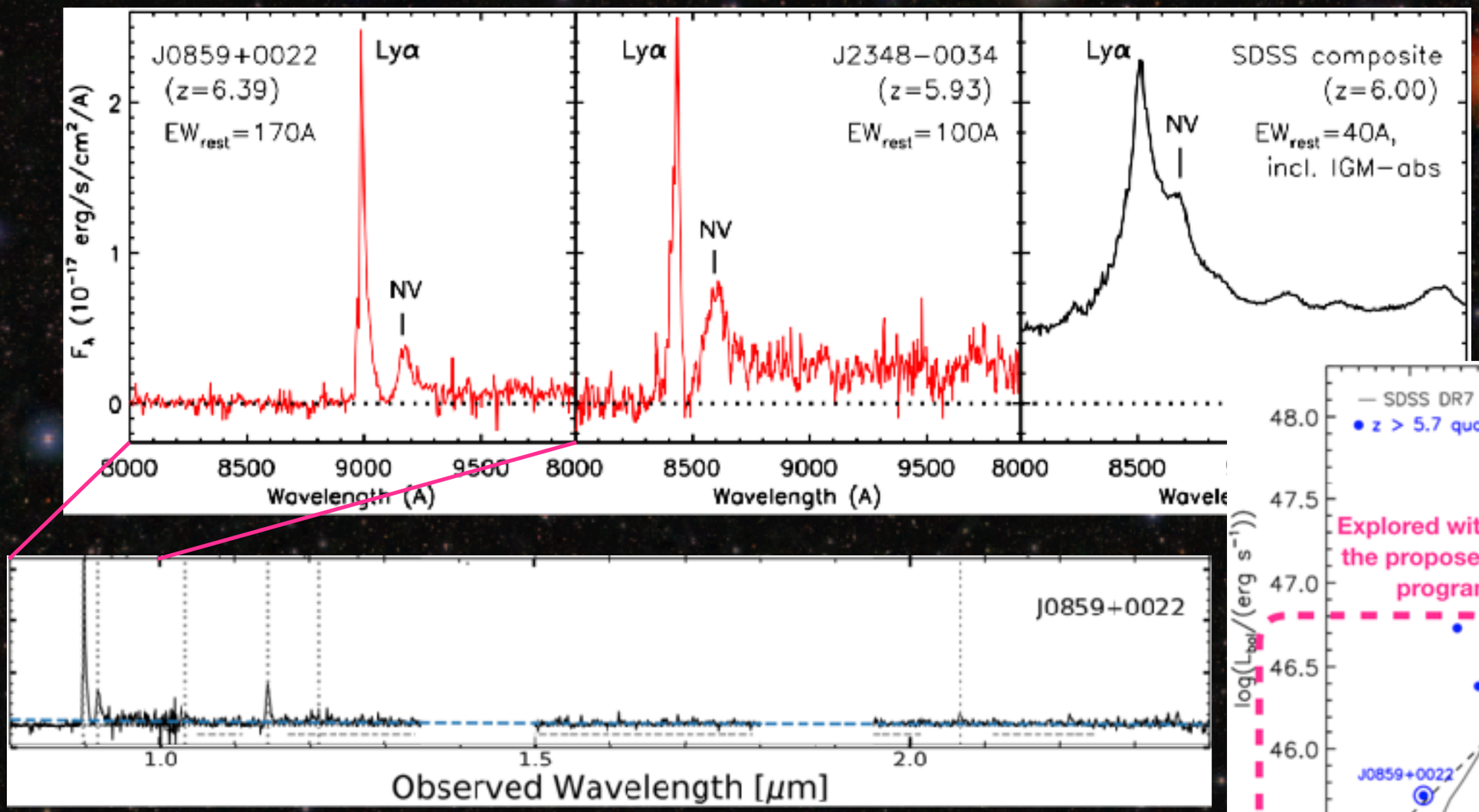




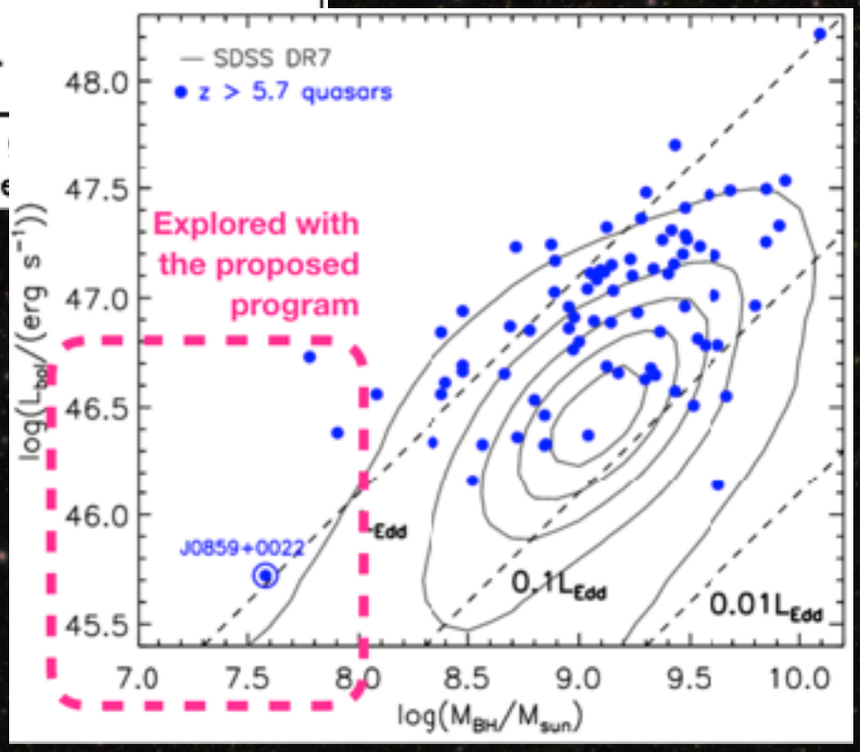
(for PDR3 candidates)

We are opening up a new frontier…

✓ **High-z cousins of narrow-line Seyfert 1s** with the youngest SMBHs?



Onoue et al. (2019)



→ Systematic spectroscopic survey with FOCAS

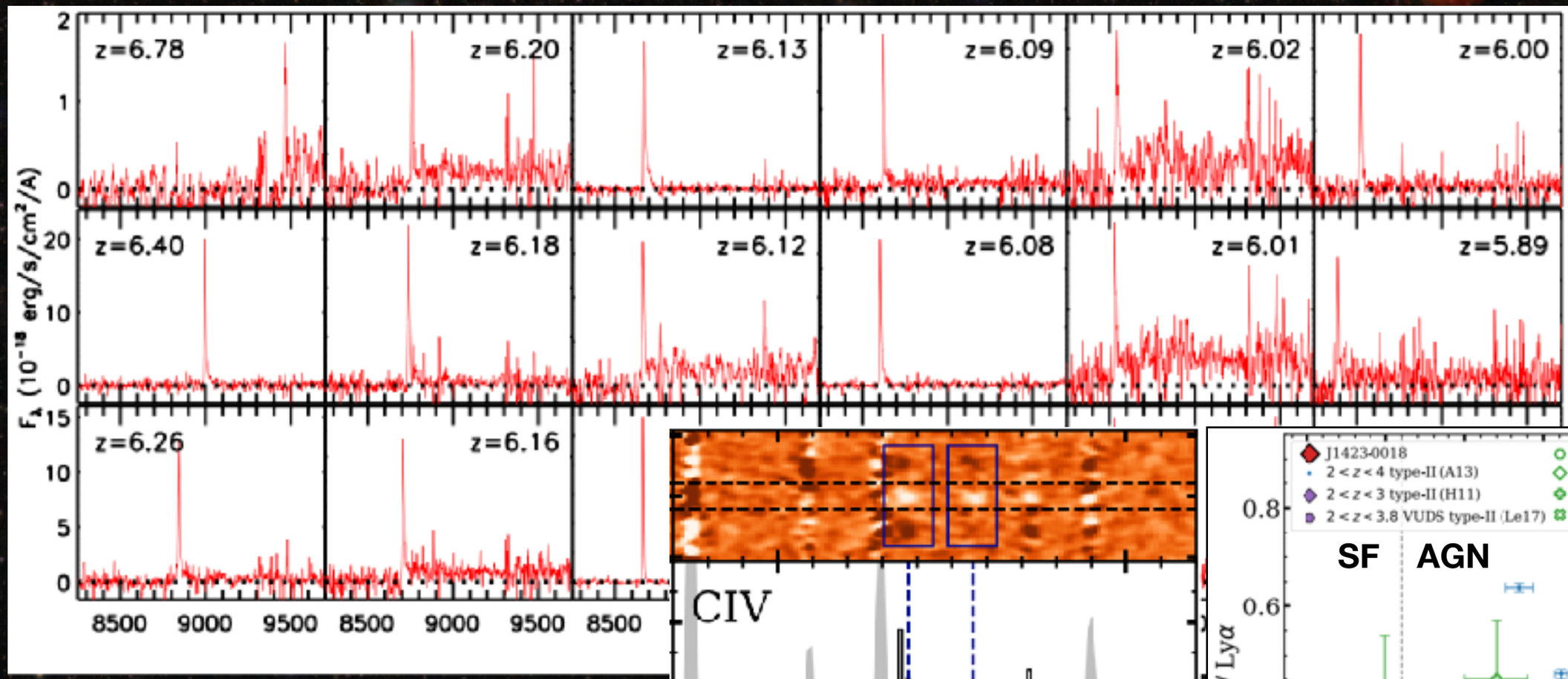
★ S22A-025 *"A Search for the Youngest Quasars in the Early Universe"* (1 night)

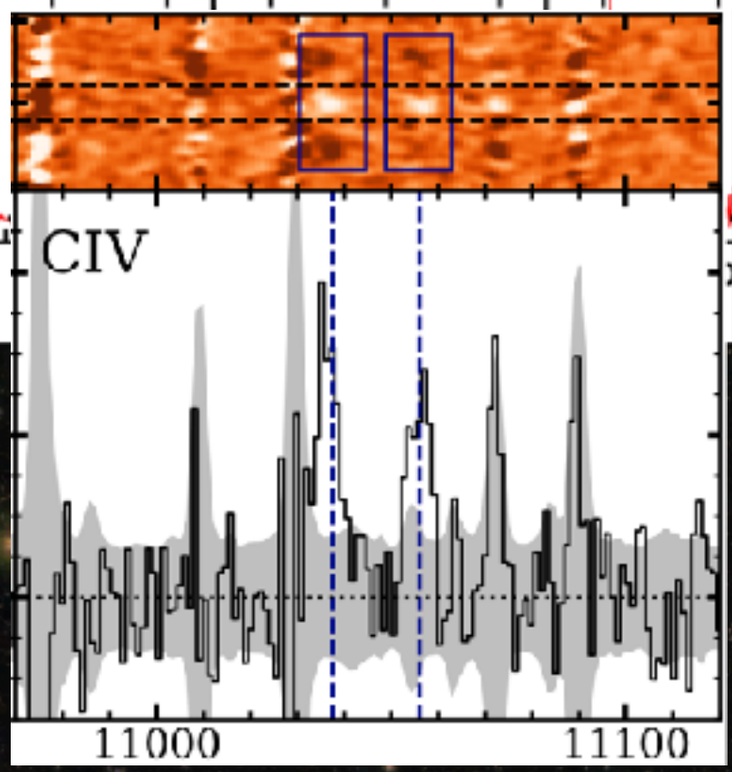
★ We plan to propose for more observing time in future semester(s)

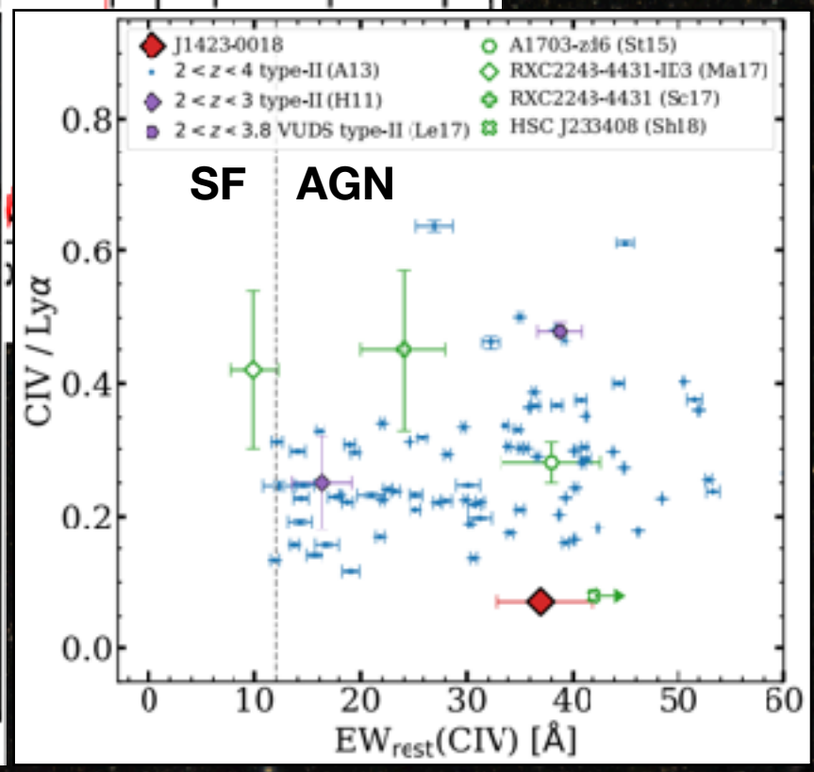
We are opening up a new frontier…

✓ **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?





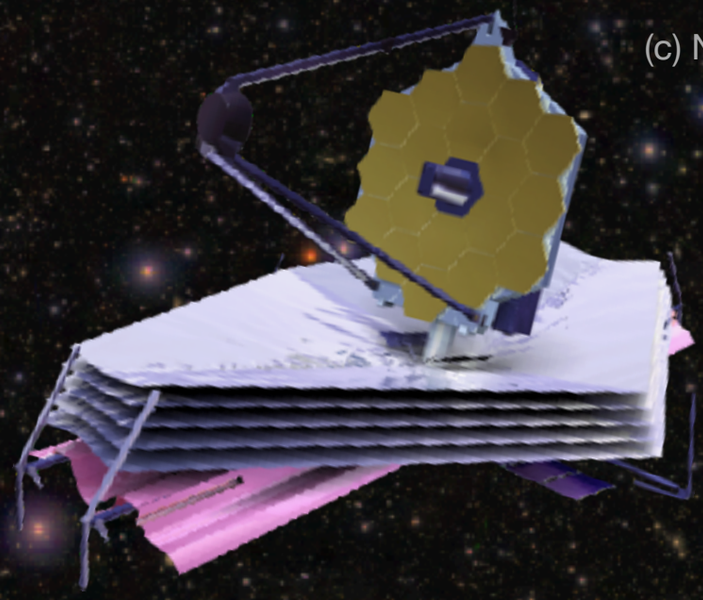


Onoue et al. (2021)

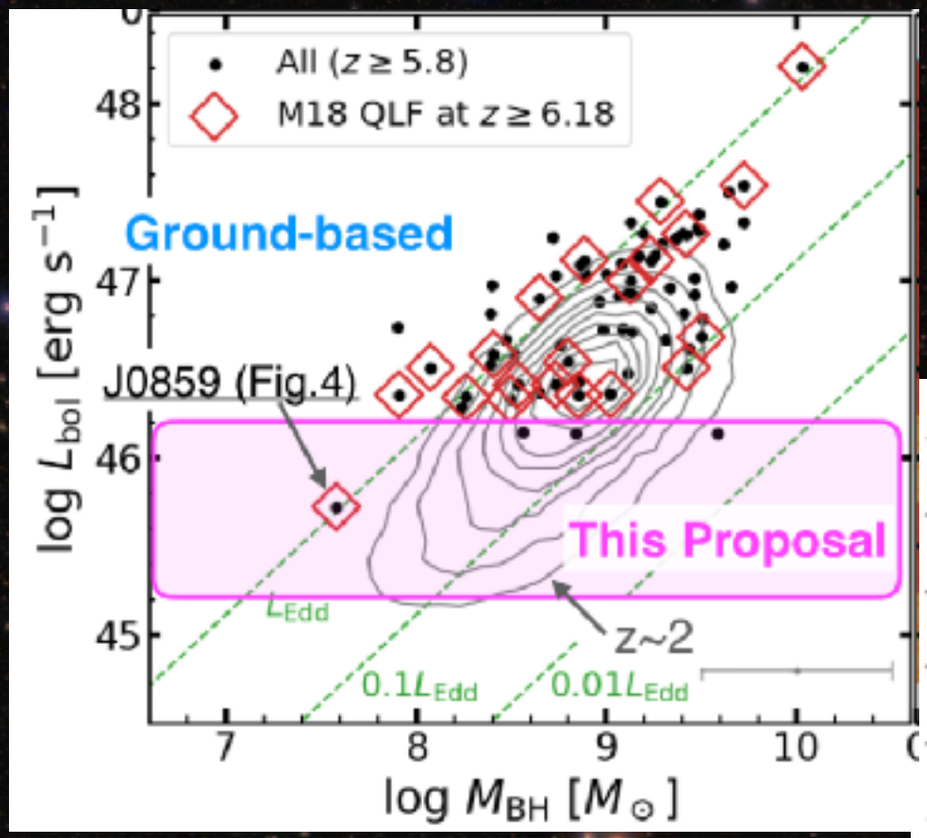
→ Chandra observations approved to look for AGN signature in four objects

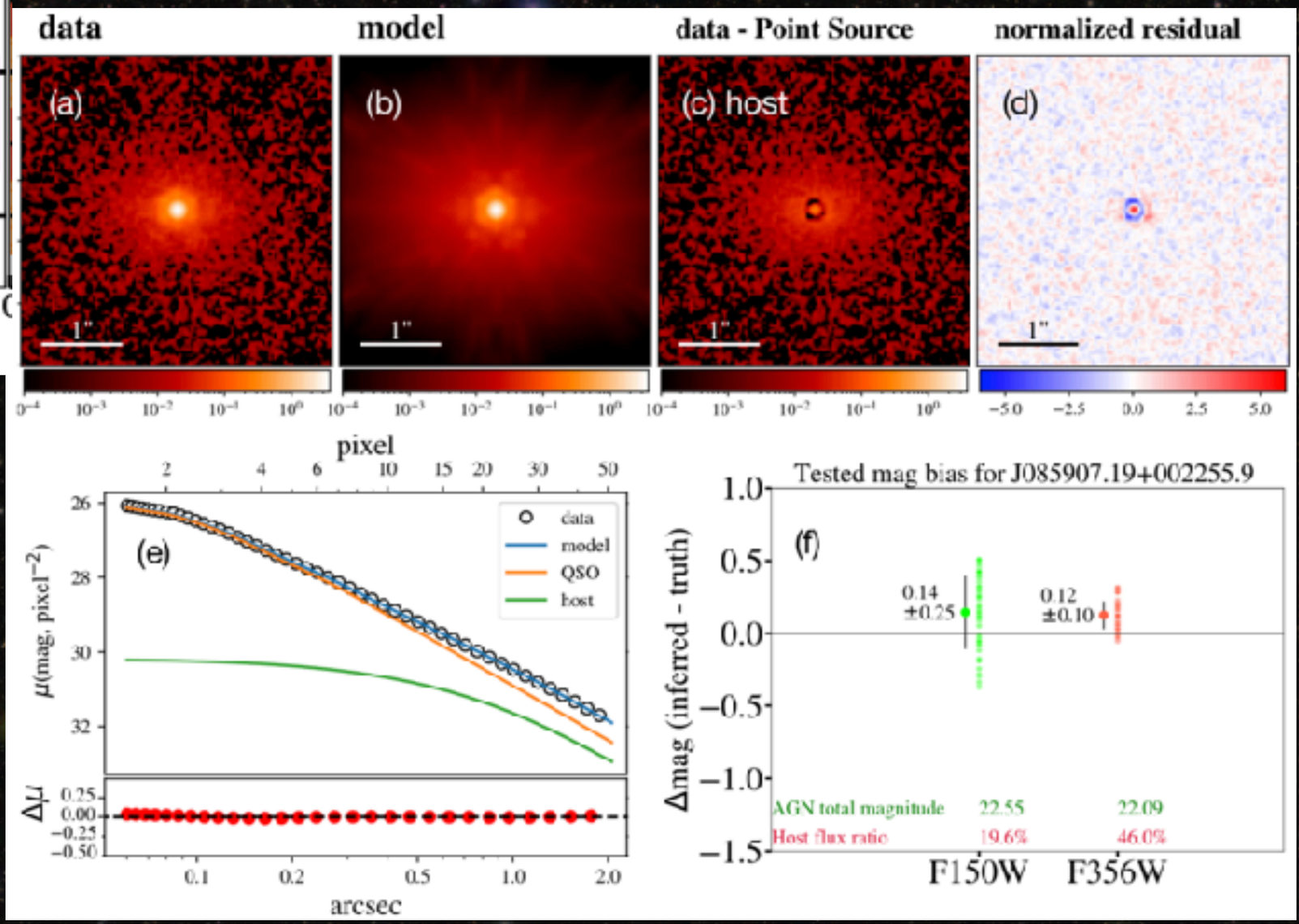
JWST medium-sized program

(50 hours with NIRCam and NIRSpec)



(c) NASA





Conclusion and future prospects

- We are making good progress. We've discovered 30 (175) quasars at $z > 6.5$ (5.8), probing unprecedentedly low luminosity and thus enabling significant discoveries on the early Universe.

- Our next goal is to establish the first accurate quasar luminosity function at $z \sim 7$, which we hope to complete this year.

- Diverse new programs have been emerging, including exploration of type-II quasars, NLS1-type quasars, and dust-reddened quasars, as well as large follow-up observations with JWST and ALMA.