Explorations for high-z dusty AGNs, quasars, and radio galaxies, with Subaru **Hyper Suprime Cam**

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on behalf of the HSC-AGN WG

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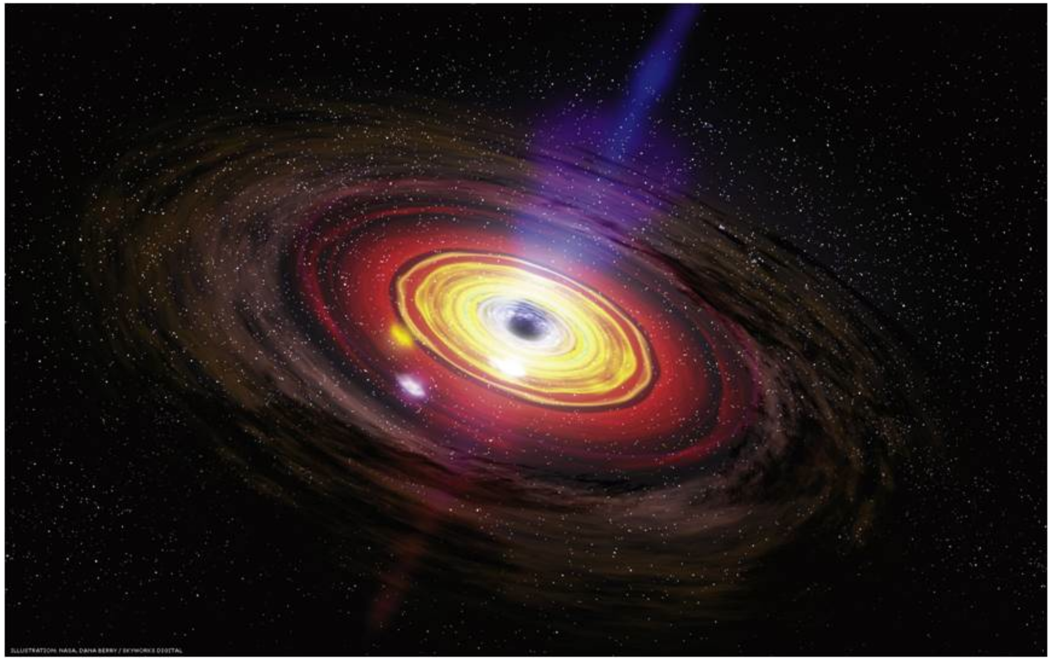
Symposium "Why does the Universe accelerate?"
10-12 February 2018, Aoba Science Hall, Tohoku Univ.

Big questions



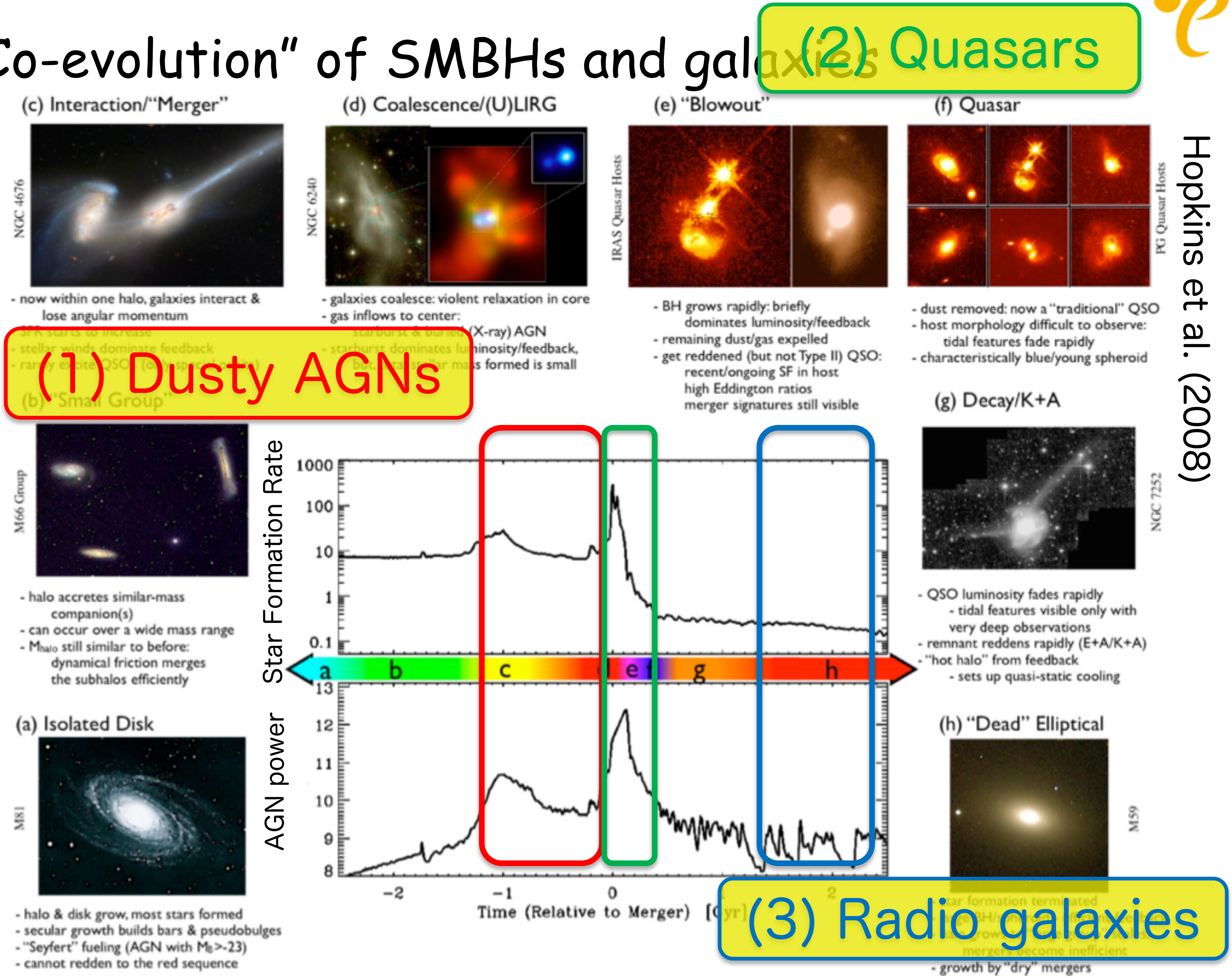
We already know:

Most massive galaxies harbor a **supermassive black hole (SMBH)** at their center. It causes quasar (or AGN) activities through gas accretion. The SMBH mass reaches up to **$M_{BH} \sim 10^{9\text{-}10}\ M_{sun}$**.

We still do not know (→ targets of this work):

- When the first "massive" BHs appeared in the Universe?
- When and how SMBHs grew in the cosmological timescale?
- How the statistical properties of quasars depend on redshift?
- **How the SMBH growth is related to the galaxy evolution?**

"Co-evolution" of SMBHs and galaxies

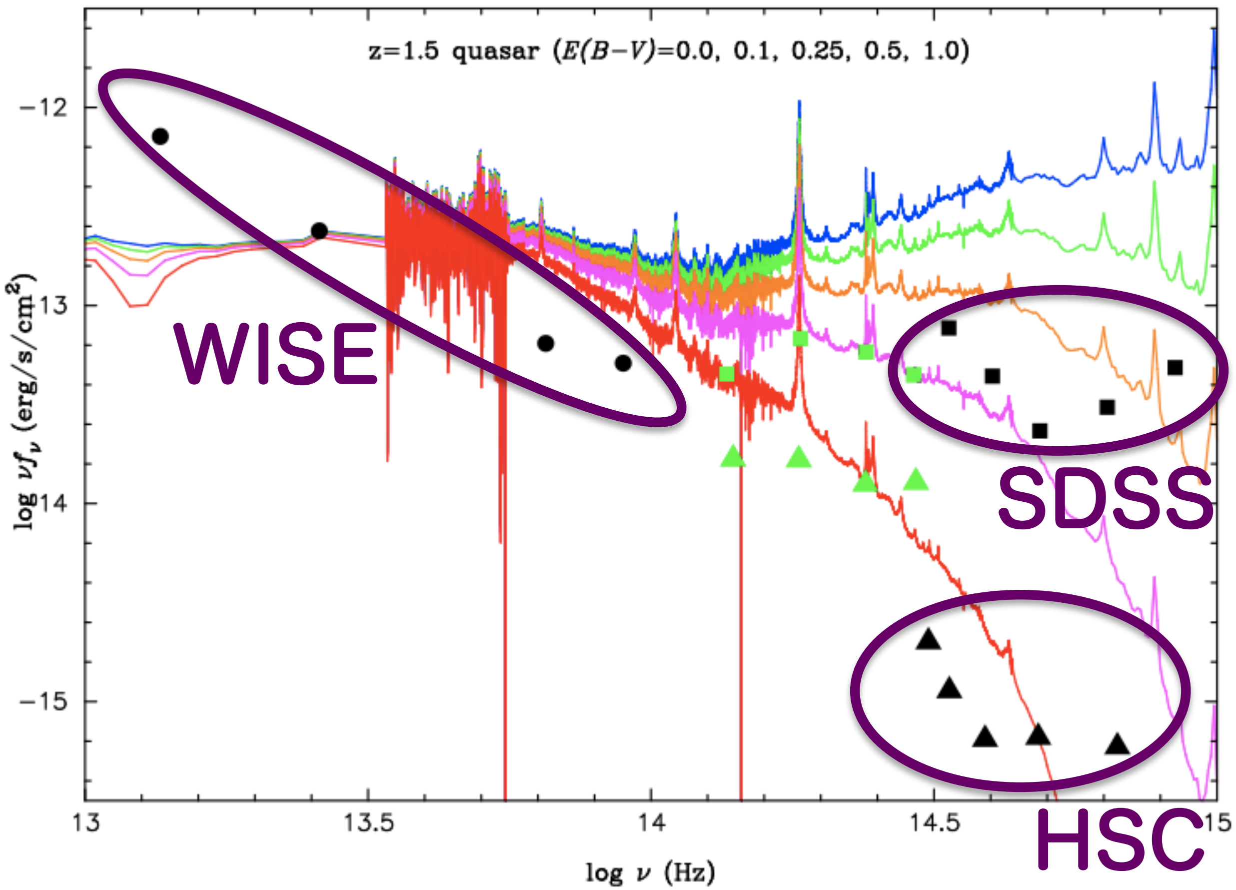


Dusty AGNs in "dust obscured galaxies (DOGs)"

➢identifying red AGNs with HSC & MIR all-sky data

~ WISE all-sky survey data → Wide & Deep MIR image

~ HSC-SSP data → Wide & Deep optical image

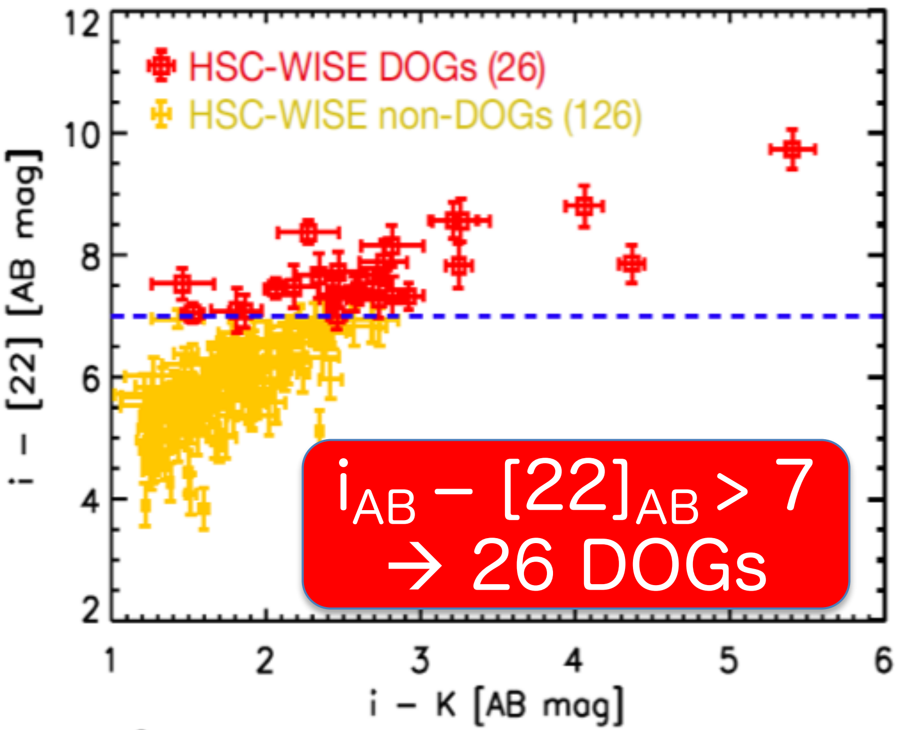


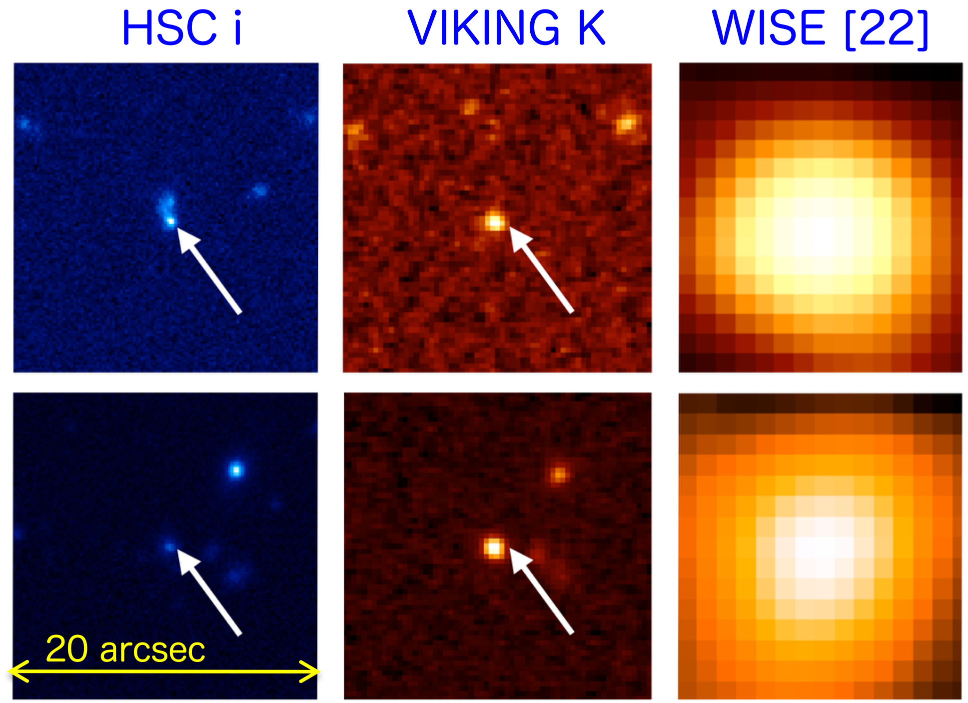
z=1.5 quasar spectrum with various E(B-V)

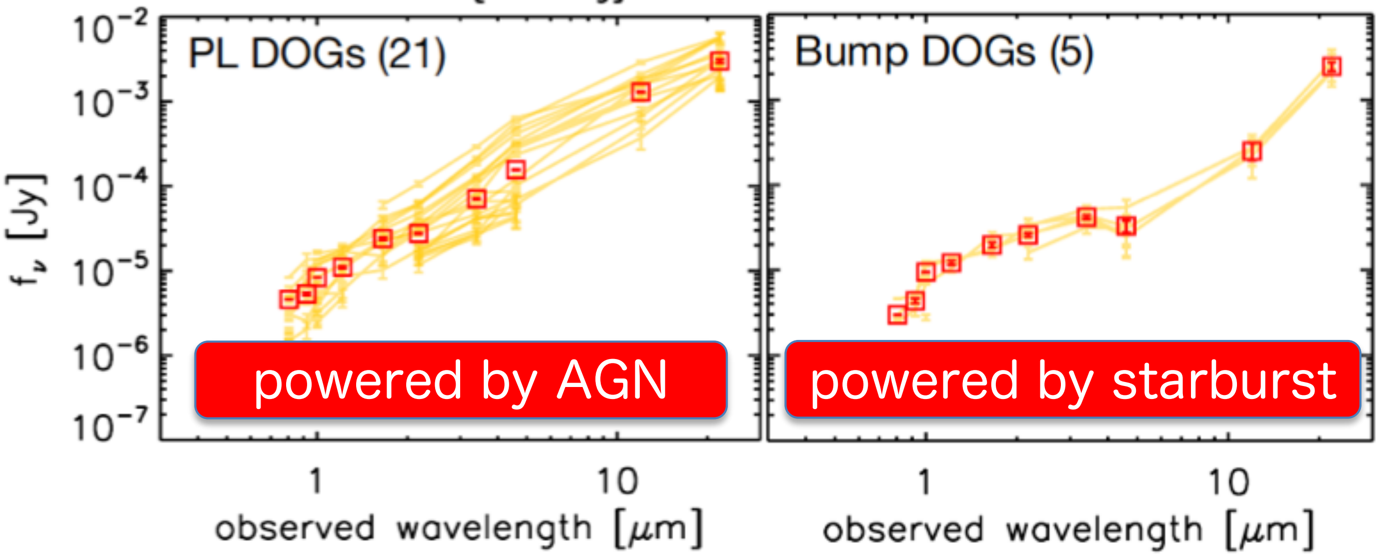
Red WISE-detected quasars cannot be detected in SDSS

HSC is deep enough to detect them!

DOGs in the initial 10 deg^2 of the HSC-SSP

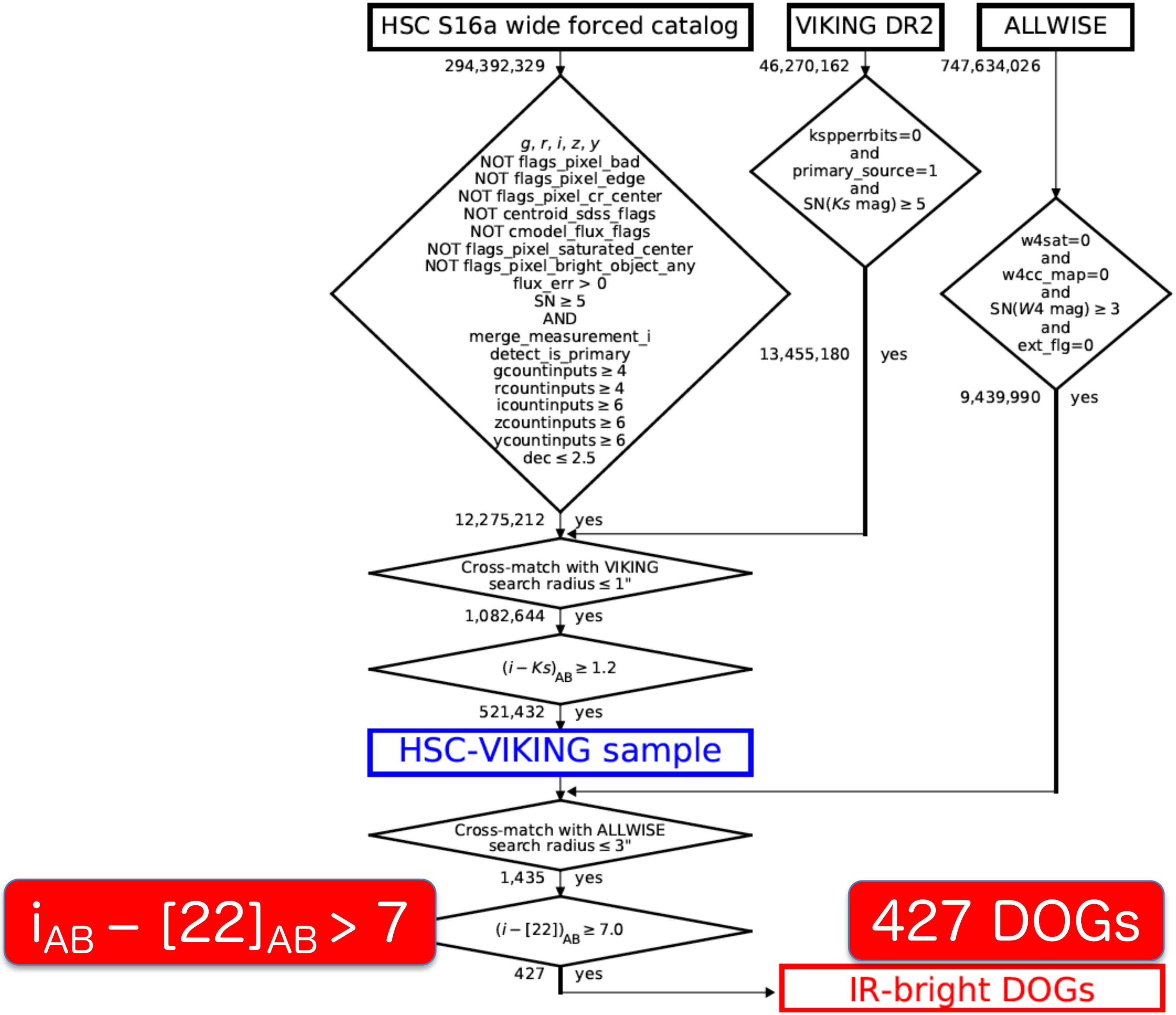






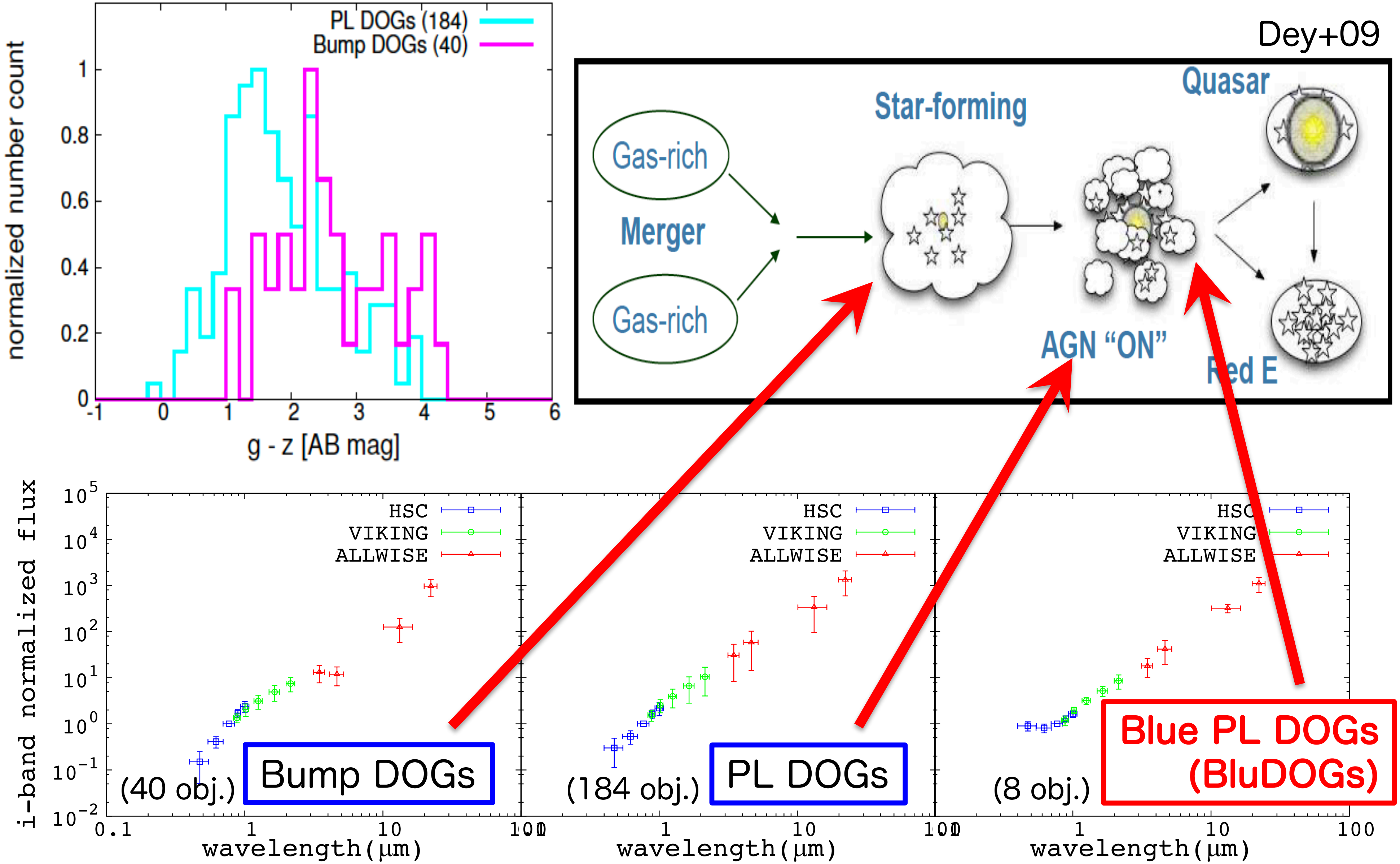
Toba, TN, et al., 15
based on initial
~10 deg^2 data

DOGs in the latest 53 deg^2 of the HSC-SSP



Noboriguchi, TN, Toba, et al., in prep.

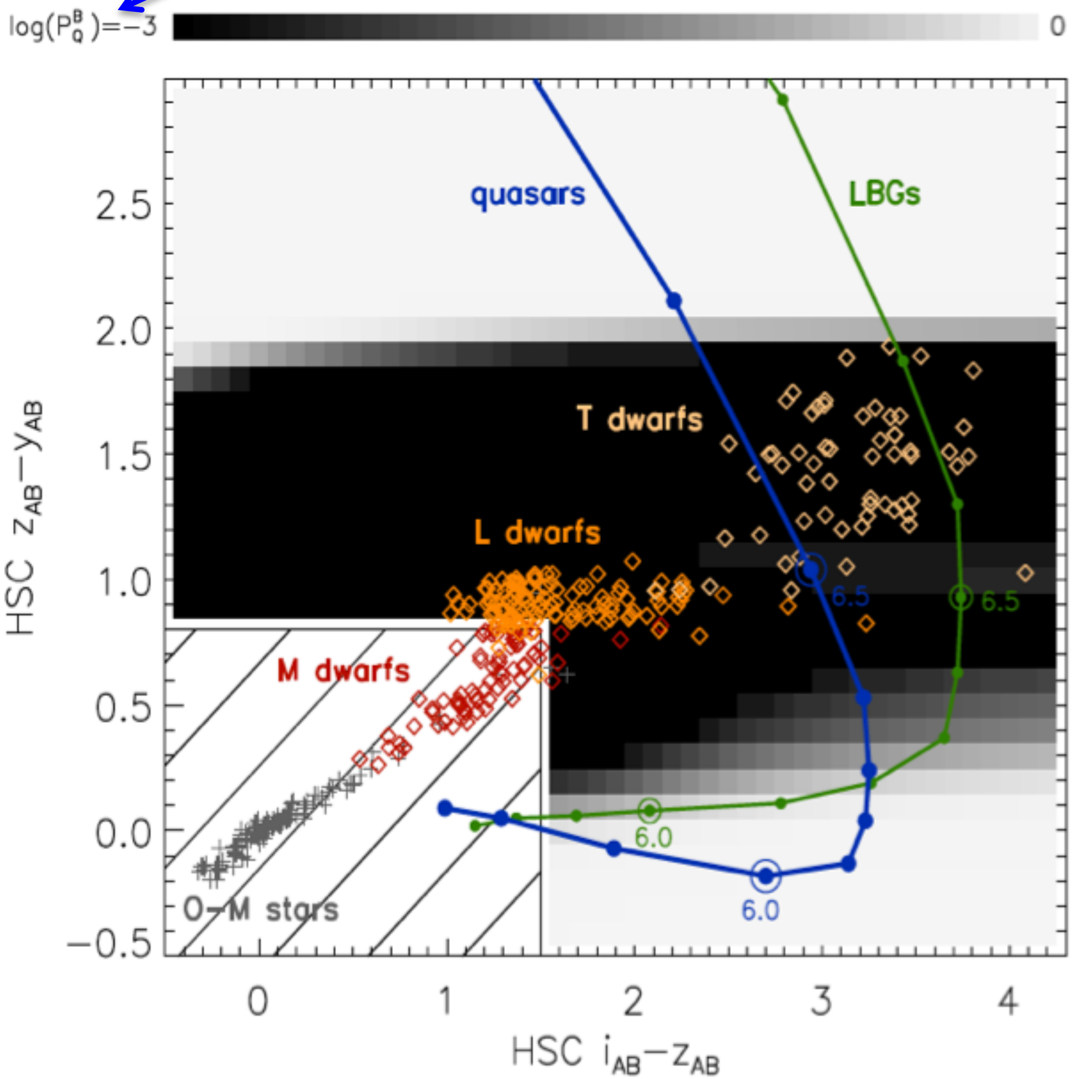
HSC DOGs: evolutionary effects?



Noboriguchi, TN, Toba, et al., in prep.

HSC quasars at z > 6: candidate selection

Bayesian quasar probability



Matsuoka et al. incl. TN, 2016, 2017, and the next paper will be submitted soon

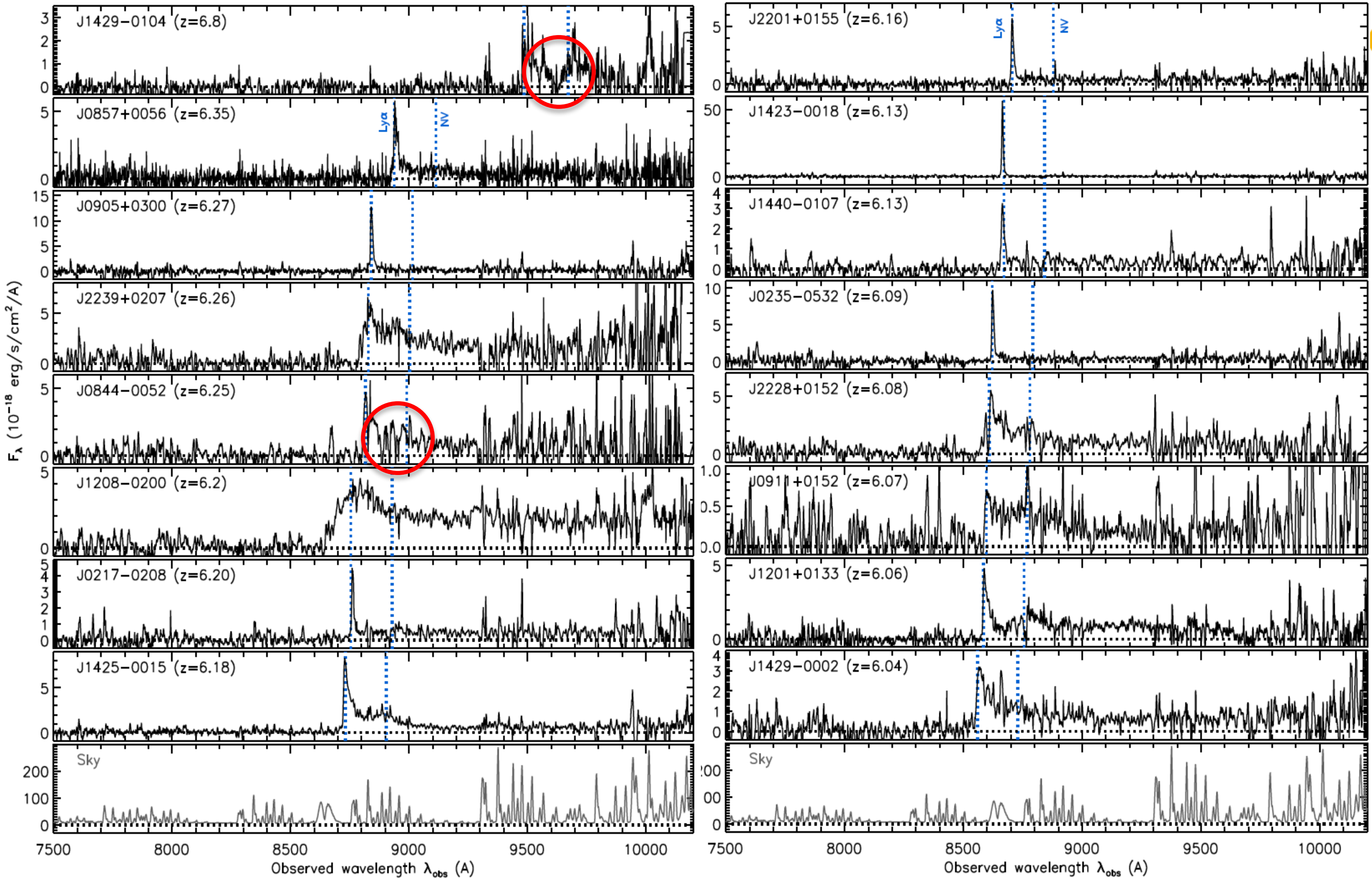
Candidates are selected with HSC i, z, y photometry (y-band is powerful).

We calculate the Bayesian quasar probability for every point sources, for selecting our spectroscopic targets.

$$P_Q^B(\boldsymbol{d}) = \frac{W_Q(\boldsymbol{d})}{W_Q(\boldsymbol{d}) + W_D(\boldsymbol{d})}$$

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

d : mag of HSC bands
p : luminosity, redshift, spectral type
S : surface density of objects with ***p***
Pr(det|***p***) : detection probability under the current sensitivity
Pr(***d***|***p***) : probability that objects with ***p*** will be observed as ***d***



Matsuoka et al. (incl. TN) 2016, 2017, and the next paper will be submitted soon

>60 quasars at 5.7 < z < 6.9 have been newly discovered!!

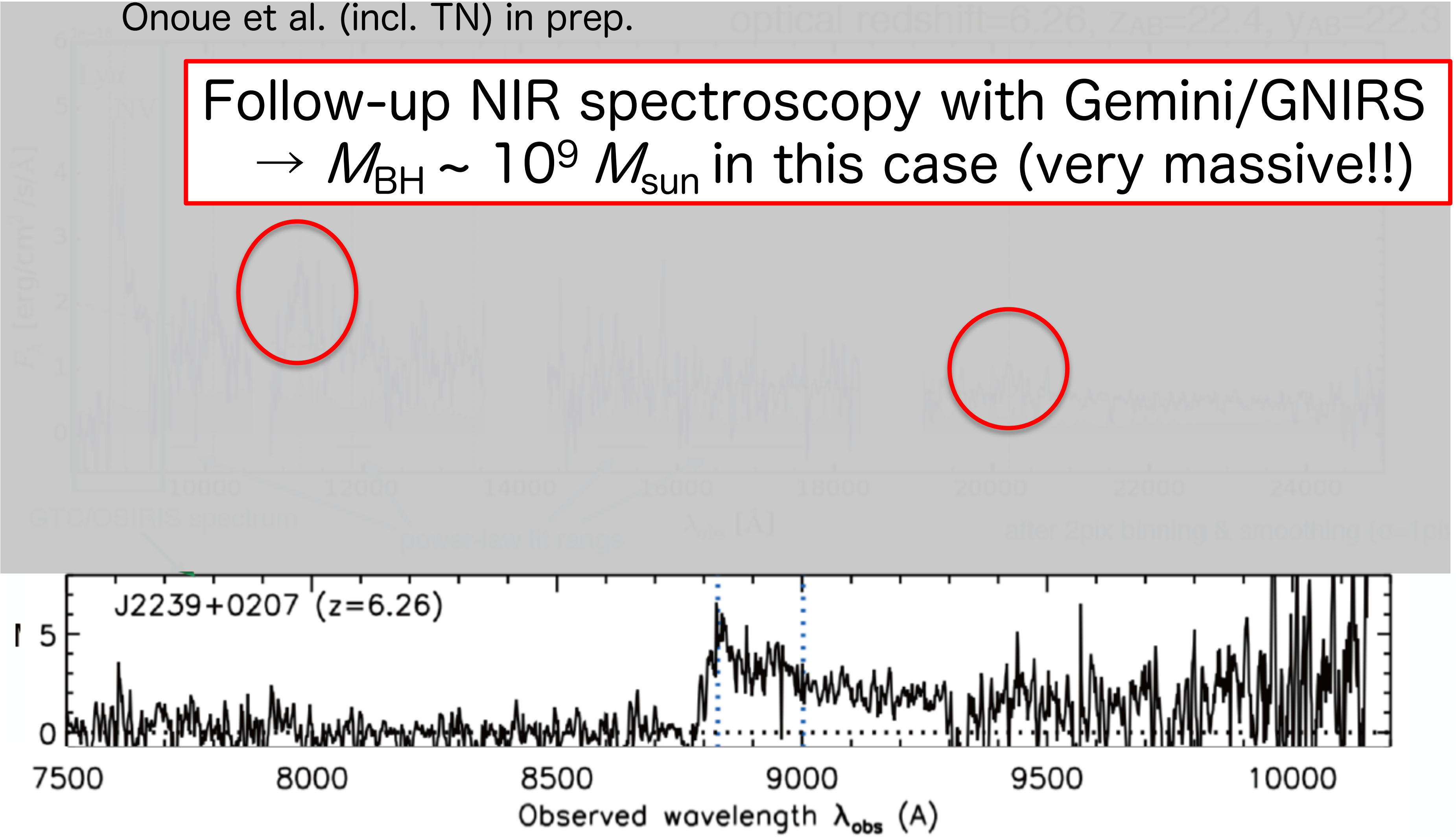
Some quasars show strong outflow features

→ They may be objects in the "blowing-out" phase

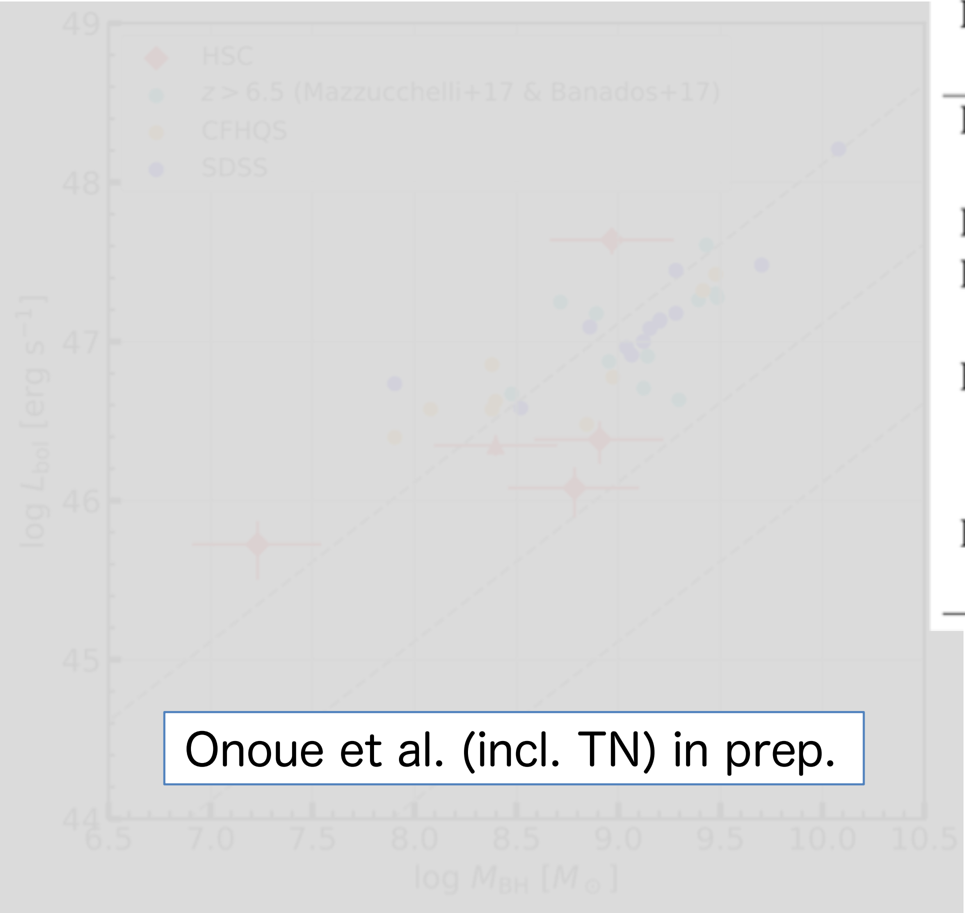
SMBH mass of HSC quasars at z>6

Onoue et al. (incl. TN) in prep.

Follow-up NIR spectroscopy with Gemini/GNIRS
→ $M_{BH} \sim 10^9\ M_{sun}$ in this case (very massive!!)



SMBH mass of HSC quasars at z>6



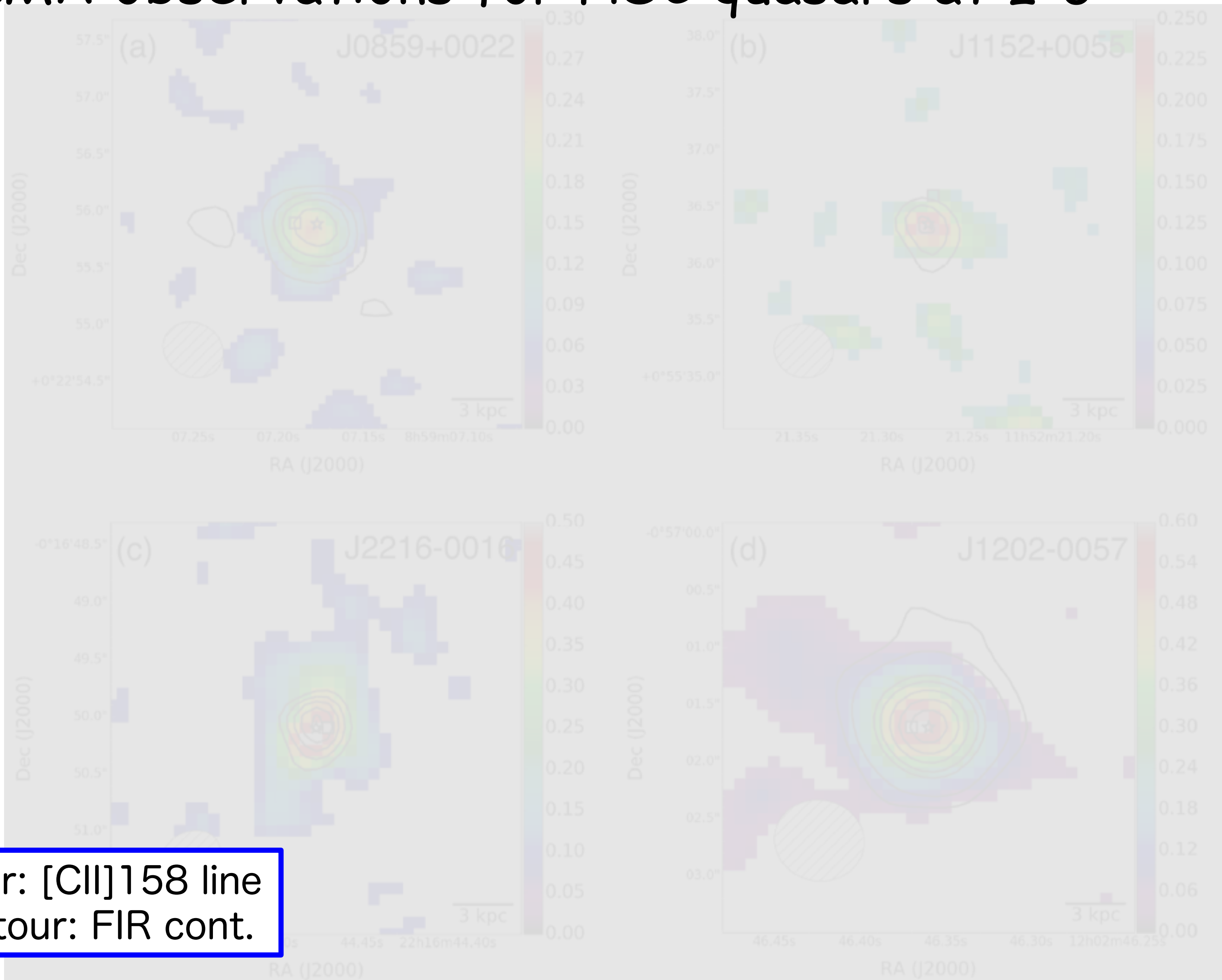
Onoue et al. (incl. TN) in prep.

ID	Redshift[a]	y^b_{AB} (mag)	Instrument	t^c_{exp} (hour)
HSC J2239+0207	6.26	22.33	Gemini/GNIRS	2.7
HSC J1208-0200	6.2	22.05	Gemini/GNIRS	3.7
HSC J2216-0016	6.09	22.94	Gemini/GNIRS	9.0
HSC J0859+0022	6.39	23.23	VLT/X-SHOOTER	7.2 (NIR) 6.5 (VIS)
HSC J1205-0000[d]	6.7 – 6.9	22.61	VLT/X-SHOOTER	0.8 (NIR) 0.7 (VIS)

ID	M_{BH} ($\times 10^8$ M_{sun})	L_{bol}/L_{Edd}
J2239	8.1±1.9	0.23±0.07
J1208	2.5±0.2	0.67±0.09
J2216	6.1±1.6	0.15±0.05
J0859	0.17±0.04	2.4±1.0
J1205	9.3±1.1	3.6±0.7

Number density of SMBHs with M_{BH} ~ $10^{8\text{-}9}$ M_{sun} at z~6 much higher than z~6 SDSS quasars !

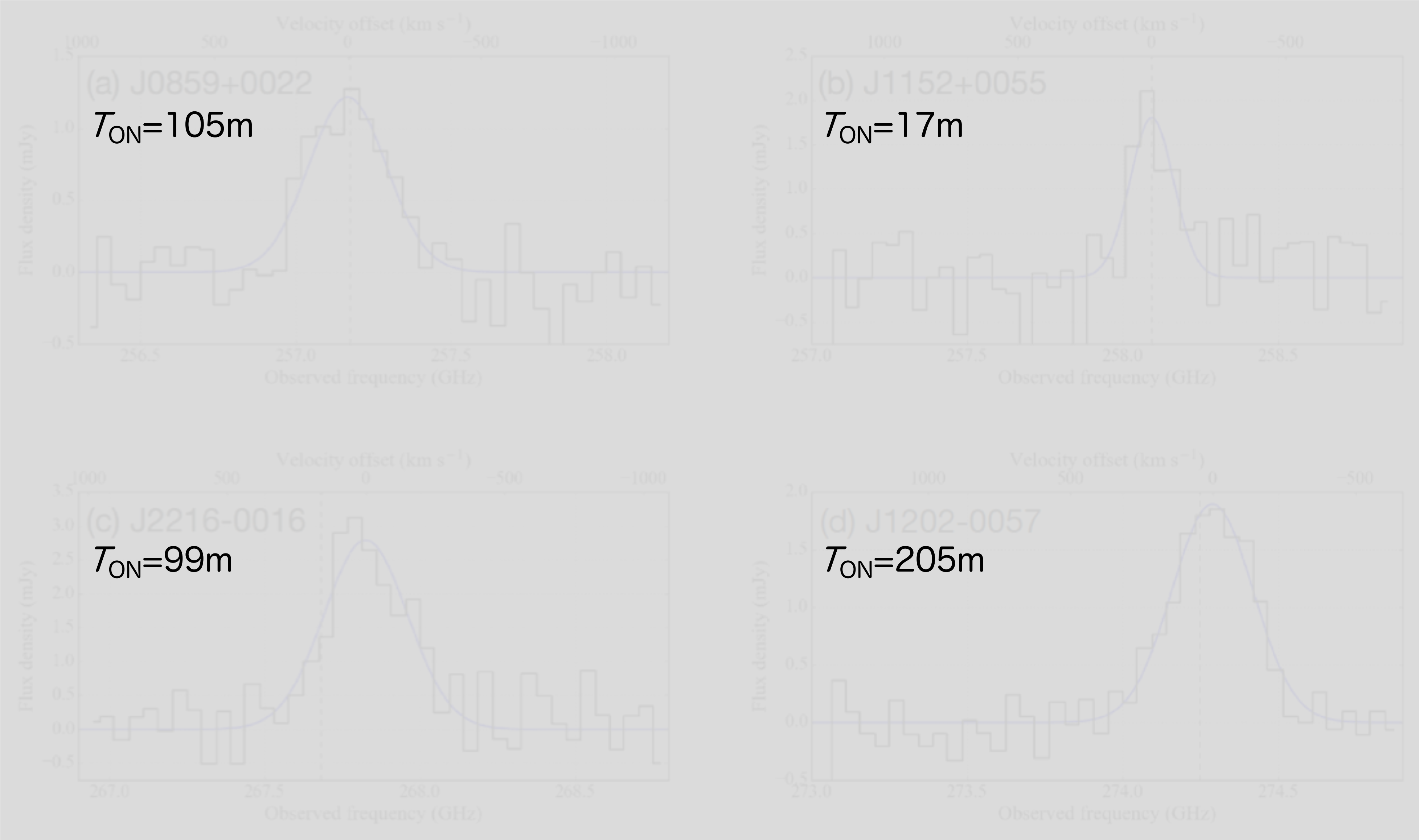
ALMA observations for HSC quasars at z>6



Color: [CII]158 line
Contour: FIR cont.

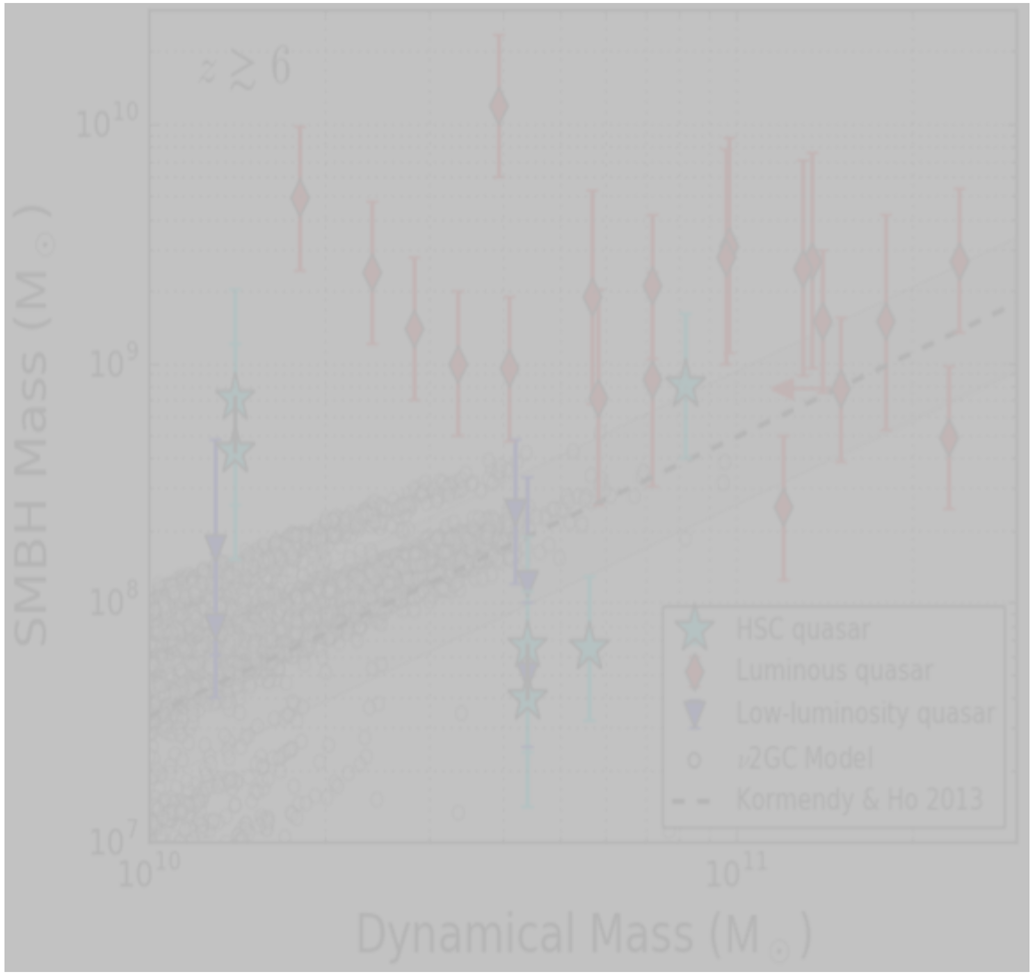
Izumi, Onoue, Shirakata, Nagao, et al., submitted

ALMA [CII]158 spectra of HSC quasars at z>6



Izumi, Onoue, Shirakata, Nagao, et al., submitted

Galaxy-SMBH coevolution in the early Universe



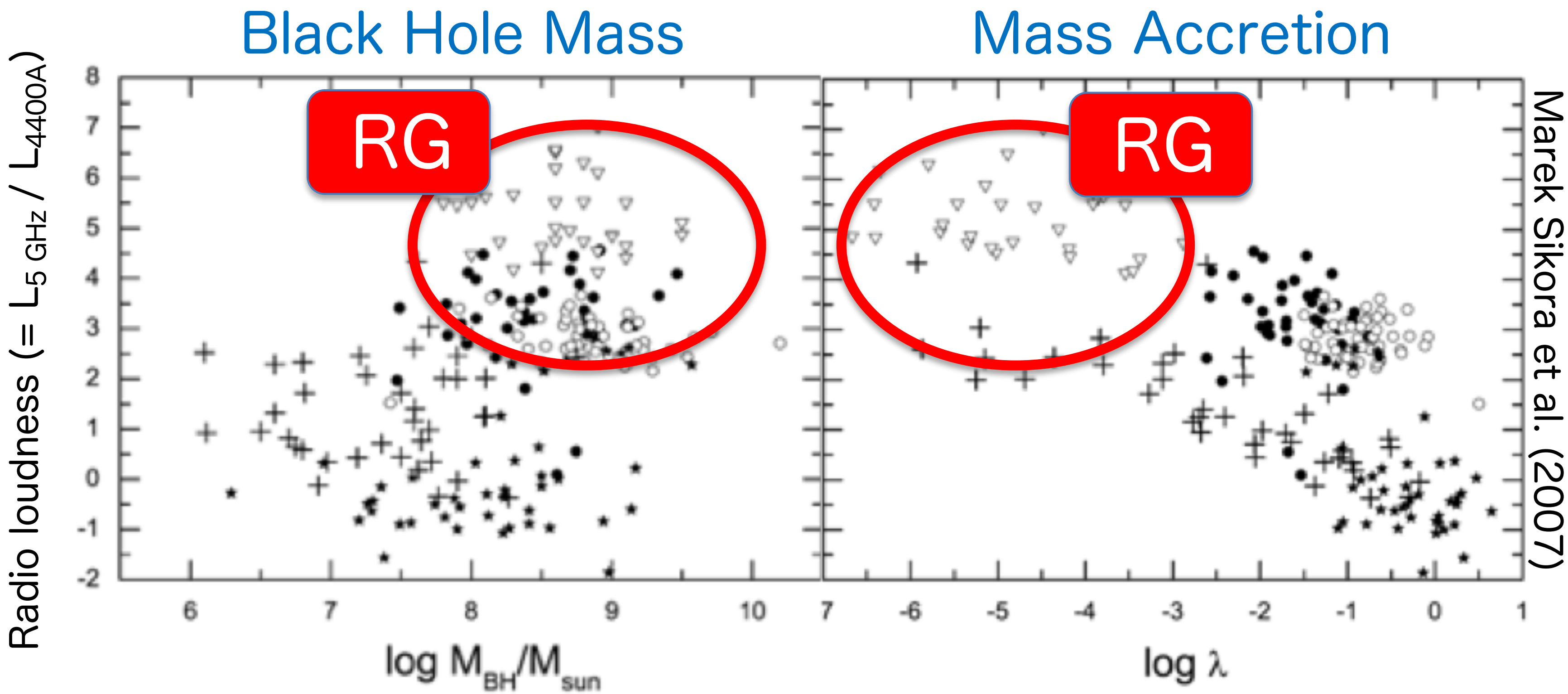
M_{BH}/M_{gal} of low-luminosity quasars looks consistent to the ratio seen in low-z, while high-luminosity quasars show significant deviation.

Probably the results for high-luminosity quasars are affected by selection effects.

Galaxies and SMBHs experienced the coevolution with keeping their flux ratio.

Izumi, Onoue, Shirakata, Nagao, et al., submitted

Radio galaxies: in the final phase of SMBH growth

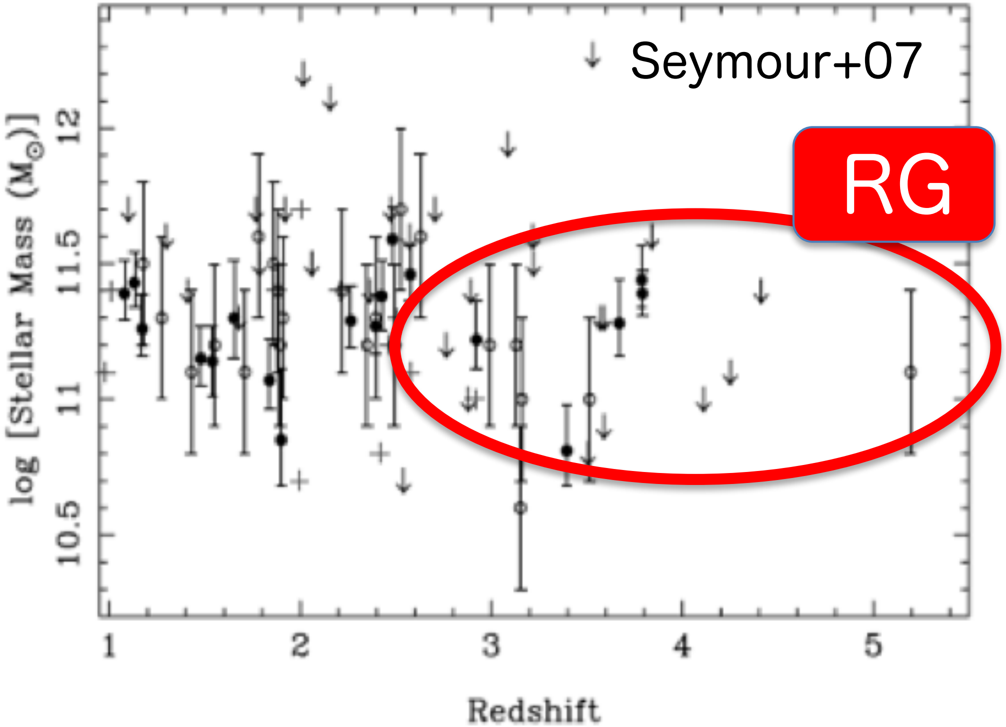


RGs are characterized by high M_{BH} and low accretion rate

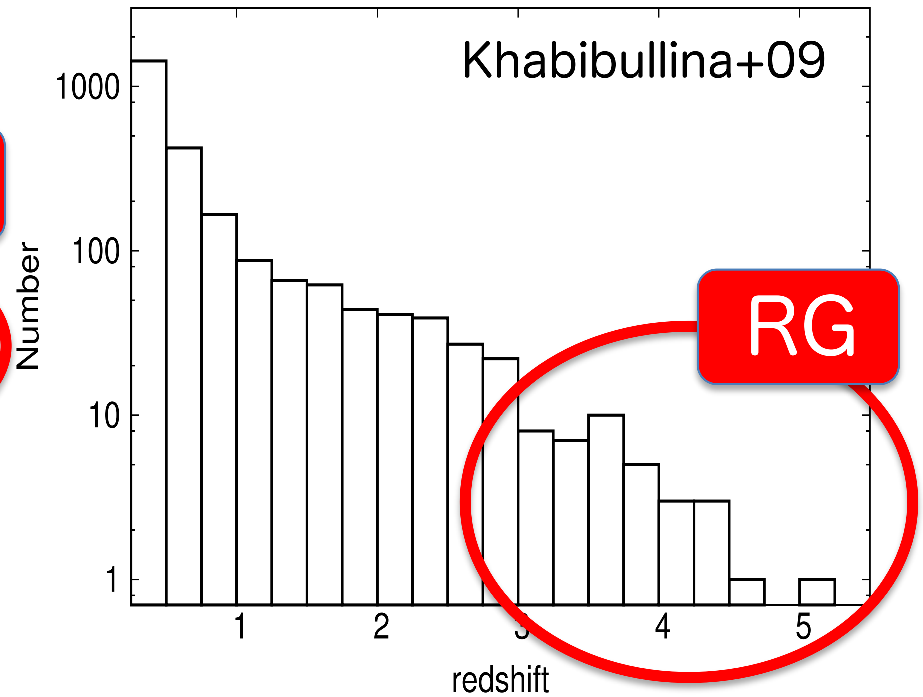
→ RGs are in the final phase of the growth of SMBHs

Radio galaxies: in the final phase of galaxy growth

Host Galaxy Mass of RGs

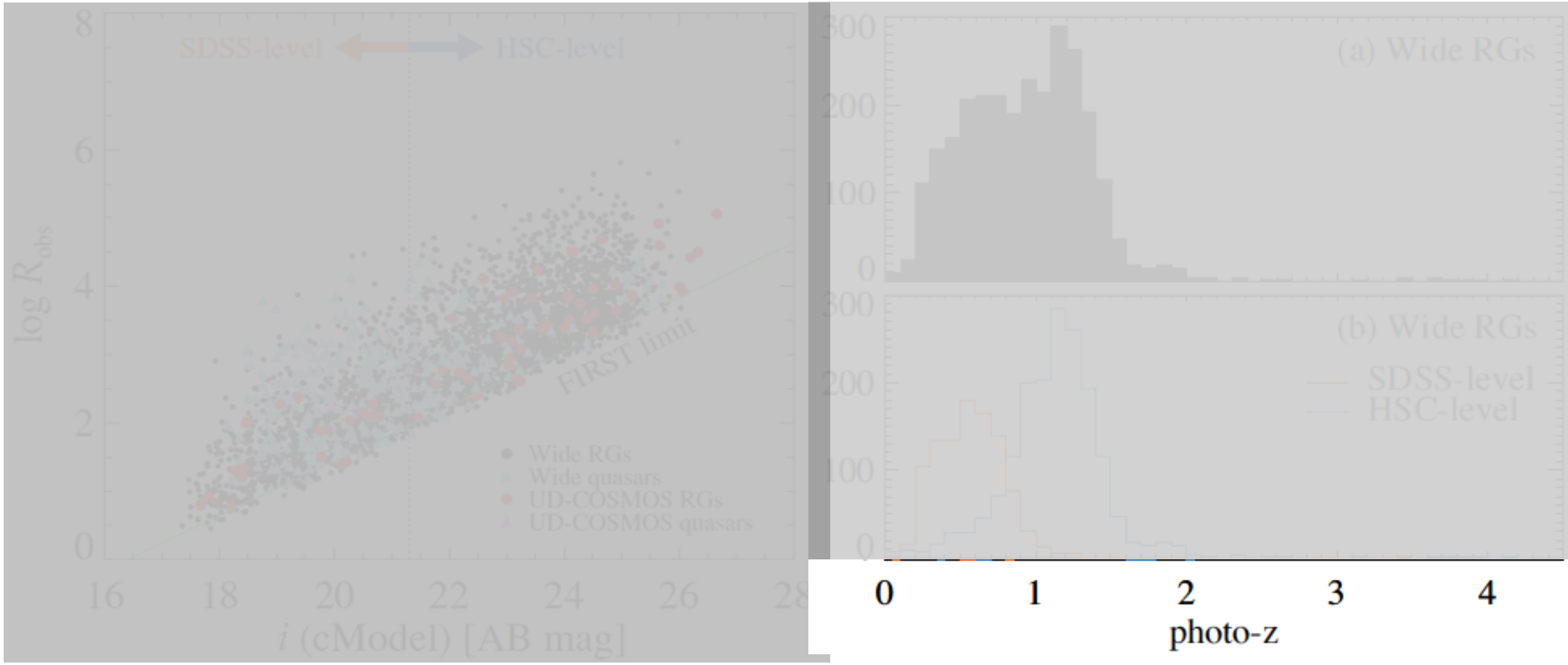


N(*z*) of known RGs



RGs are hosted by massive quiescent galaxies even at high-z
→ RGs are in the final phase of the growth of massive galaxies
Only few RGs have been identified so far…
→ new survey needed → HSC !!

Radio galaxies: SDSS-RGs vs. HSC-RGs



Yamashita, Nagao, et al., to be submitted soon

HSC-FIRST search for radio galaxies

- ~ larger "radio-loudness" objects than SDSS-FIRST
- ~ higher redshift (~1-2) than SDSS-FIRST (~0-1)

Summary

- Toward understanding the total picture of the SMBH evolution
  - ~ focusing on dusty AGNs, quasars, and radio galaxies
  - ~ utilizing the HSC-SSP data combined with multi-wav. data
- HSC search for dusty AGNs in dust-obscured galaxies (DOGs)
  - ~ HSC+WISE → DOGs (AGN-dominated + SF-dominated)
  - ~ Blue-excess DOGs: in the "blowing-out" phase?
- HSC search for quasars at $z > 6$
  - ~ discovery of new >60 quasars at $z > 6$
  - ~ NIR spectroscopy → many SMBHs with $M_{BH} \sim 10^{8-9}\, M_{sun}$
  - ~ ALMA → galaxy-SMBH coevolution with constant M_{BH}/M_{gal}
- HSC search for radio galaxies
  - ~ HSC is powerful to find RGs with a larger radio loudness & higher redshift
  - ~ follow-up spectroscopy now on-going (and waiting for PFS!!)

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