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

Progress Report

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on behalf of the SHELLQs collaboration
SHELLQs

Subaru High-z Exploration of Low-Luminosity Quasars

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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: \( P_Q = \frac{W_Q}{W_Q + W_D} \)

\[
W_Q (m, \text{det}) = \int \int \rho_Q (m_{\text{int}}, z) \Pr (\text{det} | m_{\text{int}}, z) \Pr (m | m_{\text{int}}, z) \, dm_{\text{int}} \, dz \\
W_D (m, \text{det}) = \int \int \rho_D (m_{\text{int}}, t_{sp}) \Pr (\text{det} | m_{\text{int}}, t_{sp}) \Pr (m | m_{\text{int}}, t_{sp}) \, dm_{\text{int}} \, dt_{sp}
\]

→ Spectroscopic follow-up of all the photometric candidates with \( P_Q > 0.1 \)
SHELLQs progress to date

- The HSC S16A data release contains ~430 deg² (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 $\rightarrow$ ~80% clear
  20 nights in S16B-S18A intensive program
    - Sep 2016 (2 nights) $\rightarrow$ ~70% clear
    - Dec 2016 (2 nights) $\rightarrow$ 0% (storm; no access to the summit)
    - Jan 2017 (1 night) $\rightarrow$ ~50% clear
    - Mar 2017 (3.5 nights) $\rightarrow$ 100% clear
    - Apr 2017 (1.5 nights) $\rightarrow$ 0% (wind-screen trouble)
    - May 2017 (0.5 night) $\rightarrow$ 100% clear
    - Sep 2017 (5 nights) $\rightarrow$ 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...

- J1429-0104 (z = 6.8)
- J1205-0000 (z = 6.75)
- J0921+0007 (z = 6.56)
- J1545+4232 (z = 6.50)
- J1004+0239 (z = 6.41)
We are achieving full success!

- 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 Lyα 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 Lyα objects (led by T. Nagao)  
  dust torus (led by Y. Toba)
What’s next? (from discovery viewpoint)

First systematic exploration of quasars at $z \geq 7$
(Perhaps with FOCAS + NIR spectrograph)

$z = 7.54$ quasar (Banados+17)
$z = 7.09$ quasar (Mortlock+11)