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

Progress Report

Yoshiki Matsuoka (Ehime Univ.)
on behalf of the SHELLQs collaboration

SHELLQs

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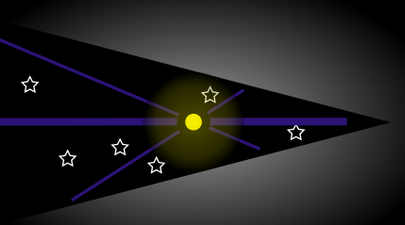

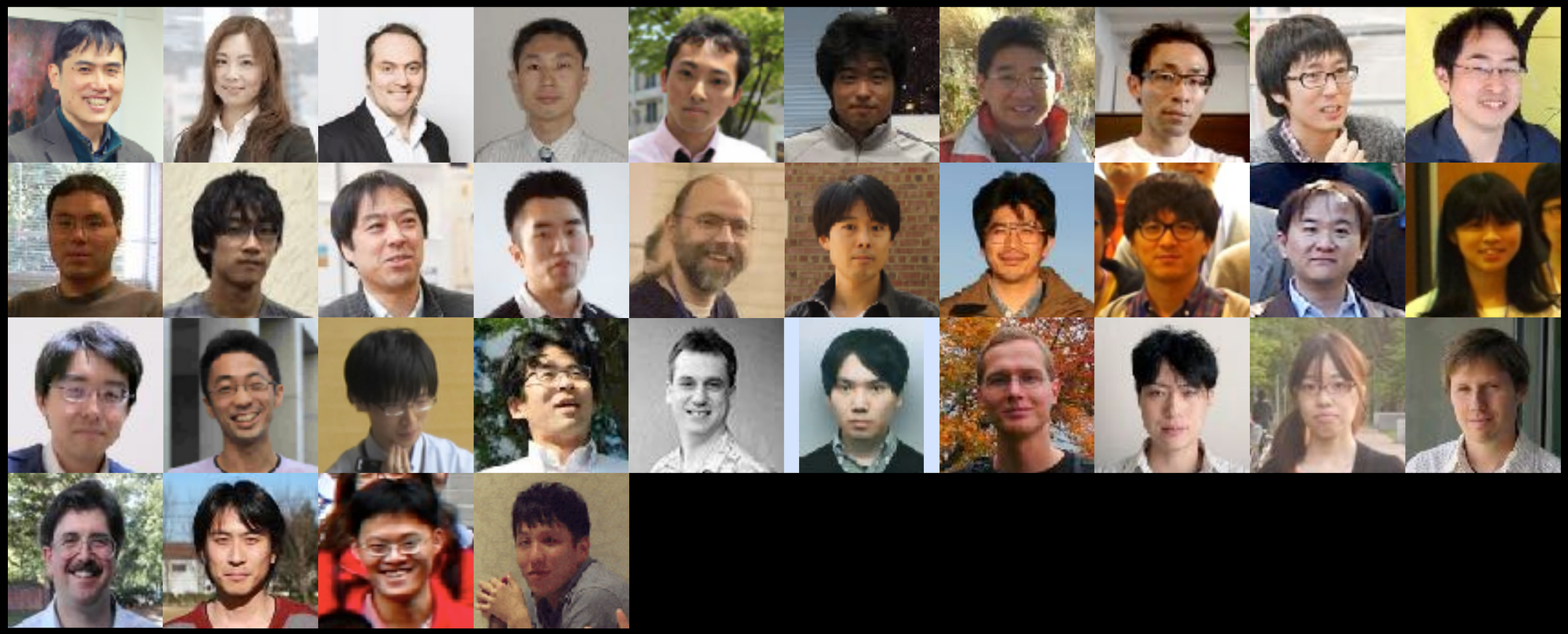

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High-z quasars - Unique probe of the early Universe

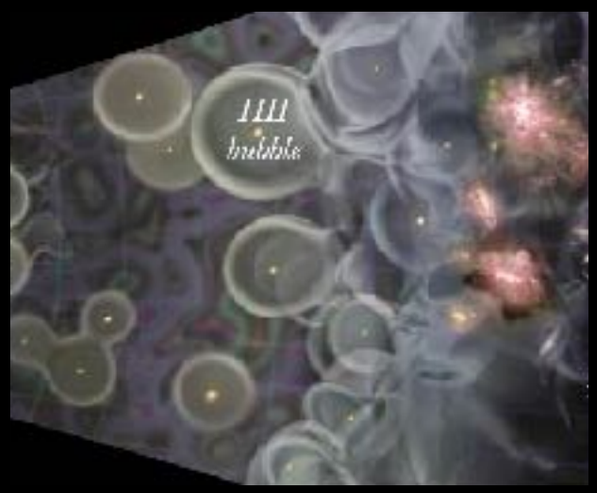
Fundamental questions we aim to answer:

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?

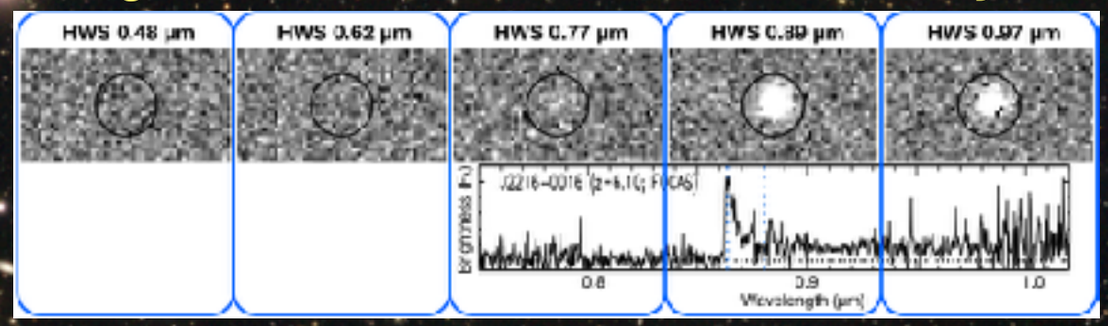
✶ When and how did the first stellar-mass assembly happen?
✶ Did SMBHs impact the host galaxy evolution? If so, how?
✶ Do they mark the highest density peaks of the DM distribution?



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!



HSC SSP survey

Bayesian probabilistic selection

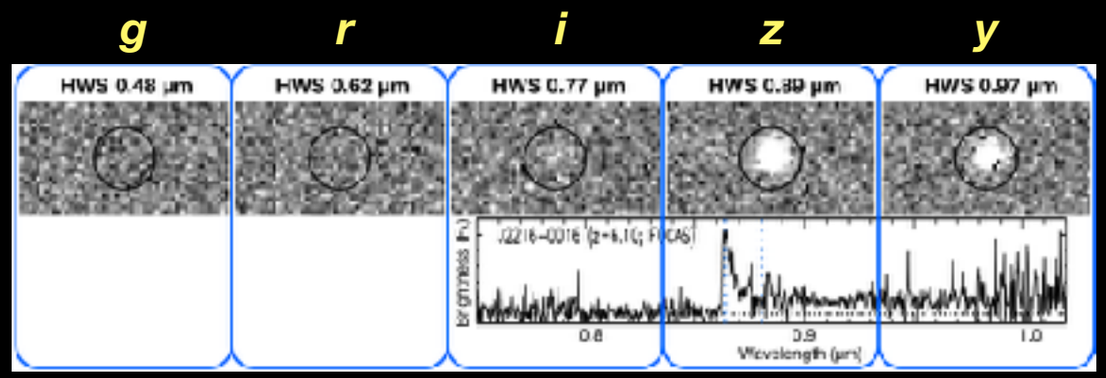
Quasar probability: $P_Q = W_Q/(W_Q+W_D)$

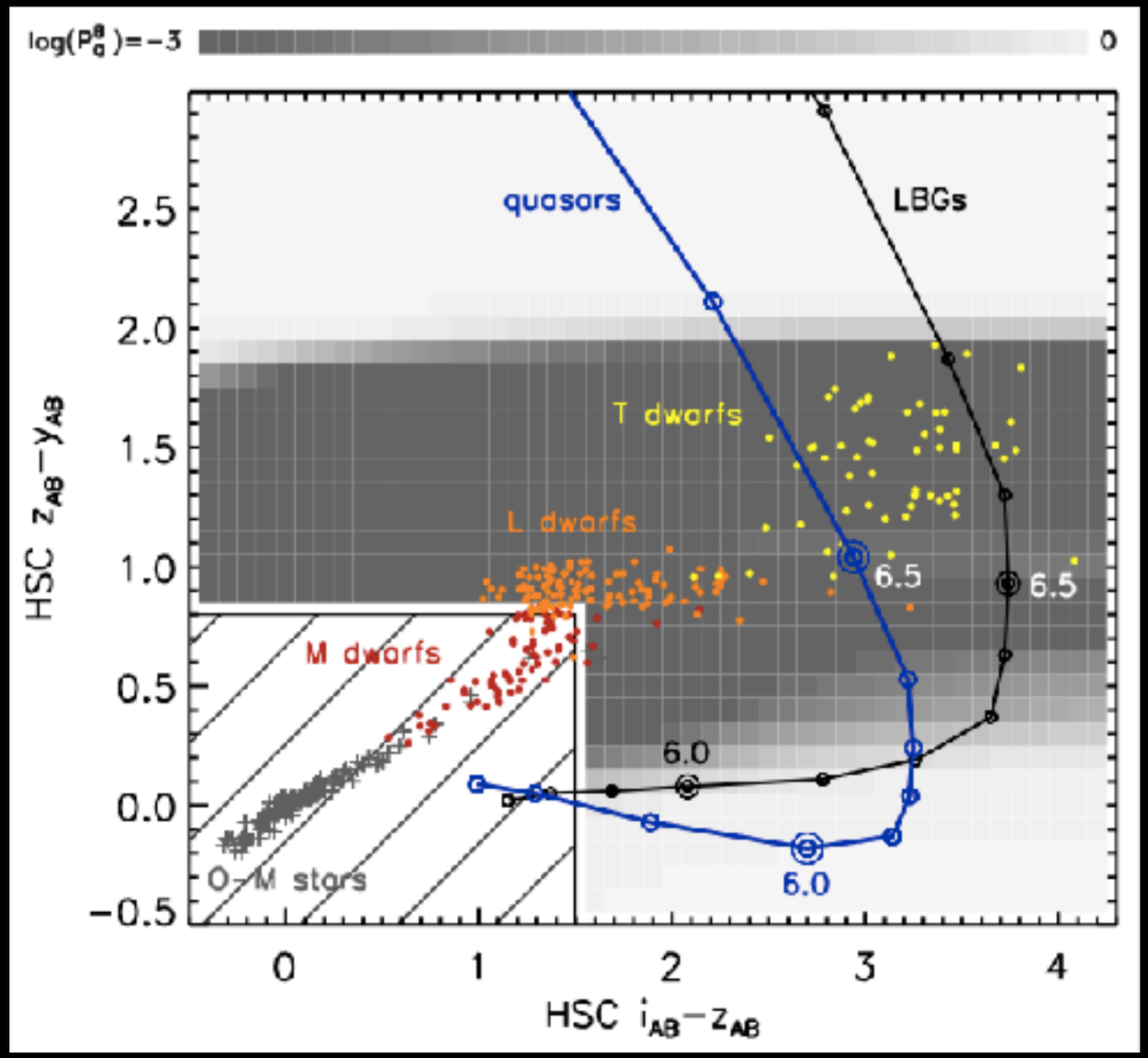
W_Q (**m**, det) = $\int\int \rho_Q (m_{int}, z)$ Pr (det | m_{int}, z) Pr (**m** | m_{int}, z) $dm_{int}\, dz$

W_D (**m**, det) = $\int\int \rho_D (m_{int}, t_{sp})$ Pr (det | m_{int}, t_{sp}) Pr (**m** | m_{int}, t_{sp}) $dm_{int}\, dt_{sp}$

observed magnitudes in HSC + NIR bands

source detection





→ Spectroscopic follow-up of all the photometric candidates with $P_Q > 0.1$

SHELLQs progress to date

✶ The HSC S16A data release contains ~430 deg^2 (S17A contains more) of the Wide fields, with more than a single exposures in the *i*, *z*, and *y* bands.

✶ Spectroscopic follow-up is underway: >100 HSC sources have been identified so far.



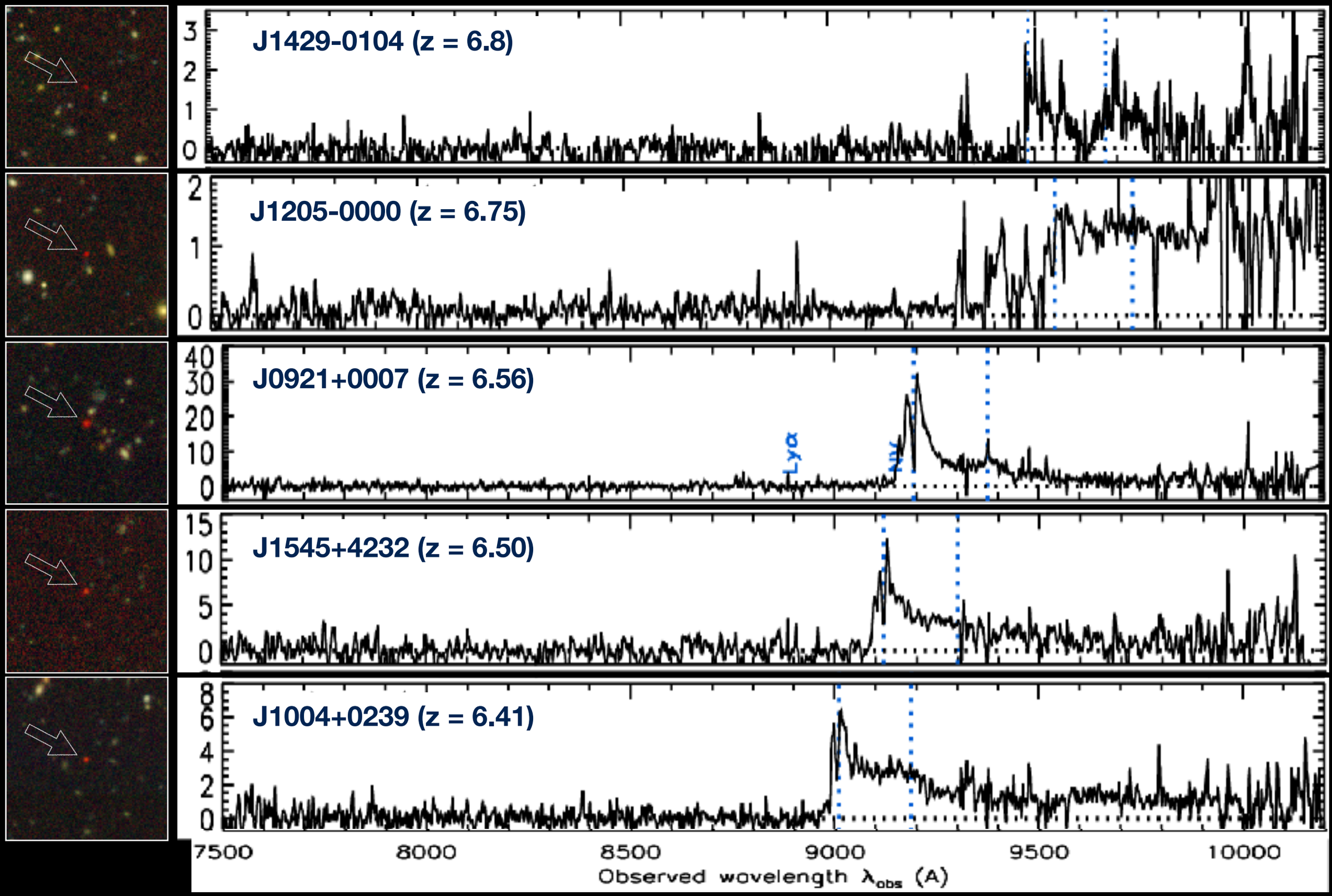
✔ Subaru/FOCAS: 10 nights in S15A-S16A normal programs → ~80% clear

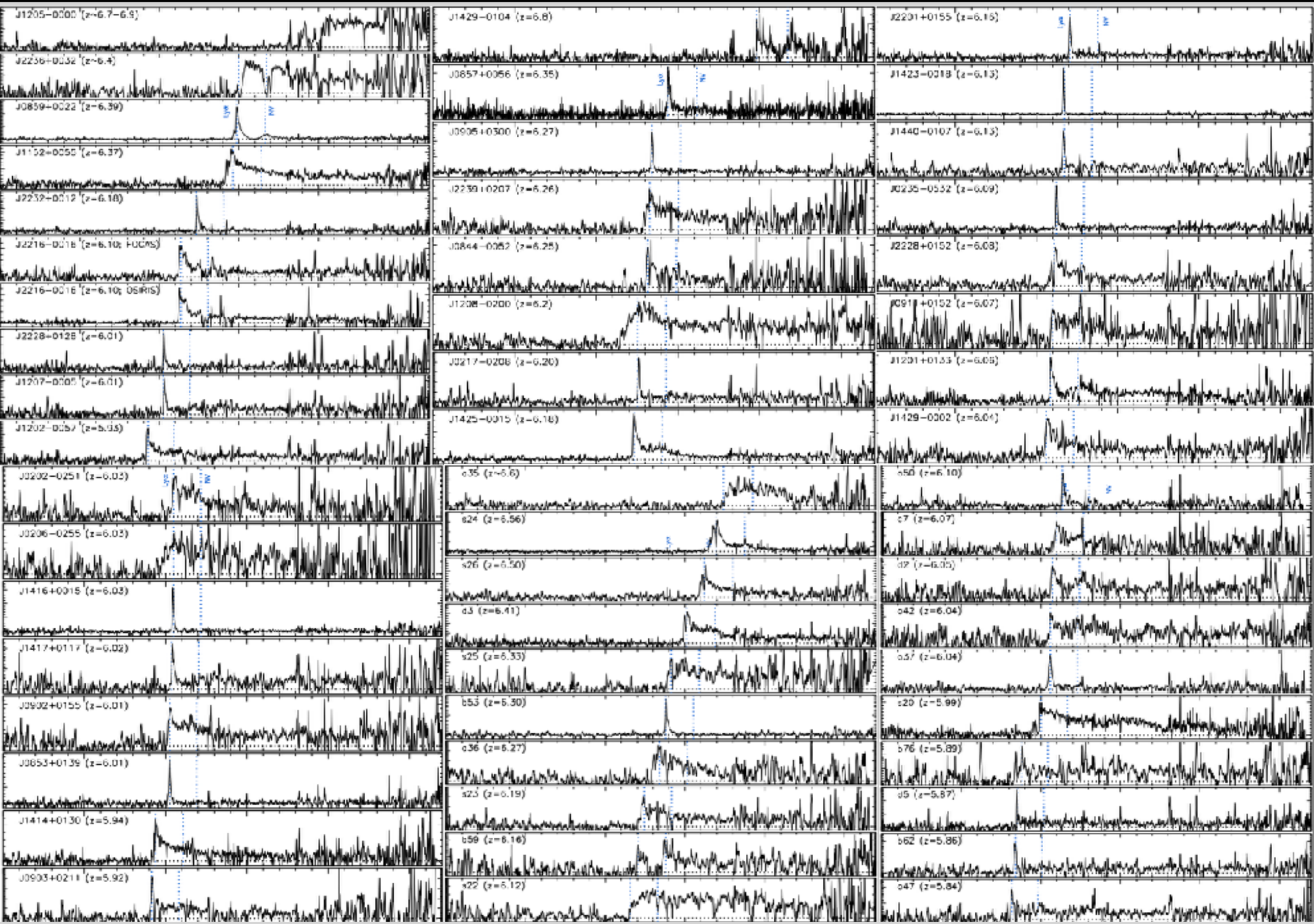
20 nights in S16B-S18A intensive program

- Sep 2016 (2 nights) → ~70% clear
- Dec 2016 (2 nights) → 0% (storm; no access to the summit)
- Jan 2017 (1 night) → ~50% clear
- Mar 2017 (3.5 nights) → 100% clear
- Apr 2017 (1.5 nights) → 0% (wind-screen trouble)
- May 2017 (0.5 night) → 100% clear
- Sep 2017 (5 nights) → 100% clear
- 5 more nights in S18A semester

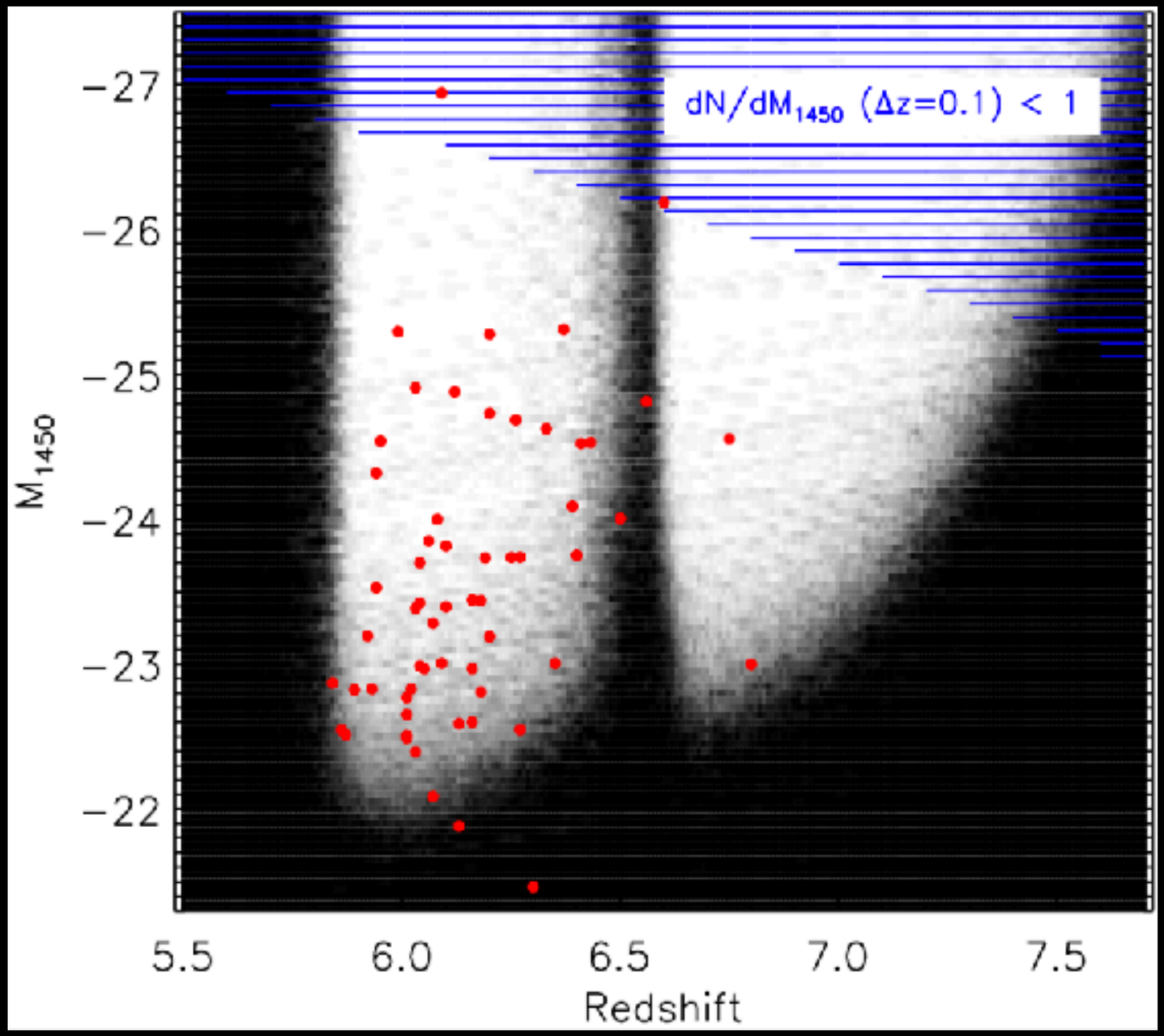
✔ GTC/OSIRIS and Gemini/GMOS-S: for brighter candidates than FOCAS targets

We are finding A LOT…




J1205−0000 (z~6.7–6.9)
J2236+0032 (z~6.4)
J0859+0022 (z=6.39)
J1152+0055 (z=6.37)
J2232+0012 (z=6.18)
J2216−0016 (z=6.10; FOCAS)
J2216−0016 (z=6.10; DEIMOS)
J2228+0128 (z=6.01)
J1207−0005 (z=6.01)
J1202−0057 (z=5.93)
J0202−0251 (z=6.03)
J0206−0255 (z=6.03)
J1416+0015 (z=6.03)
J1417+0117 (z=6.02)
J0902+0155 (z=6.01)
J0853+0139 (z=6.01)
J1414+0130 (z=5.94)
J0903+0211 (z=5.92)
J1429−0104 (z=6.8)
J0857+0056 (z=6.35)
J0905+0500 (z=6.27)
J2239+0207 (z=6.26)
J0844−0052 (z=6.25)
J1208−0200 (z=6.2)
J0217−0208 (z=6.20)
J1425−0015 (z=6.18)
s35 (z~6.6)
s24 (z=6.56)
s26 (z=6.50)
d3 (z=6.41)
s25 (z=6.33)
b53 (z=6.30)
c36 (z=6.27)
s23 (z=6.19)
b59 (z=6.16)
s22 (z=6.12)
J2231+0155 (z=6.15)
J1423−0018 (z=6.13)
J1440−0107 (z=6.13)
J0235−0532 (z=6.09)
J2228+0152 (z=6.08)
J091[illegible]+0152 (z=6.07)
J1231+0153 (z=6.05)
J1429−0002 (z=6.04)
s50 (z=6.10)
c7 (z=6.07)
d2 (z=6.05)
b42 (z=6.04)
b57 (z=6.04)
s20 (z=5.99)
b76 (z=5.89)
d5 (z=5.87)
b62 (z=5.86)
b47 (z=5.84)

We are achieving full success!

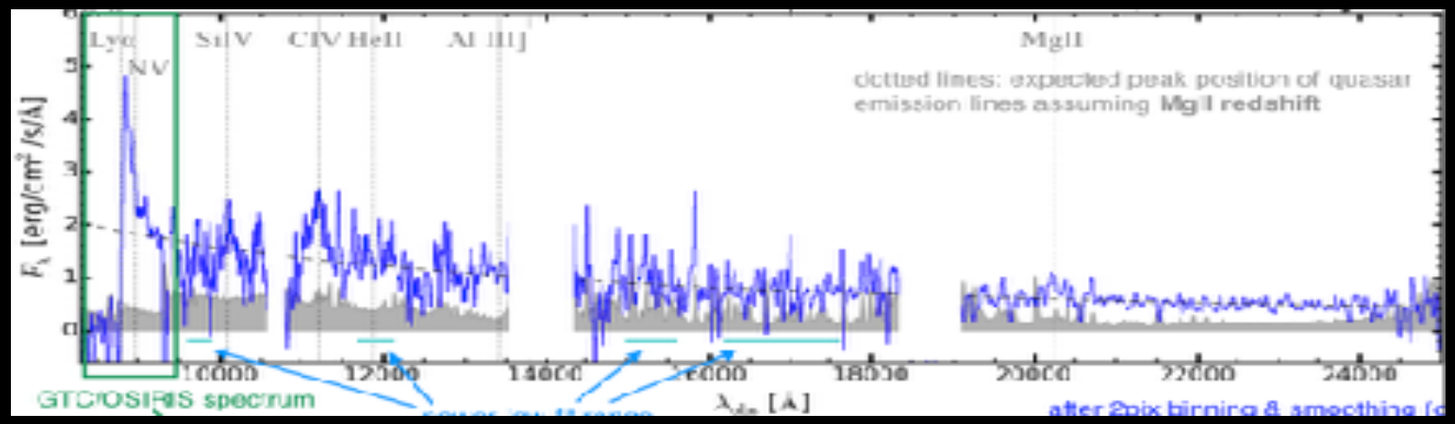


Survey completeness

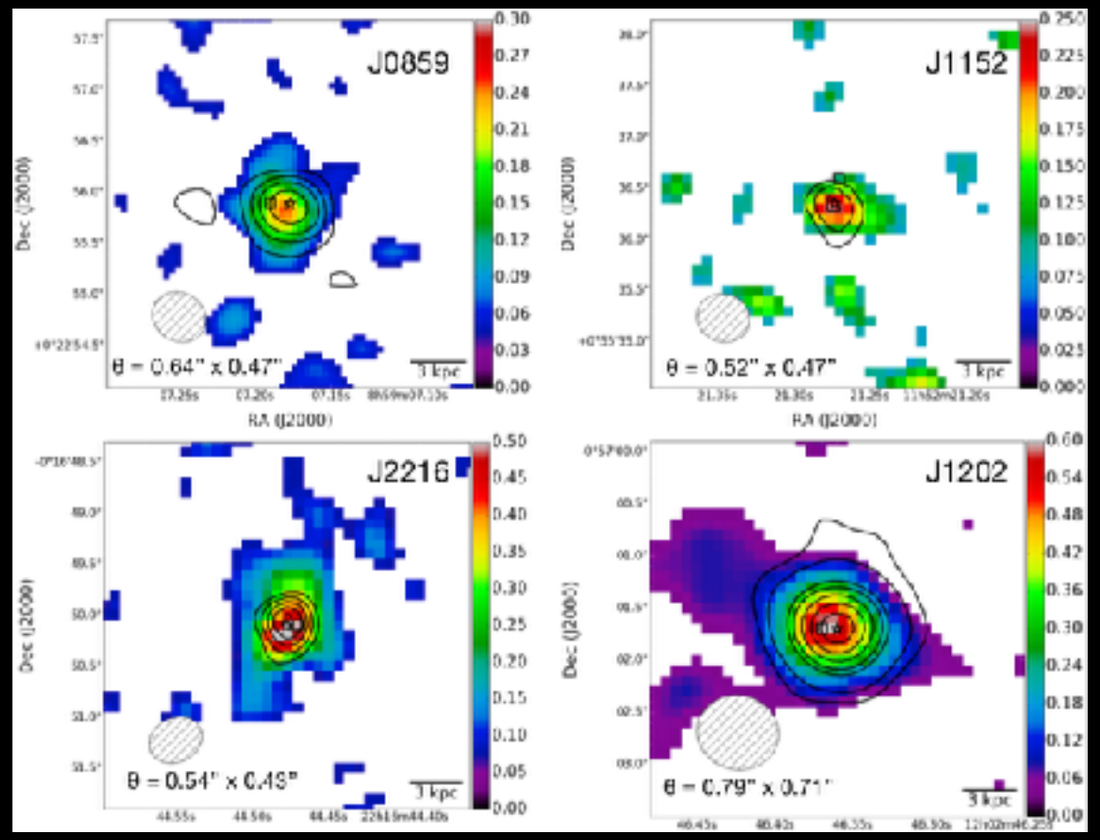
- We discovered ~70 quasars at $5.9 < z < 6.9$ so far (Matsuoka+16,17,18).
- 29 quasars with $z_{AB} < 24$ mag at $z < 6.5$ constitute our "complete sample" now.
  → luminosity function, and the contribution to cosmic reionization

Multi-wavelength follow-up observations

✶ *BH mass measurements*
(led by M. Onoue)
✓ VLT/X-shooter (16B)
✓ Gemini/GNIRS (FT + 17A)
✓ Subaru/MOIRCS (18A)



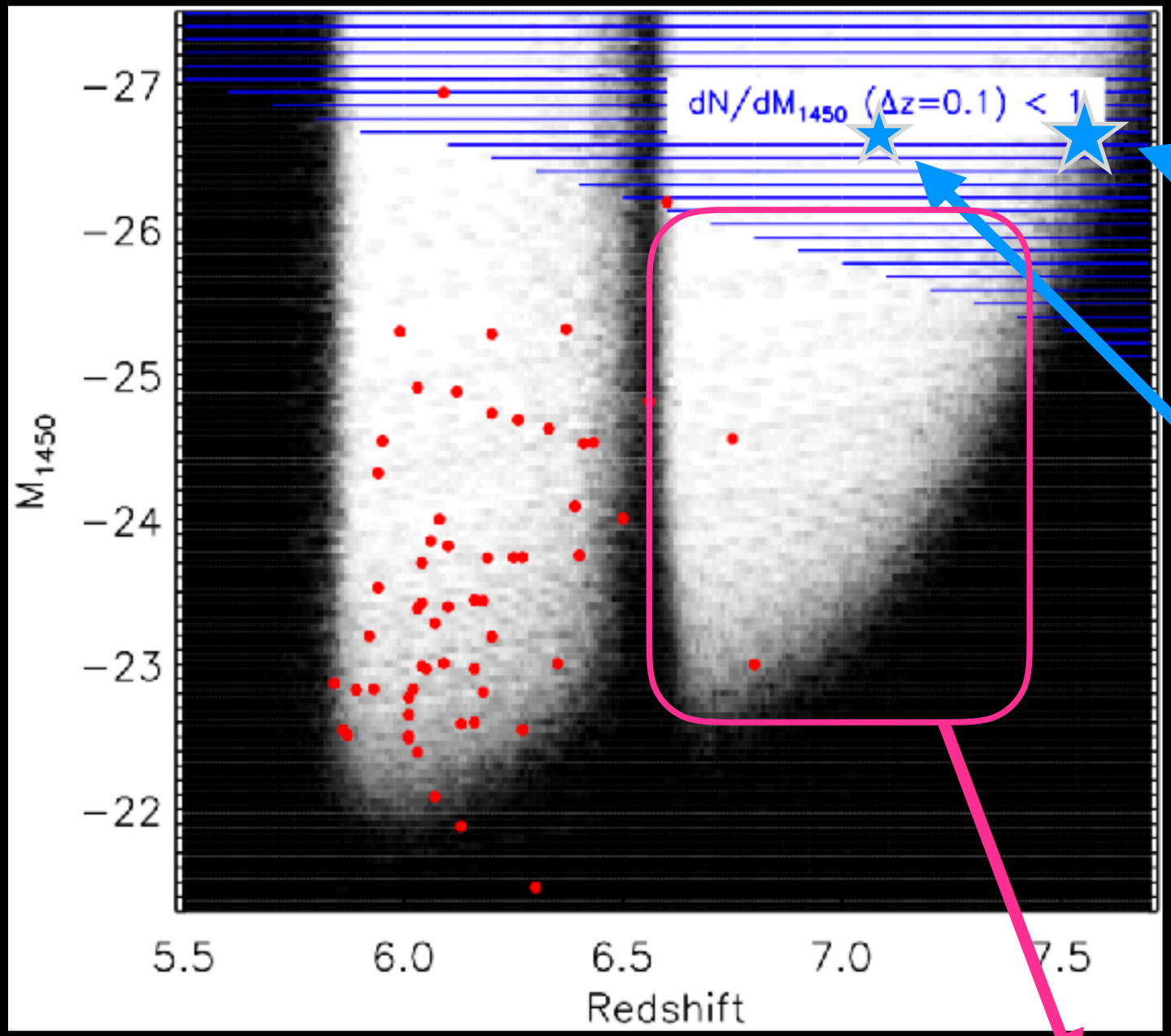
✶ *Extremely-luminous Ly**α** objects*
(led by M. Onoue & N. Kashikawa)
✓ VLT/X-shooter (18A)



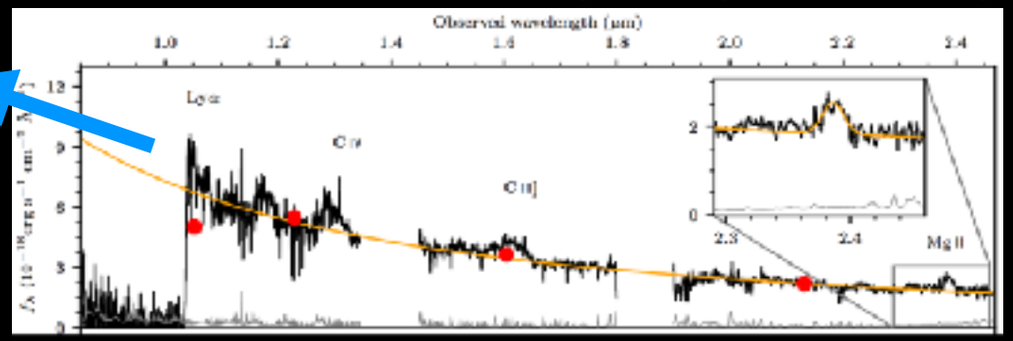
✶ *Star formation, dust, and mass of the host galaxies* (led by T. Izumi)
✓ ALMA Band 6 (Cycles 4 & 5)

✶ *Proposals being considered*
✓ JVLA … radio properties (led by C.-F. Lee)
✓ JWST … host galaxies (led by YM & T. Izumi)
BH mass (led by M. Onoue)
nature of extremely-luminous Ly**α** objects (led by T. Nagao)
dust torus (led by Y. Toba)

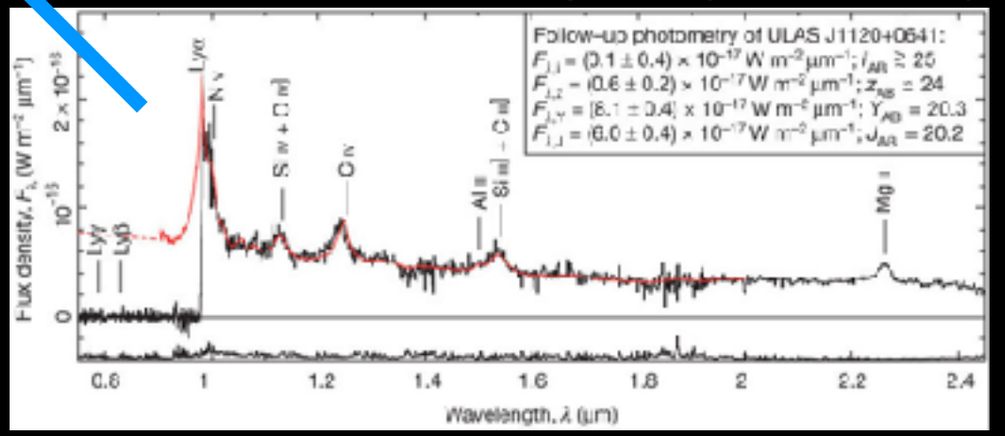
What's next? (from discovery viewpoint)



z = 7.54 quasar (Banados+17)



z = 7.09 quasar (Mortlock+11)



First systematic exploration of quasars at z ≳ 7

(perhaps with FOCAS + NIR spectrograph)