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

Yoshiki Matsuoka (NAOJ)
on behalf of
the SHELLQs collaboration

SHELLQs

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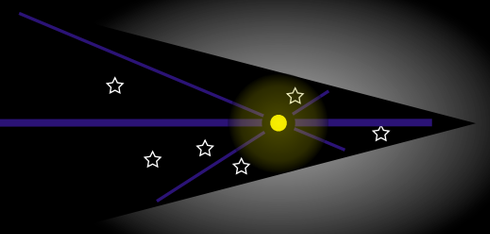

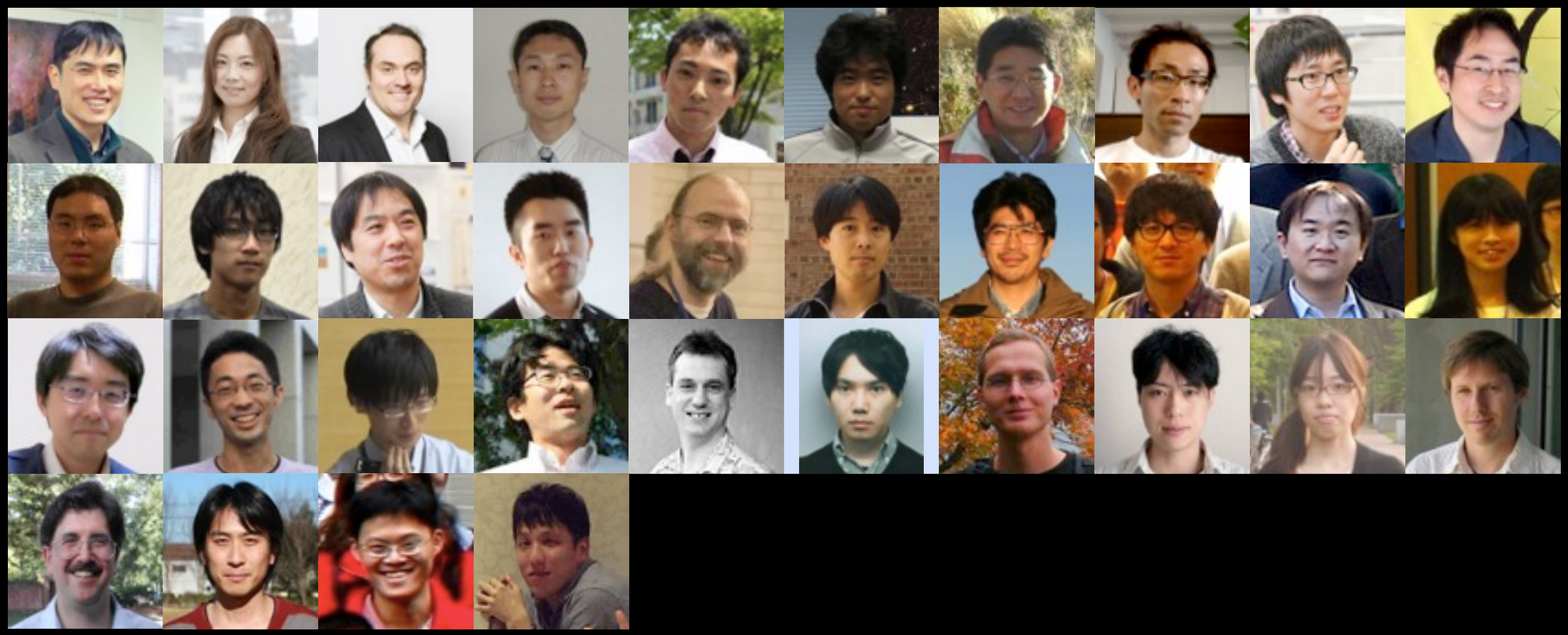

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High-z quasars - Unique probe of the early Universe

Fundamental questions we aim to answer:

Why do supermassive black holes (SMBHs) exist?

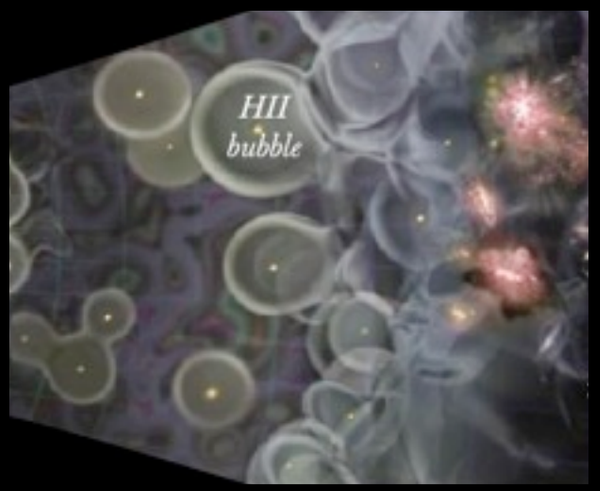
✶ When were they born?
✶ What were their seeds?
✶ How did they grow in the early and late epochs of the cosmic history?

[Observational signatures]
- What are the luminosity/mass functions of quasars/SMBHs?
- Are 10^9 M_{sun}-class SMBHs common or exceptional at $z > 6$?
- How do the luminosity/mass functions evolve towards lower redshift?

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 underlying matter distribution?

[Observational signatures]
- What are the current and past star formation activities, inferred from the amount and kinematics of the gas, current SFR, and chemical enrichment?
- Do we find special (e.g., over-dense) environments around the quasars/host galaxies?



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?

[Observational signatures]
- How does the IGM neutral fraction change along redshift and transverse direction?
- Do low-luminosity quasars emit enough UV photons to re-ionize the Universe?

and many more!

Past/ongoing surveys and their immense legacy value


SDSS 2.5m

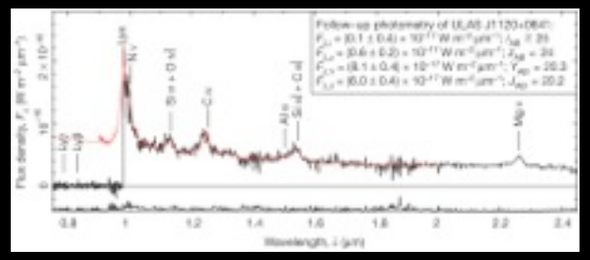

CFHT 3.6m


UKIDSS/VIKING 4m

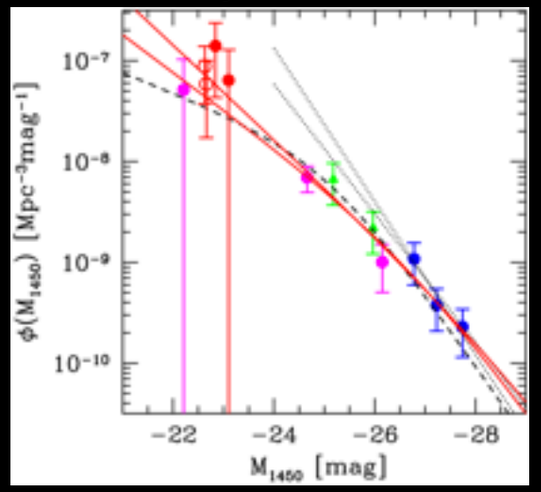

Pan-STARRS1 1.8m


DES 4m

~100 quasars known at z > 5.7:
only a few (one) at z > 6.5 (z > 7)
or M_{1450} > –24 mag

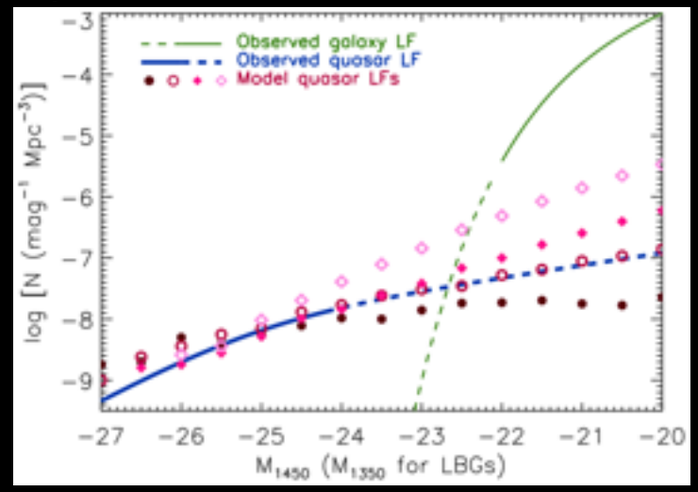

Mortlock+11

Luminosity function



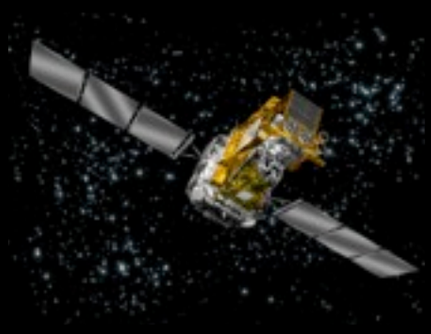
Kashikawa+15

Comparison with theoretical models



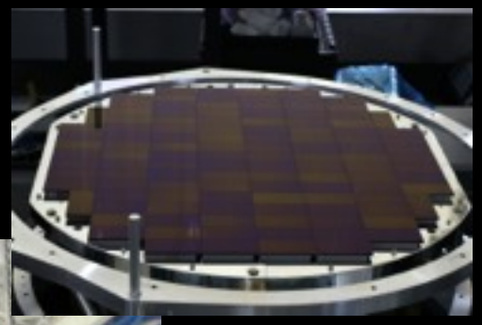
A wide variety of follow-up observations with

✶ ALMA for FIR-based SFR, gas and dust masses, gas kinematics, dynamical galaxy mass, ...
✶ Subaru and other large optical/near-IR telescopes (→ELTs) for SMBH mass, metallicity distribution, IGM properties, ...
✶ HST (→JWST) for the morphology, UV-based SFR, etc. in the host galaxies, surrounding ionized gas, ...
✶ Chandra and XMM-Newton (→ATHENA) for intrinsic mass accretion rate, Eddington ratio, absorbers, ...



Subaru Hyper Suprime-Cam SSP survey

Hyper Suprime-Cam (HSC)
- 116 2K x 4K Hamamatsu FD CCDs
  (104 CCDs are used for science exposures)
- Circular FoV of 1°.5 diameter
- Installed on the Subaru 8.2-m telescope
- Miyazaki et al. (2016, in prep.)



The HSC SSP (Subaru Strategic Program) survey
- 300 Subaru nights over 5 years, started in early 2014.
  - Wide: $r_{AB} < 26.1$ mag over 1400 deg^2
  - Deep: $r_{AB} < 27.1$ mag over 27 deg^2
  - UDeep: $r_{AB} < 27.7$ mag over 3.5 deg^2
- Filters: (*g, r, i, z, y*) in Wide, + NBs in Deep & UDeep
- The Wide has just reached the full-depth, full-color area of 200 deg^2.

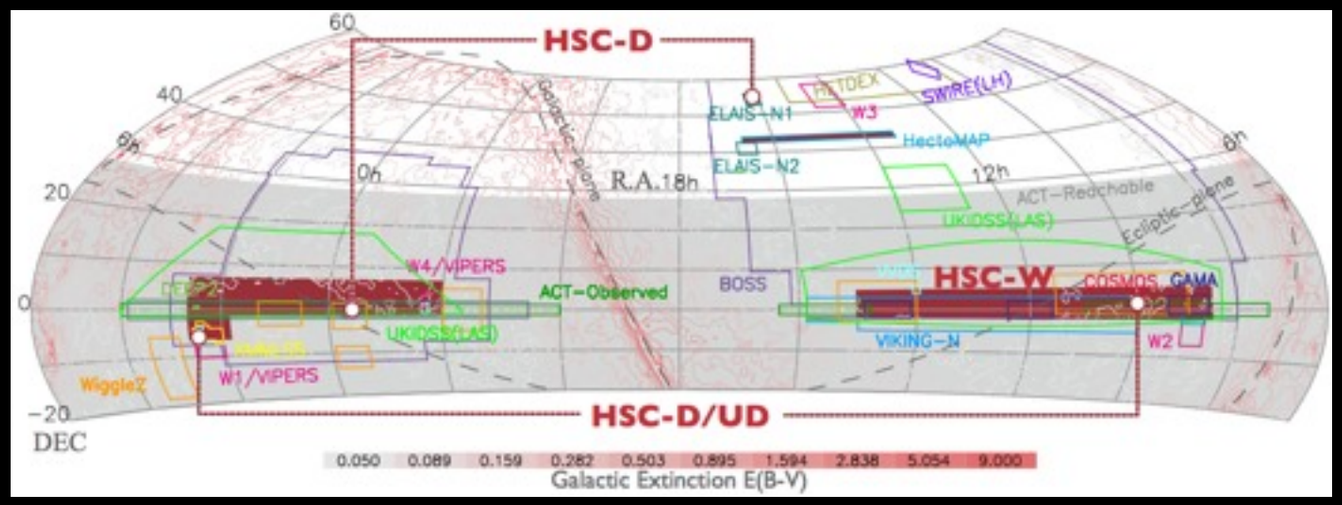


Table 7: Quasar Samples

	Wide (1400 deg^2)				Deep (27 deg^2)			
redshift	3.7–4.6	4.6–5.7	5.9–6.4	6.6–7.2	< 1	3.7–4.6	4.6–5.7	6.6–7.2
mag. range	$r < 23.0$	$i < 24.0$	$z < 24.0$	$y < 23.4$	$i < 25.0$	$i < 25.0$	$i < 25.0$	$y < 25.3$
number	6000	3500	280	50	2000	200	50	3

Candidate selection and confirmation

HSC database search for red point sources

Near-IR catalogs (UKIDSS, VIKING)

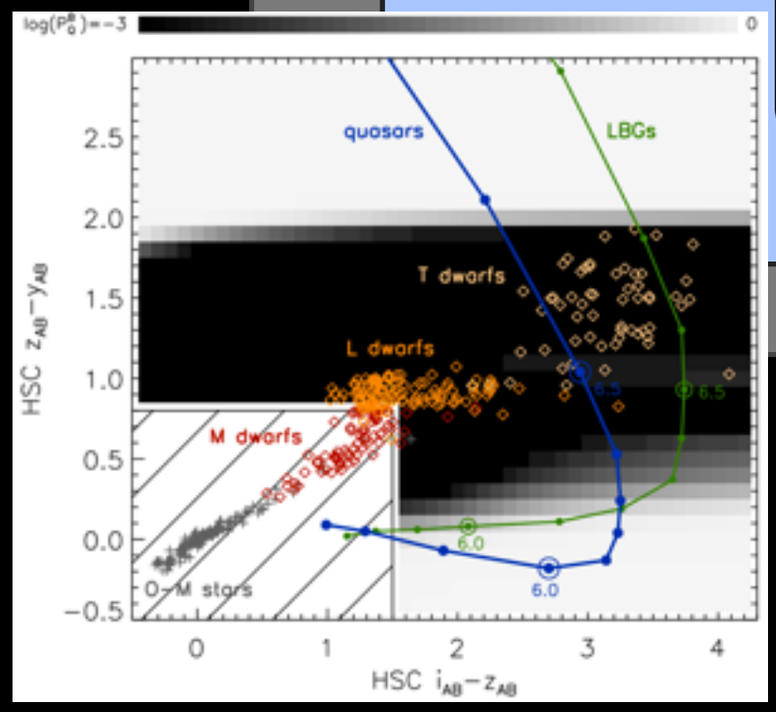
Simple color cuts

SED fitting

Bayesian probabilistic

$$P_{\rm Q}^{\rm B}(\vec{d}) = \frac{W_{\rm Q}(\vec{d})}{W_{\rm Q}(\vec{d}) + W_{\rm D}(\vec{d})}$$

$$W_{\rm Q/D}(\vec{d}) = \int S(\vec{p})\ Pr({\rm det}|\vec{p})\ Pr(\vec{d}|\vec{p})\ d\vec{p}$$

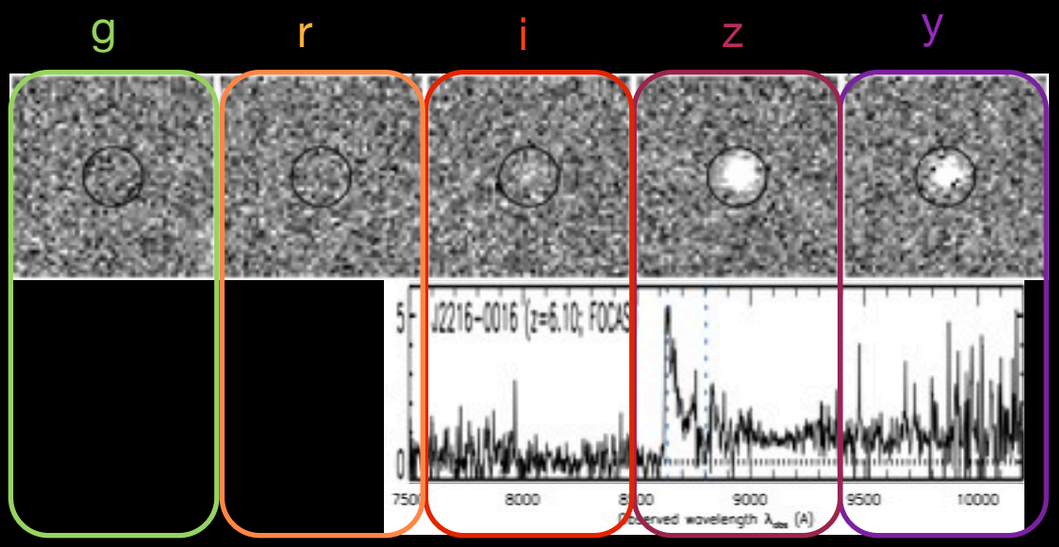


Color selection

✶ Additional quality checks (detection, photometry, shape, ...) with SExtractor, using both stacked and per-visit images.

✶ Eye inspection

Spectroscopic confirmation



Progress to date

✶ Candidate selection has been completed for the first ~100 deg^2 of the Wide fields (i.e., all the area included in the latest internal data release).

✶ Spectroscopic observations are underway.

Subaru/FOCAS

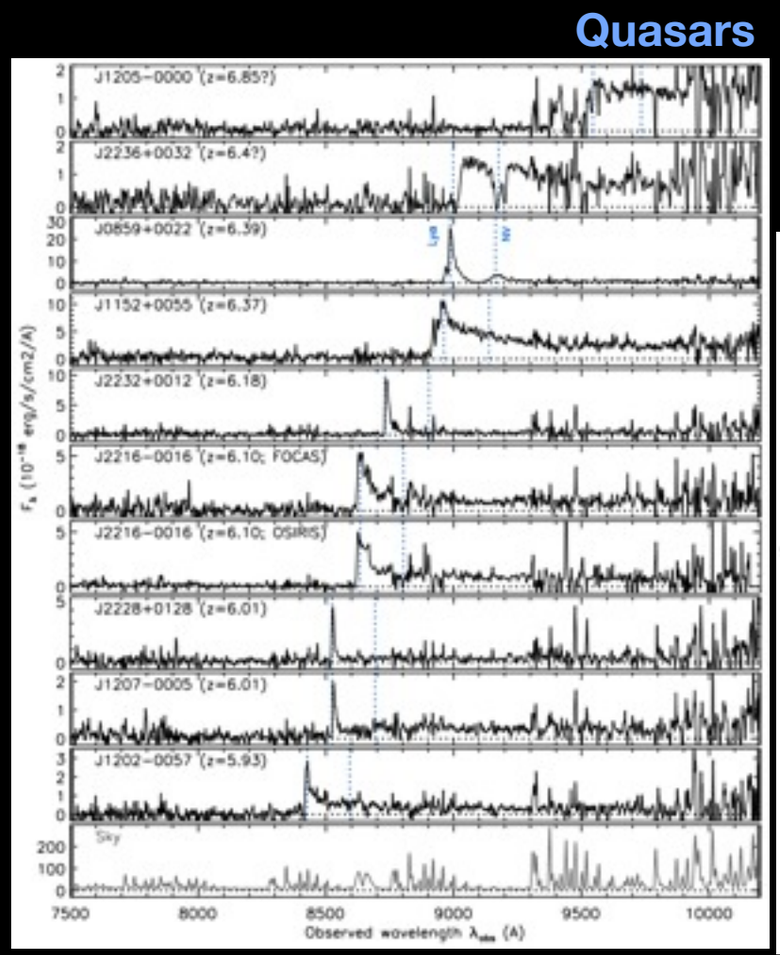
GTC/OSIRIS

Gemini/GMOS

✶ Results so far (preliminary!)

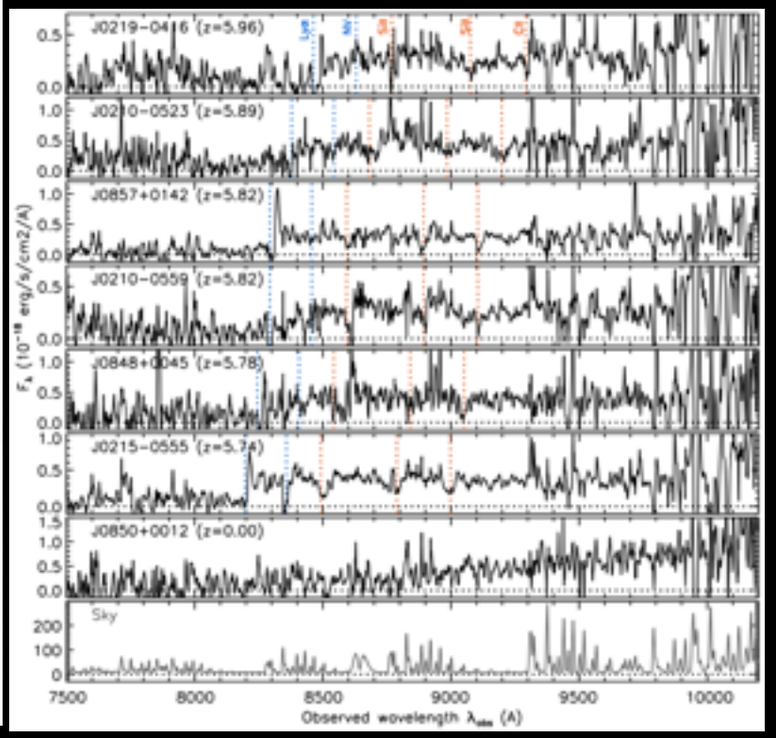
Candidates (z_{AB} < 24.5, y_{AB} < 24.0)	86
Spectroscopy done	48
Quasars at z ≥ 6	22
Galaxies at z ~ 6	14
[O III] emitters at z ~ 0.8	2
Brown dwarfs	4
Moving/transient	6

Quasars



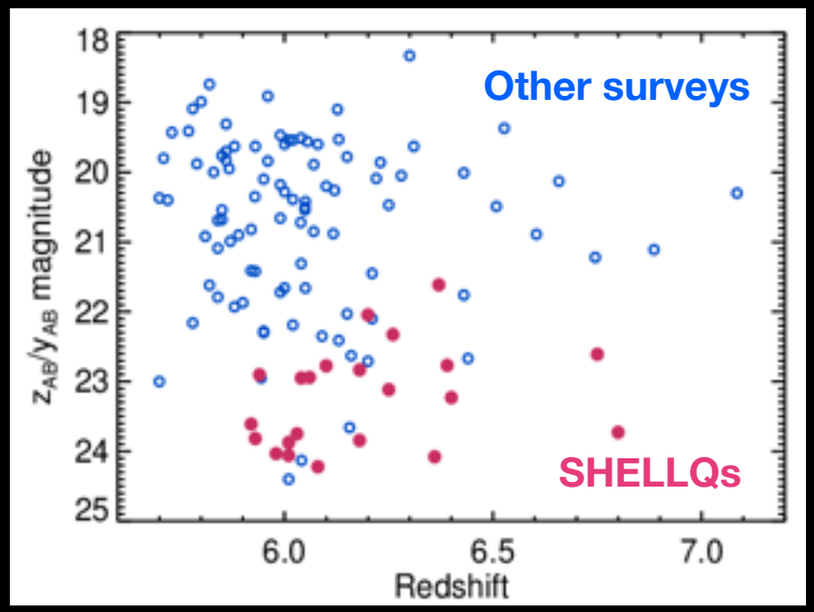
The initial results were published in Matsuoka et al. (2016, ApJ in press; arXiv:1603.02281)

Galaxies and a dwarf



Our uniqueness and challenges

✶ We are going down to z_{AB} ~ 24.5 mag, deeper than any previous wide-field (1,000-deg^2 scale) survey has reached.



(preliminary!)

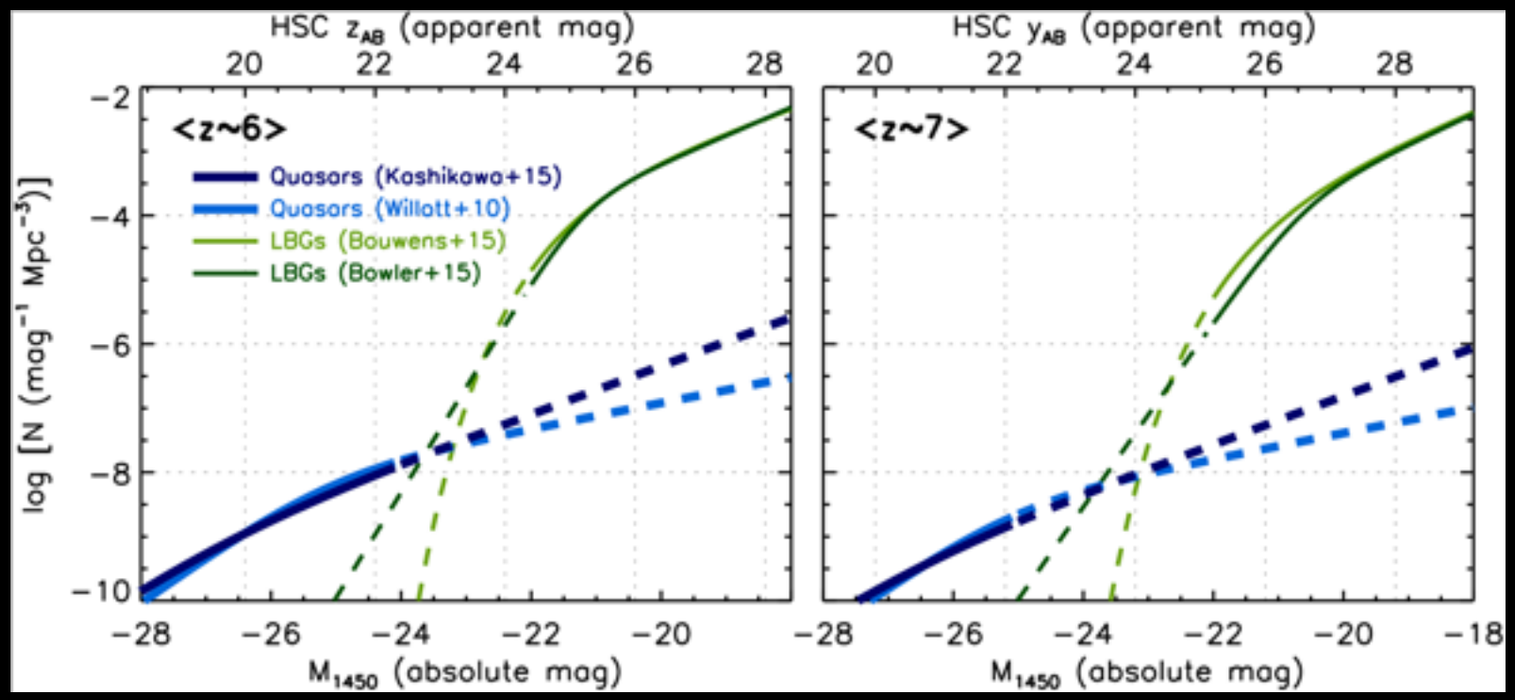
M_{1450} = −24 mag

M_{1450} = −23 mag

M_{1450} = −22 mag

✶ Spectroscopic identification needs a-few-hour integration per object, even with 8-10 m telescopes.

✶ We are starting to find many z ~ 6 galaxies contaminating to the quasar candidates.

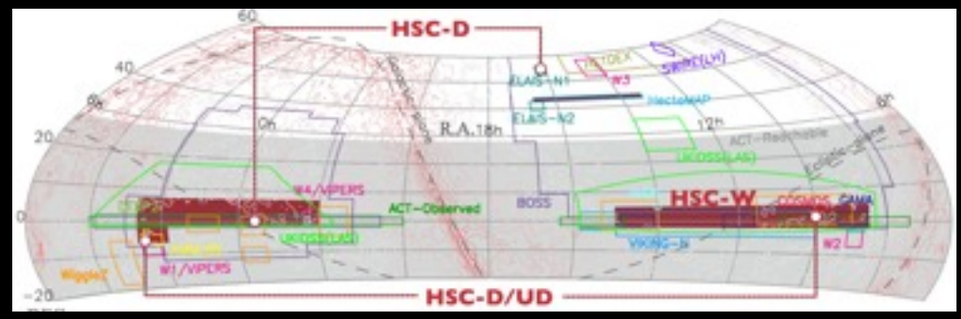


Future Prospects

✶ The HSC-SSP survey will continue to observe the planned 1,400 deg^2 in the Wide component, until 2019-2020. The observed area, in the full color and full depth, has just reached 200 deg^2.

✶ We will continue high-z quasar candidate selection in lock-step with the HSC survey.

✶ We will also soon start to look at the Deep (27 deg^2) and the Ultra-Deep (3.5 deg^2) fields.



✶ Spectroscopic observations will continue.
- “Subaru Intensive program” has been approved for our project; 20 nights awarded in the 16B - 18A semesters.

✶ Various follow-up studies are underway.
- luminosity function
- IGM neutral fraction through GP and damping-wing measurements (deep optical spectroscopy proposed)
- SMBH mass and Eddington ratio distributions (near-IR spectroscopy proposed)
- metallicity and chemical evolution (near-IR spectroscopy proposed)
- star formation, dust, and gas in the host galaxies (ALMA observations proposed)
- Lyα halos (HST narrow-band imaging proposed)

✶ Subaru Prime Focus Spectrograph (PFS) will come on stage at ~2019, and will start a massive spectroscopic survey over the HSC survey area.