Subaru Wide-Field AGN Survey with HSC: Overview and Initial Results

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on behalf of the HSC-AGN WG

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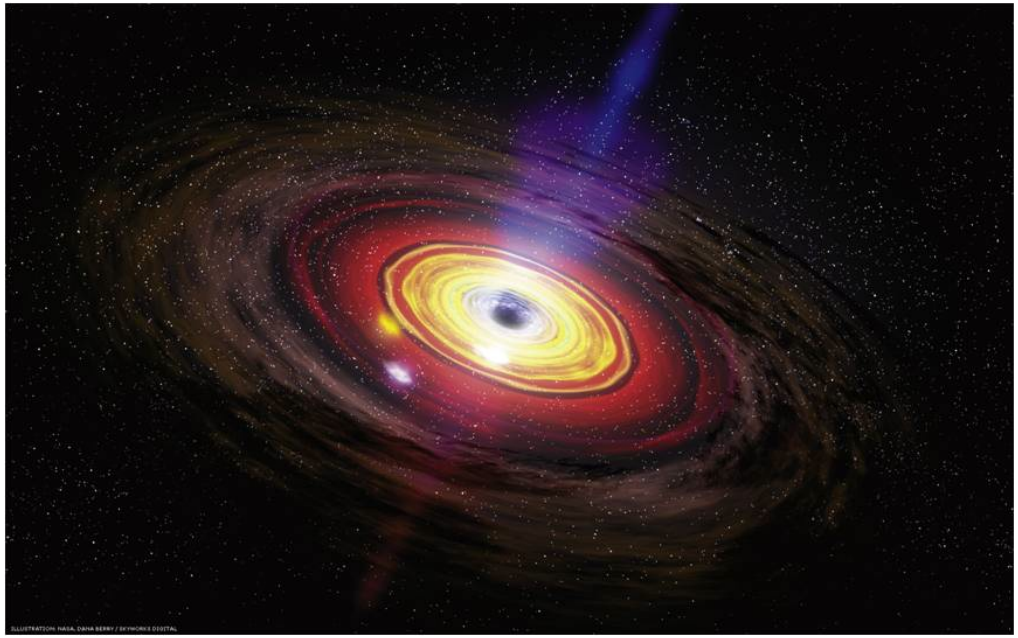
Follow-up of wide-area X-ray surveys
25-27 Apr. 2016, Ringberg Catsle, Germany

Big questions



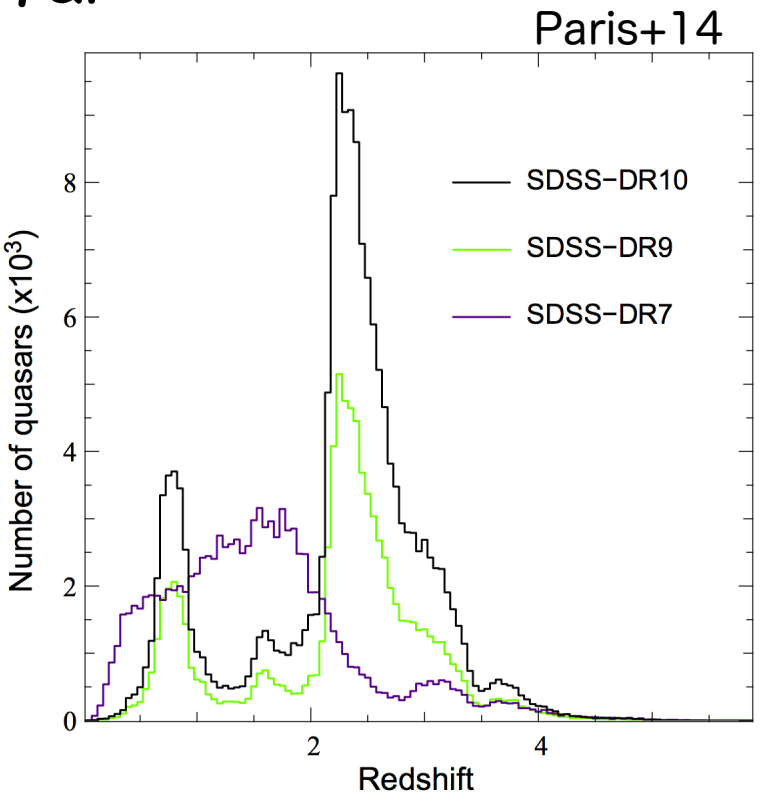
We already know:

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

We still do not know:

- 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?

Optical quasar surveys so far



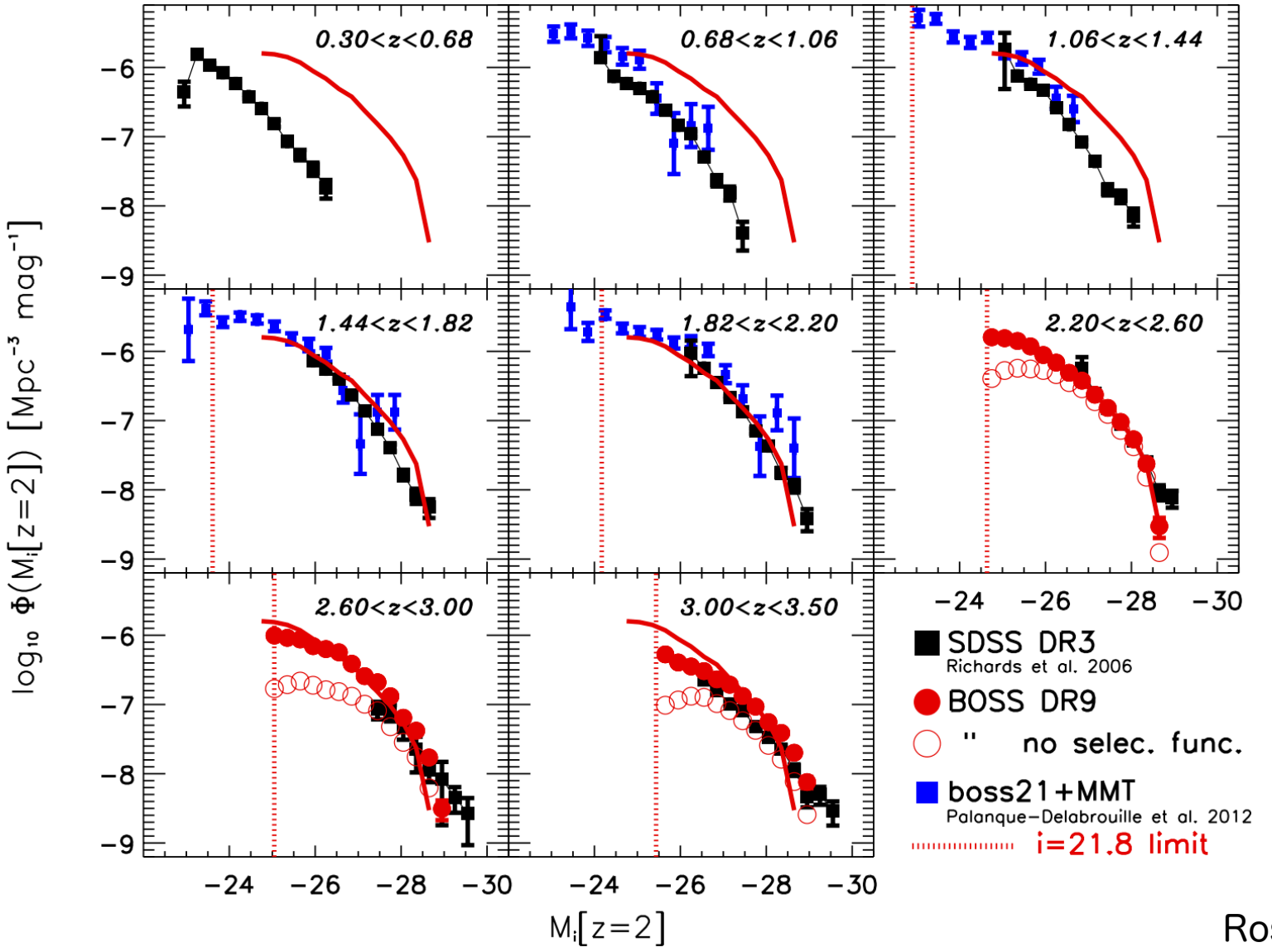
Great success of SDSS shows the power of optical multi-band wide-field observation.

SDSS: 2000-2005
BOSS: 2008-2014

SDSS (and the subsequent BOSS) have already identified numerous quasars up to z~6.4.

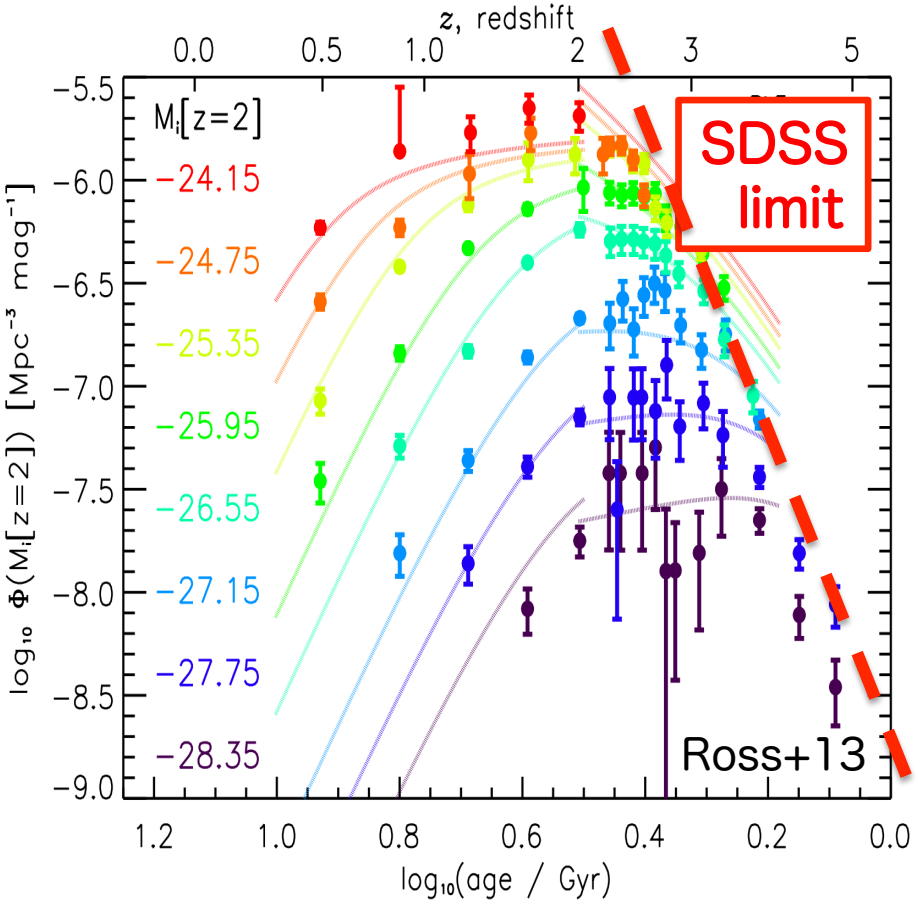
166,583 quasars listed in DR10 (BOSS catalog)

SDSS/BOSS quasar luminosity function (QLF)



Ross+13

"Luminosity dependent" evolution of the QLF



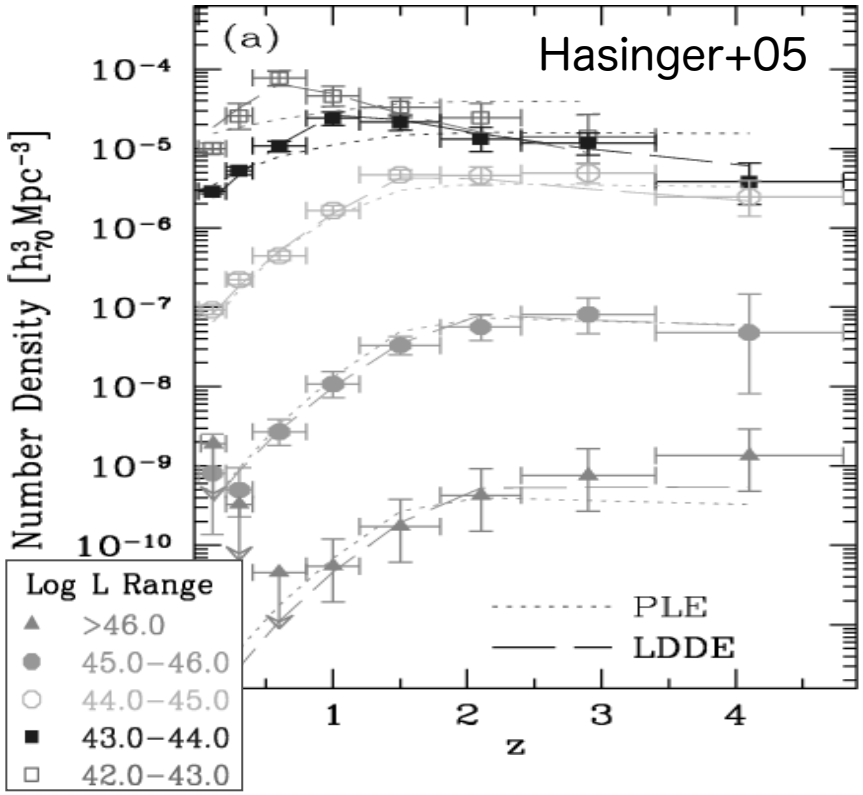
Number density evolution of SDSS III quasars. Different colors denote different luminosity ranges. See also, e.g., Croom et al. (2009); Ikeda, Nagao, et al. (2011, 2012).

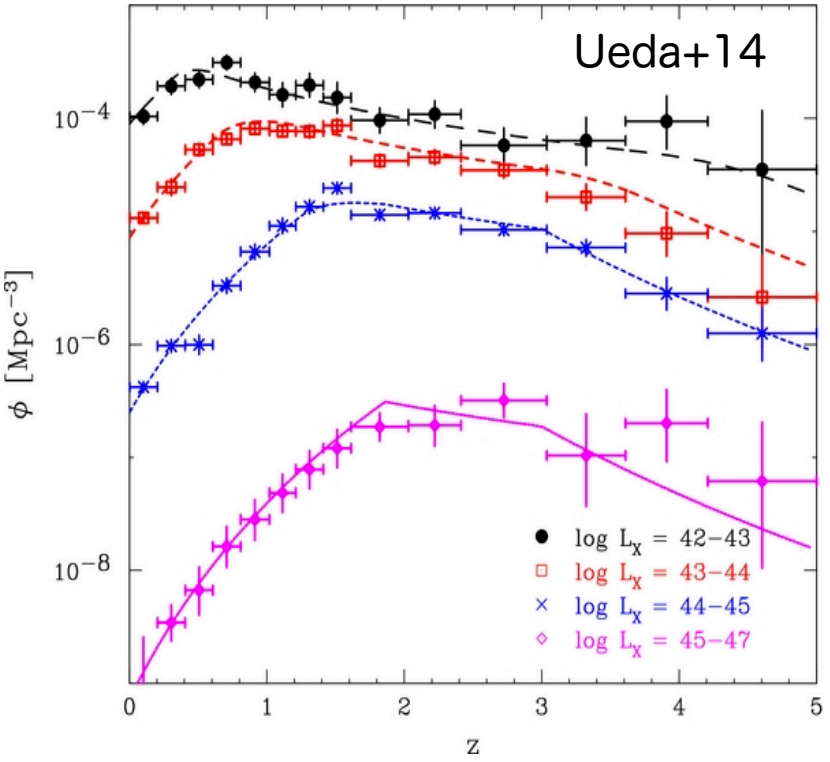
More luminous SDSS quasars show the peak of their number density evolution at higher redshifts.

Luminosity-dependent density evolution of quasars, that may be consistent to the picture of the so-called "downsizing" evolution.

Caveat: the number density is not clear at higher z & lower luminosity. Downsizing really holds also at higher z?

X-ray observations show a consistent picture

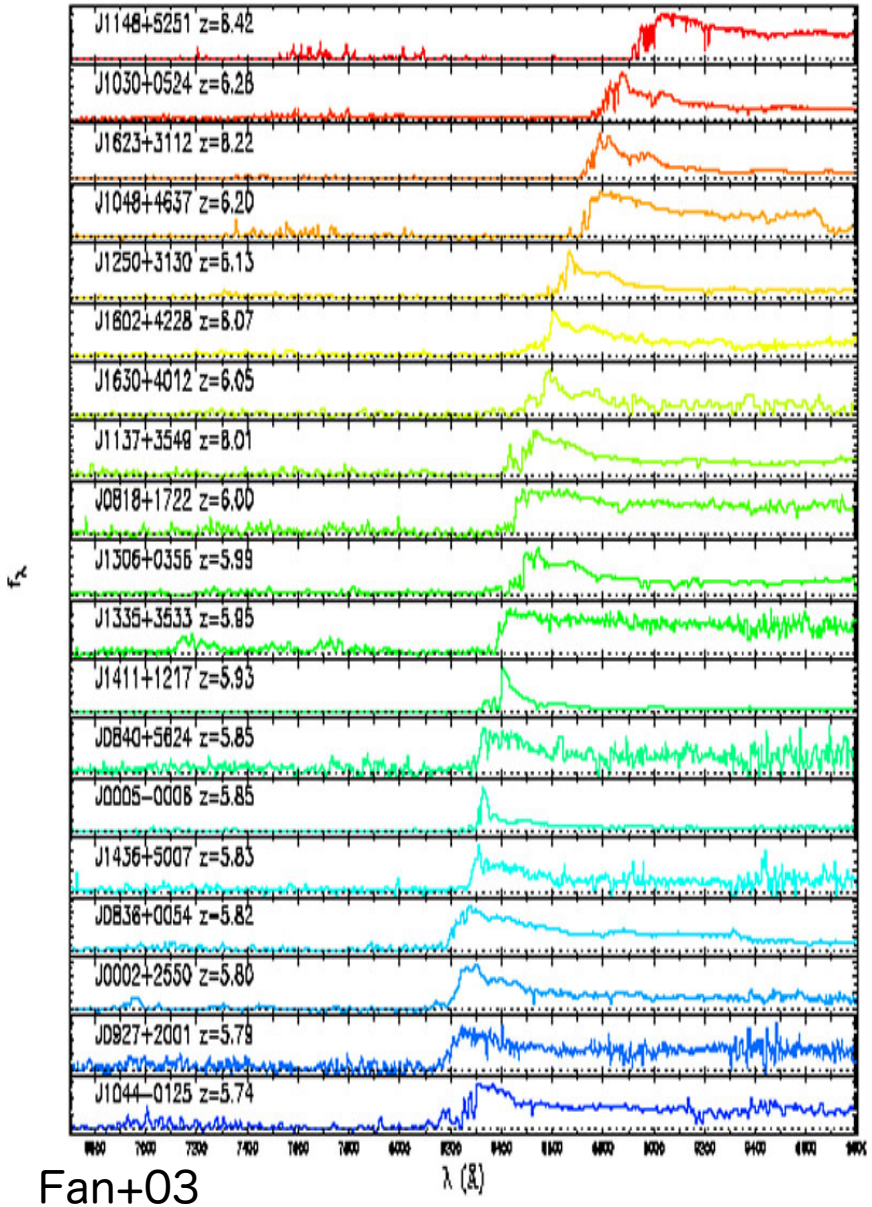




This downsizing trend of AGNs was originally pointed out in X-ray surveys.

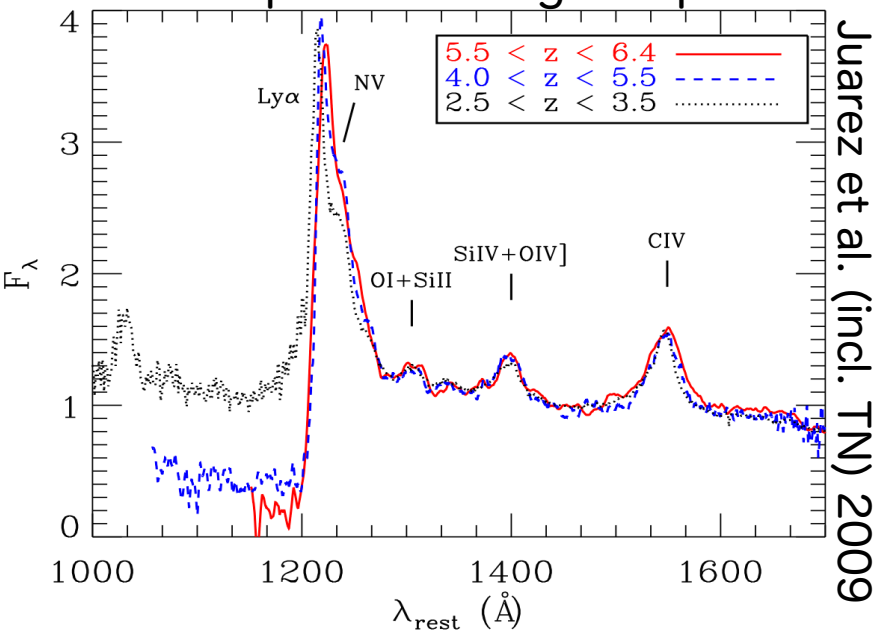
Number density of low-L AGNs is still uncertain at z > 4, even in the latest X-ray results...

SDSS/BOSS is NOT enough: also at z~6



Fan+03

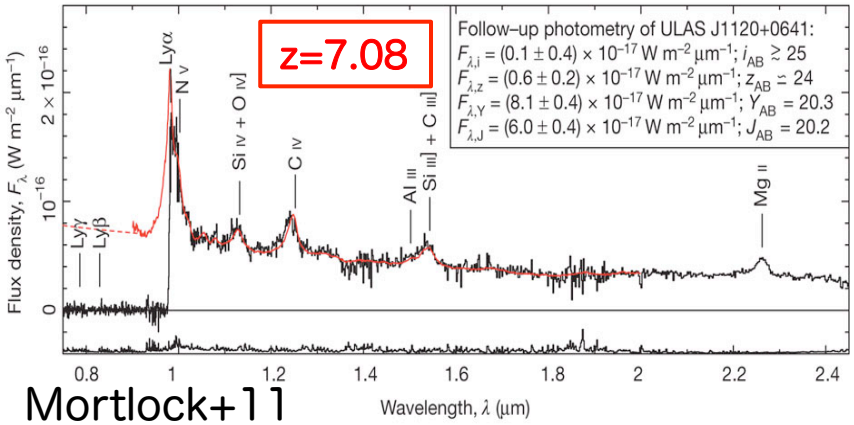
Stacked spectra of high-z quasars



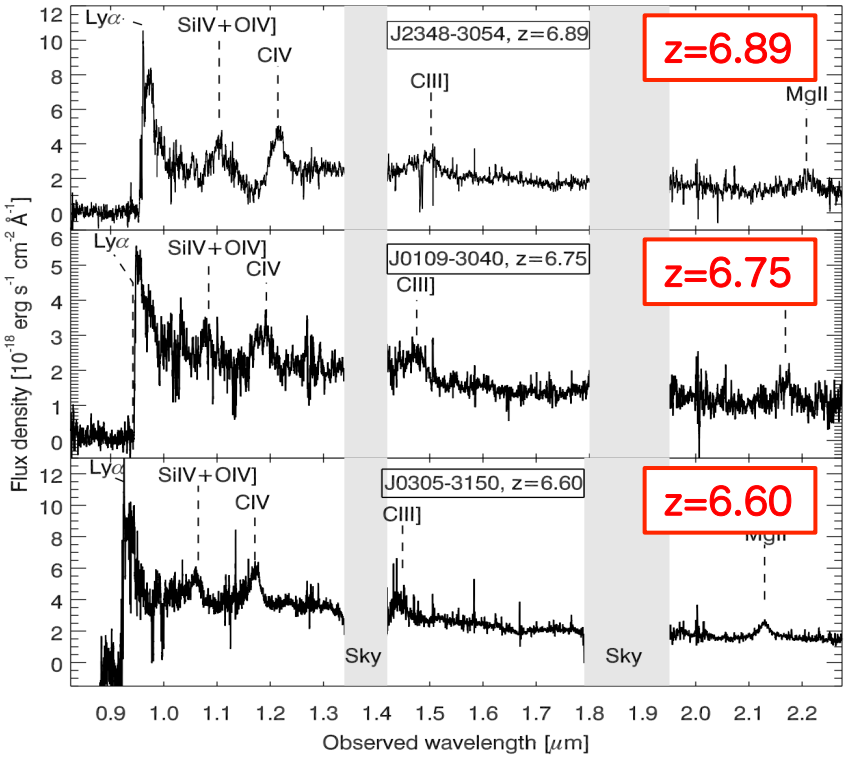
Even at z~6 (t_{age}~1 Gyr), the SMBH mass (~10^9 M_{sun}) and the metallicity are so high...

When the SMBH mass and the metals had increased?

Current NIR surveys are NOT enough: at z~7



Mortlock+11



Venemans+13, see also Venemans+15

Only <10 quasars at z > 6.5, from UKIDSS, VIKING, and Pann-STARRS surveys

NEW Surprises:

- M_{BH} ~ (1-2)x10^9 M_{sun} typically
- Strong metallic emission lines

but based on small statistics... and maybe we are missing "growing-up" low-M_{BH} quasars due to the limited sensitivity...

and we have NO quasars at z>7.1

Previous optical quasar surveys: a brief summary

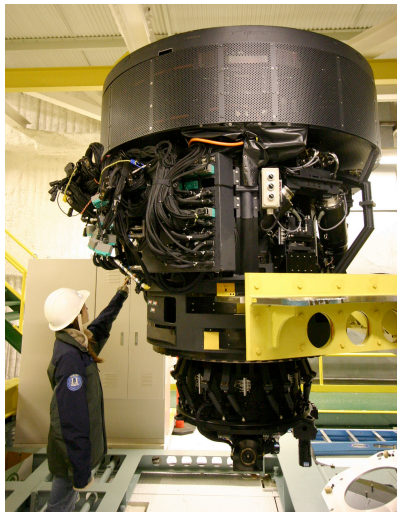
- Evolution of the quasar number density was examined
  - ~ the number density peak of luminous quasars at z~2-3
  - ~ luminosity dependent density evolution (or “down-sizing”)
  - ~ number density of low-luminosity quasars at z>3 still unknown
  - ~ dusty quasars have not been explored in optical surveys

- A few dozens of quasars at z~6 were discovered
  - ~ incomplete reionization was identified at z~6
  - ~ possible spatial variation has not been explored
  - ~ SMBH mass had already reached up to ~10^9 M_{sun} even at z~6
  - ~ low-mass SMBHs not identified; the mass function is unclear

- A few quasars were found at z~7
  - ~ very massive SMBHs (M_{BH}>10^7 M_{sun})? High metallicity AGNs?
  - ~ statistically larger sample is definitely needed

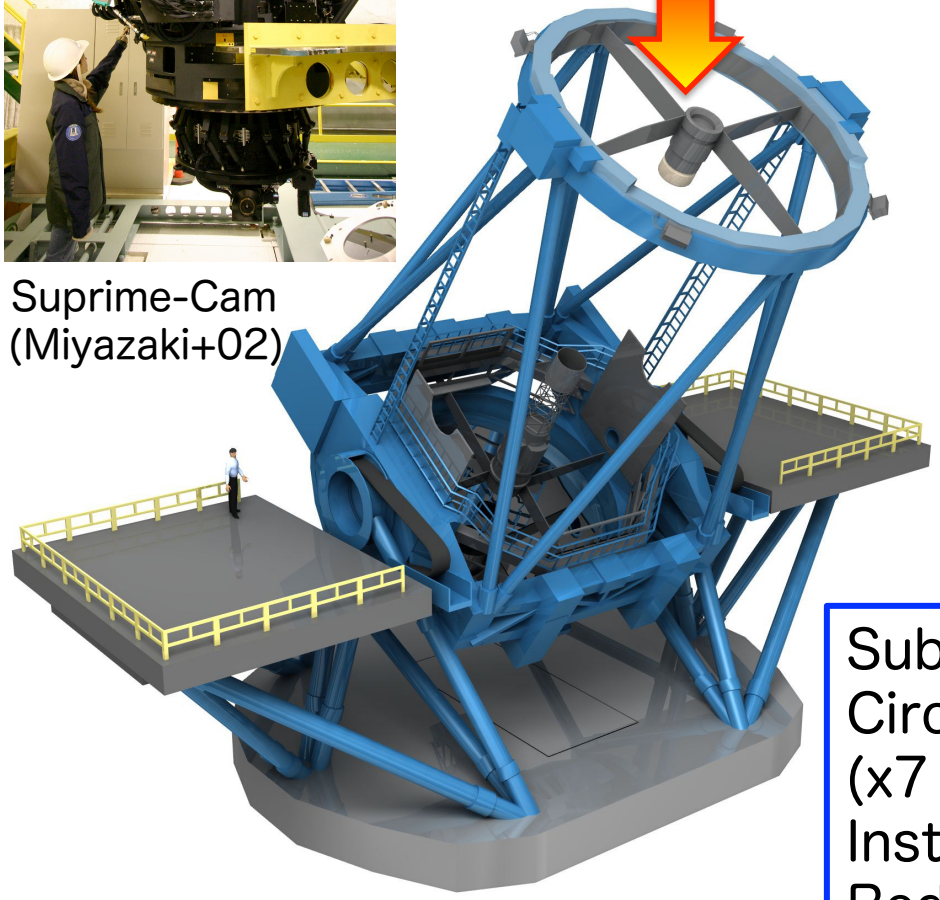
New wide and deep quasar surveys are necessary.

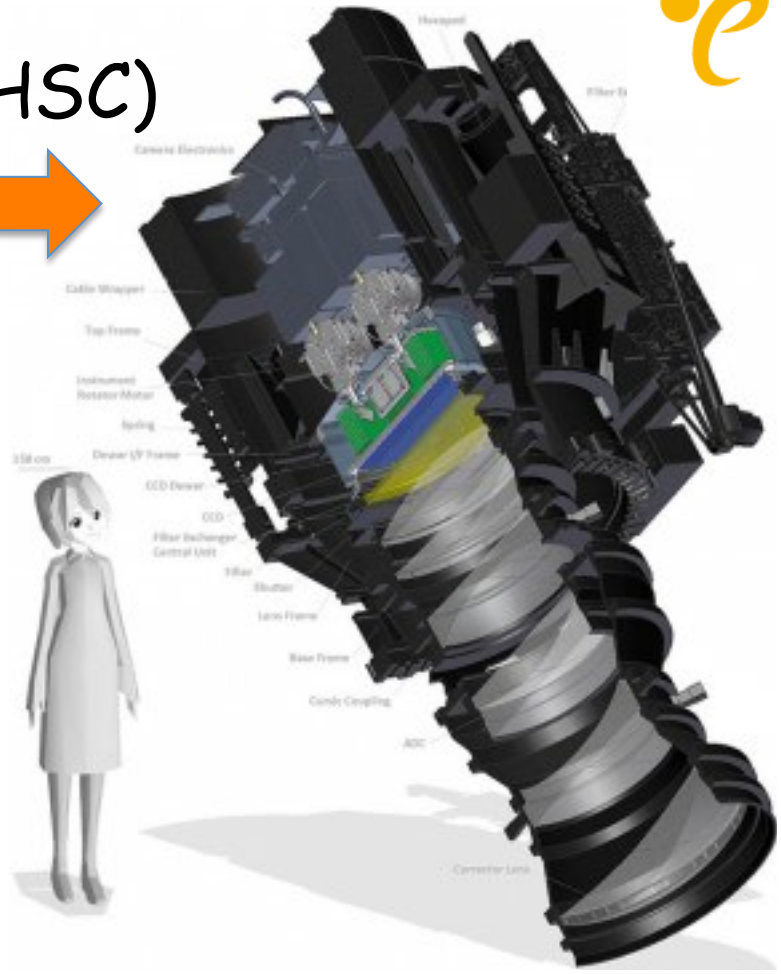
Subaru Hyper Suprime-Cam (HSC)



Suprime-Cam
(Miyazaki+02)

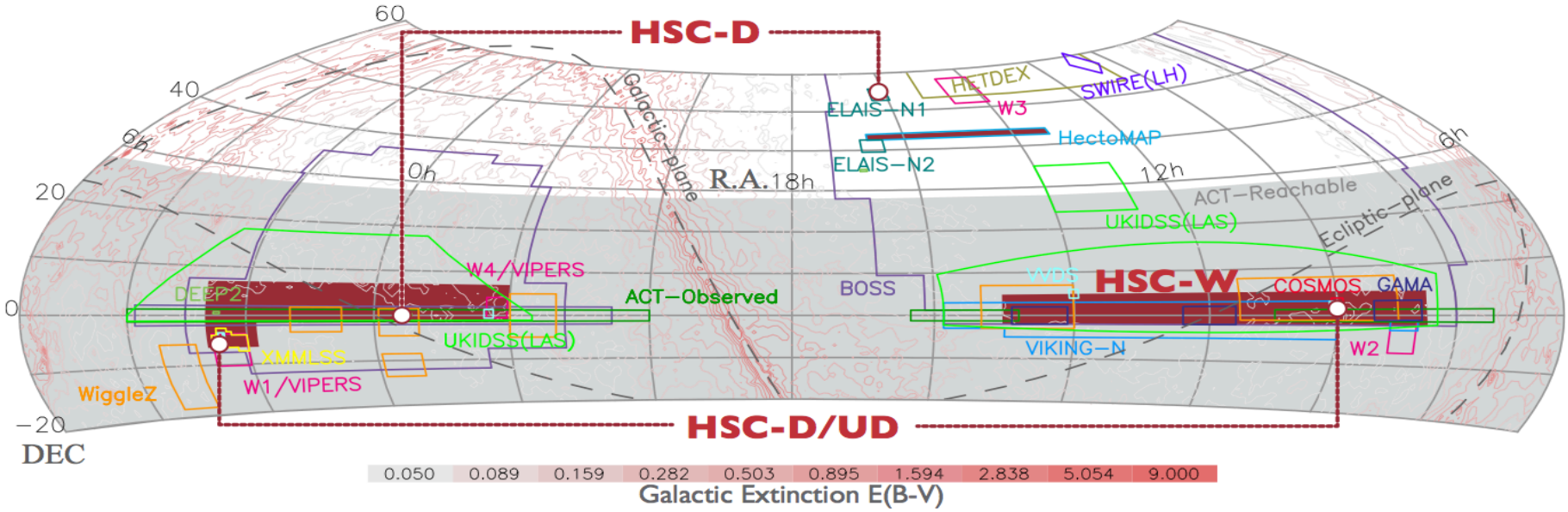
Prime Focus





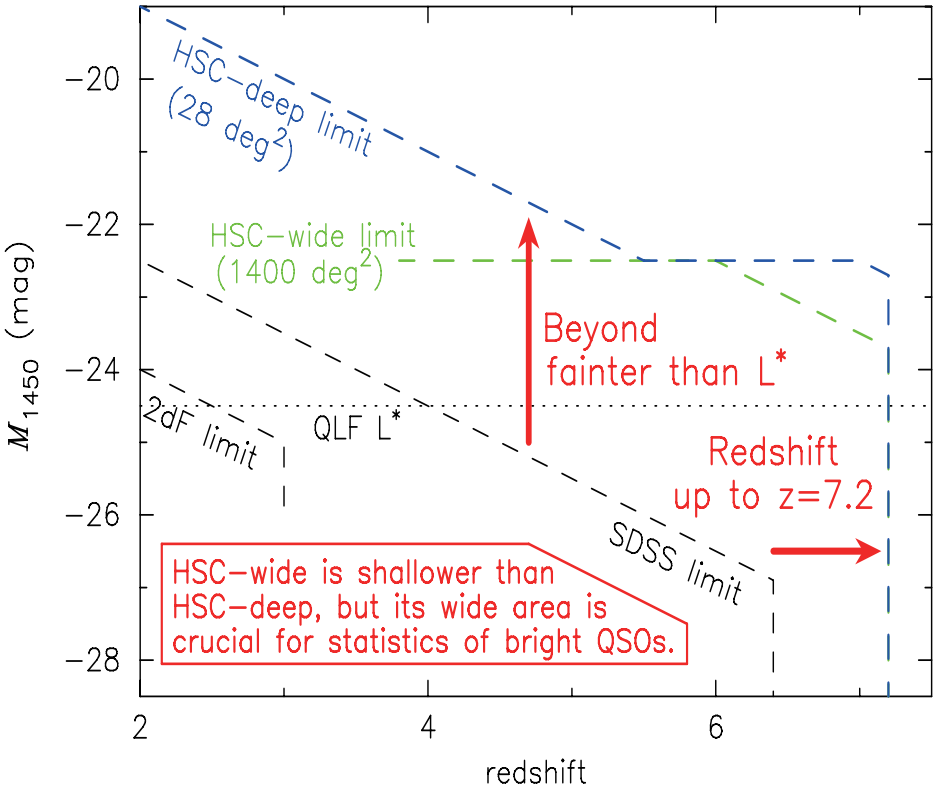
Subaru next-gen. wide-field camera
Circular FoV with a 1.5 deg diameter
(x7 wider FoV than Suprime-Cam)
Instrumental PSF: <0.1" (for the whole FoV)
Red-sensitive detectors

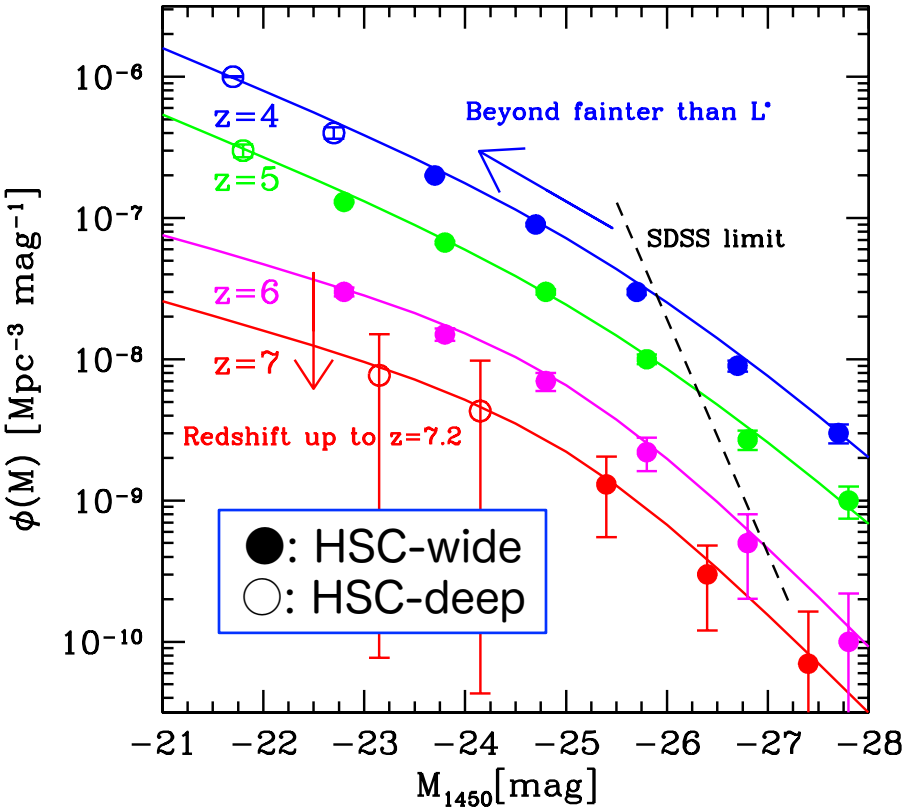
Subaru strategic program (SSP) with HSC



- Multi-layer survey consisting of 3 layers
  - ~ Wide: 1400 deg^2 down to i~25.9
  - ~ Deep: 28 deg^2 down to i~26.8, some NBs, cadence
  - ~ UD: 3.5 deg^2 down to i~27.4, some NBs, cadence
- Allocation: 300 nights in 5 yrs
  - ~ started in March 2014, now on-going
  - ~ full 5 band obs. completed for ~200 deg^2 in HSC-W
- Participation: Japan, Taiwan, Princeton U.

An on-going quasar survey with HSC





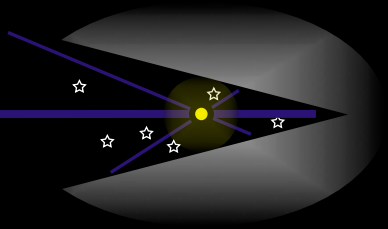
- Depth: ~3 mag (or >1 dex) deeper than SDSS
- Pushing the redshift limit up to z~7.2 (thanks to y-band)
- Combination of HSC-W and HSC-D surveys

HSC-AGN studies: initial results

- Survey for quasars at z>6
  - ~ “Subaru High-z Exploration of Low-L Quasars (SHELLQs)”
  - ~ led by Yoshiki Matsuoka (NAOJ, Japan)
  - ~ submitted to ApJ (arXiv:1603.02281)
- Dust Obscured Galaxies (DOGs)
  - ~ led by Yoshiki Toba (ASIAA, Taiwan)
  - ~ PASJ, 67, 86 (2015) (arXiv:1506.00320)
- Variability-selected low-MBH AGNs
  - ~ led by Tomoki Morokuma (U. Tokyo, Japan)
  - ~ PASJ, in press (arXiv:1603.02302)
  - ~ not based on the HSC-SSP survey (but based on HSC obs.)

SHELLQs

Subaru High-z Exploration of Low-Luminosity Quasars



Subaru Hyper Suprime-Cam SSP Project 47

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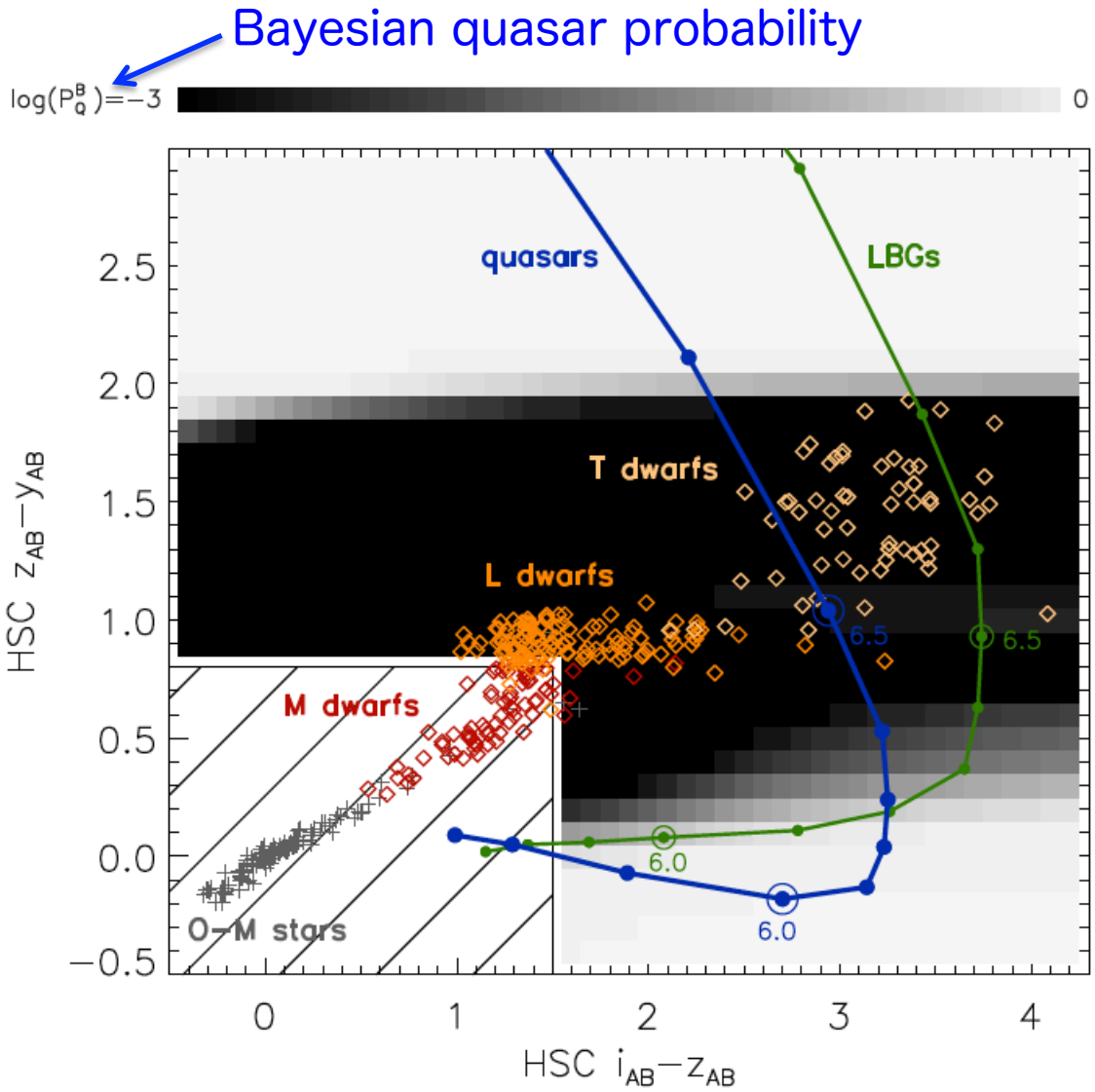
HSC quasars at z~6: candidate selection

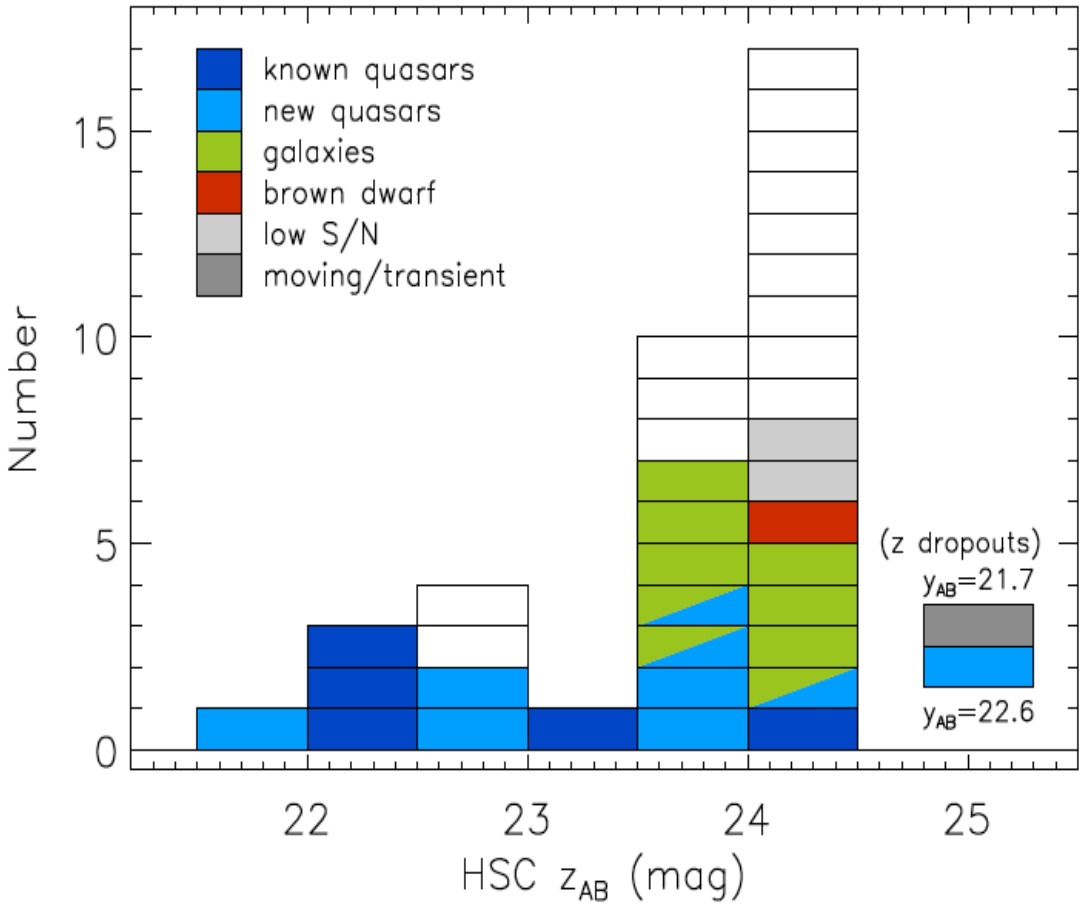


Candidates of quasars at z~6 are selected with HSC i, z, y photometry (y-band is extremely powerful).

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

Matsuoka et al. incl. TN (2016, submitted), based on ~80 deg^2 data

HSC quasars at z~6: success rate



Matsuoka et al. incl. TN (2016, submitted)
based on ~80 deg^2 data

The success rate of our candidate selection is nearly 100% at z < 23.5 !!

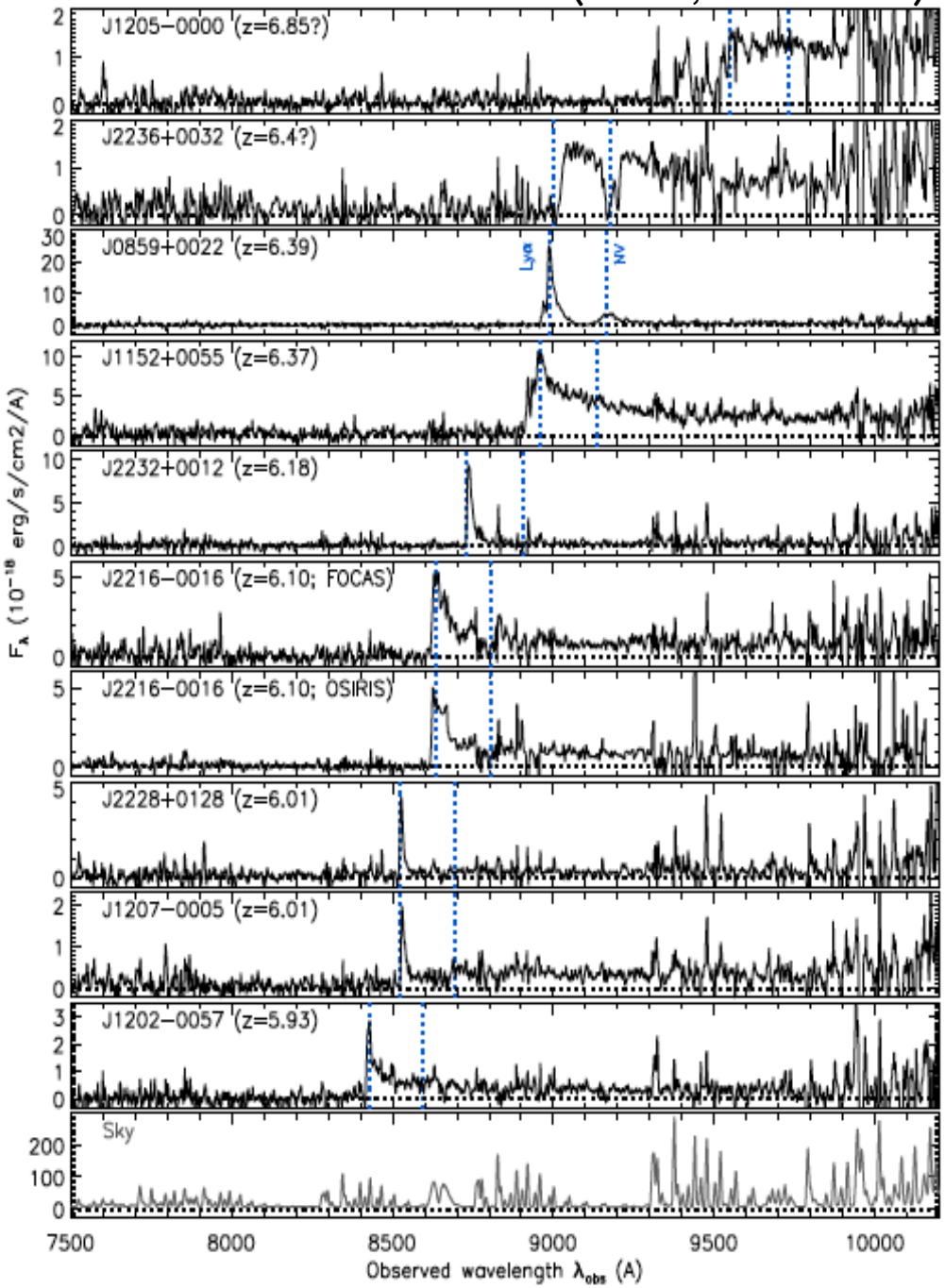
The success rate is still ~50% down to z~24, and lower at fainter than z=24.

The main contamination source is actually galaxies at similar redshift, not brown dwarf stars. Our estimate of the Bayesian probability works very well.

HSC quasars at z~6: optical spectra

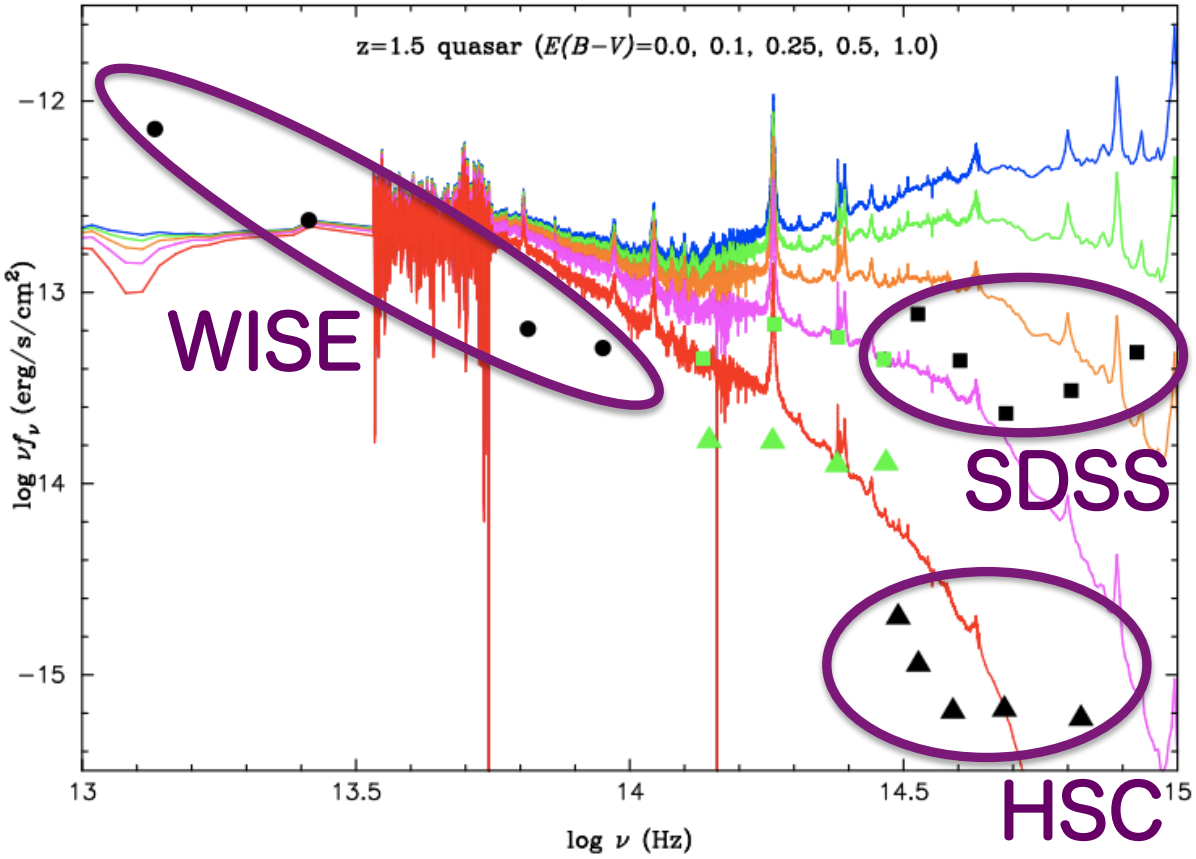
- ~10 quasars at z ~ 6-7 spectroscopically identified only in the last winter.
- including a quasar at z~6.85 (z-band dropout).
- The 2 highest-z quasars show BAL-like features (possibly in very actively outflowing phase?).
- Spectra of some HSC quasars show strange appearance (narrow Lyα, no NV, but still non-LAE).

Matsuoka et al. incl. TN (2016, submitted)



Synergy with multi-wavelength data: MIR

- identifying red quasars with HSC & MIR all-sky data
  - ~ WISE all-sky data are available
  - ~ Dusty quasars (in a special evolutionary phase?)
  - ~ Type 2 AGNs (cannot be sampled only with HSC)

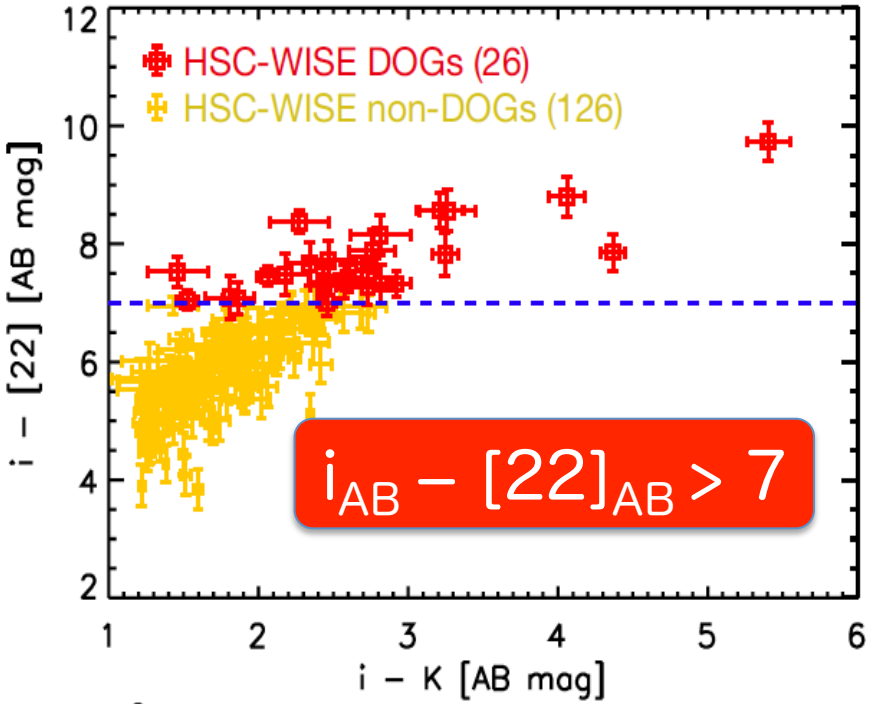


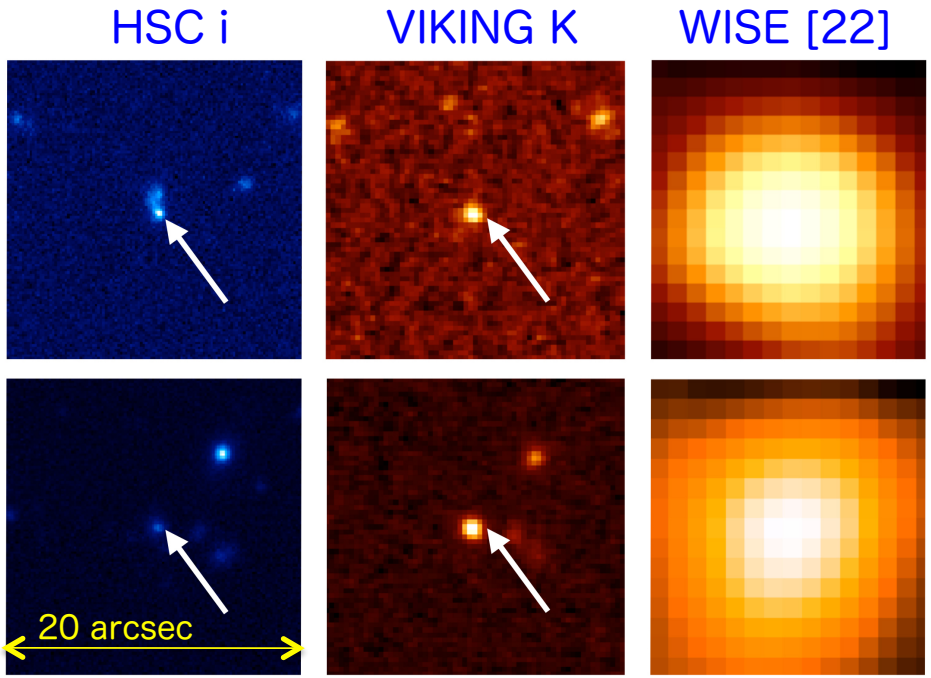
z=1.5 quasar spectrum with various E(B-V)

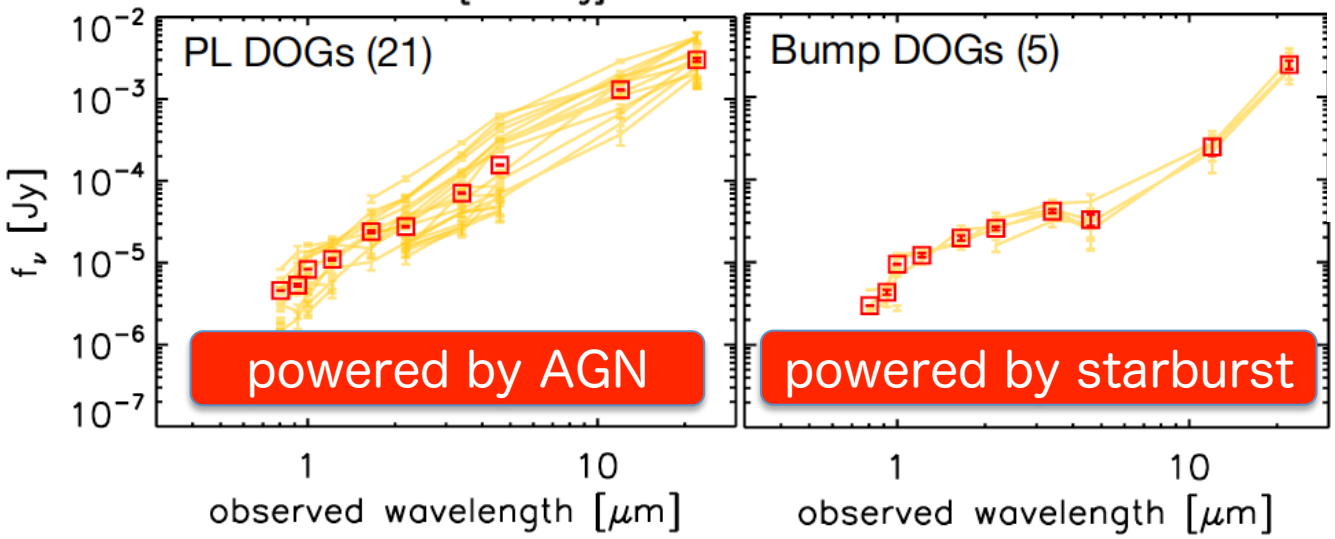
Red WISE-detected quasars cannot be detected in SDSS

HSC is deep enough to detect them!

Results of HSC "Dust Obscured Galaxies"

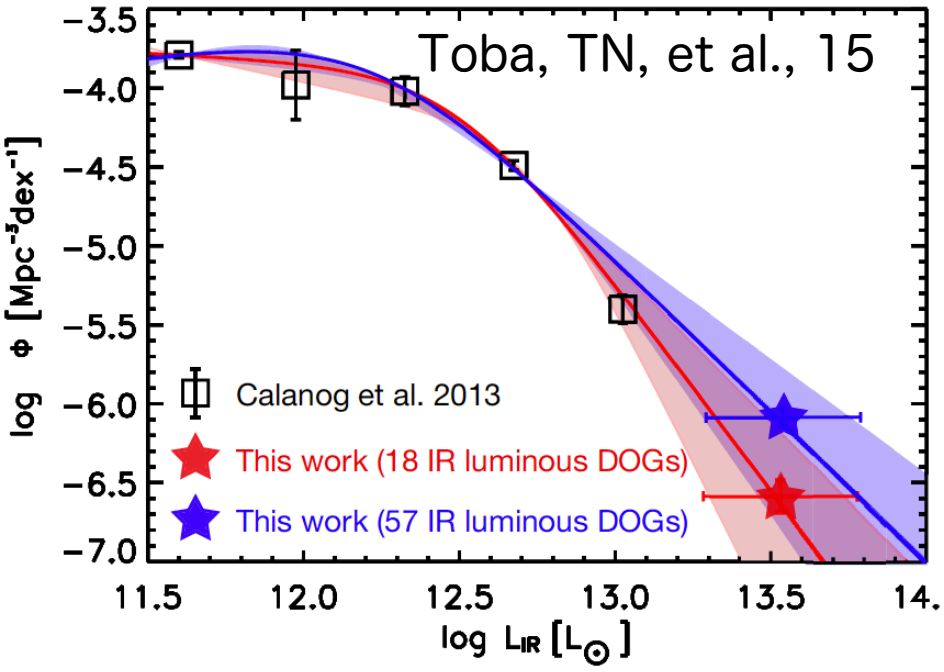


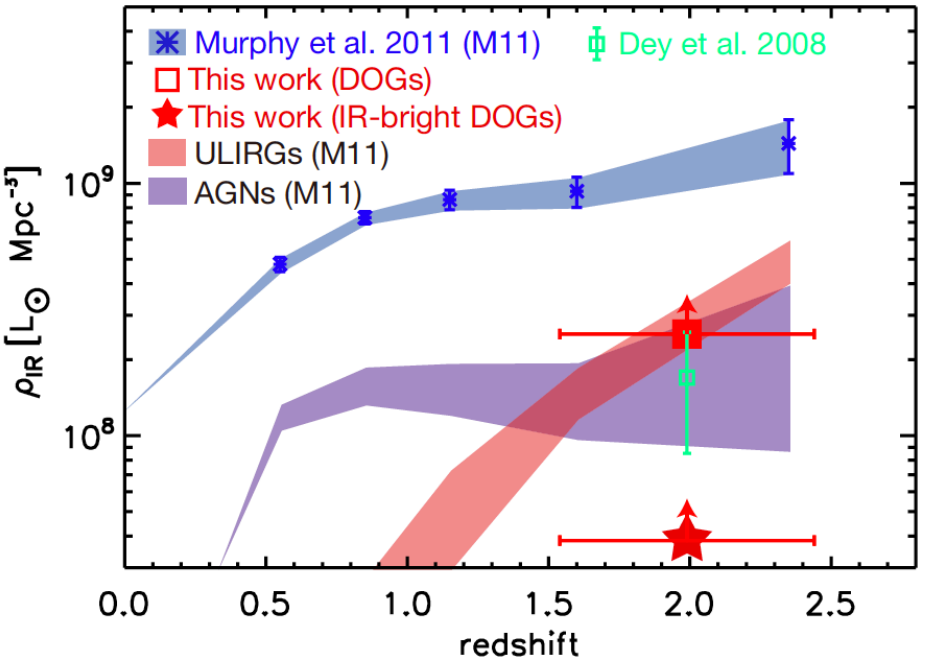




HSC project 34
Toba, TN, et al., 15
based on
~10 deg^2 data

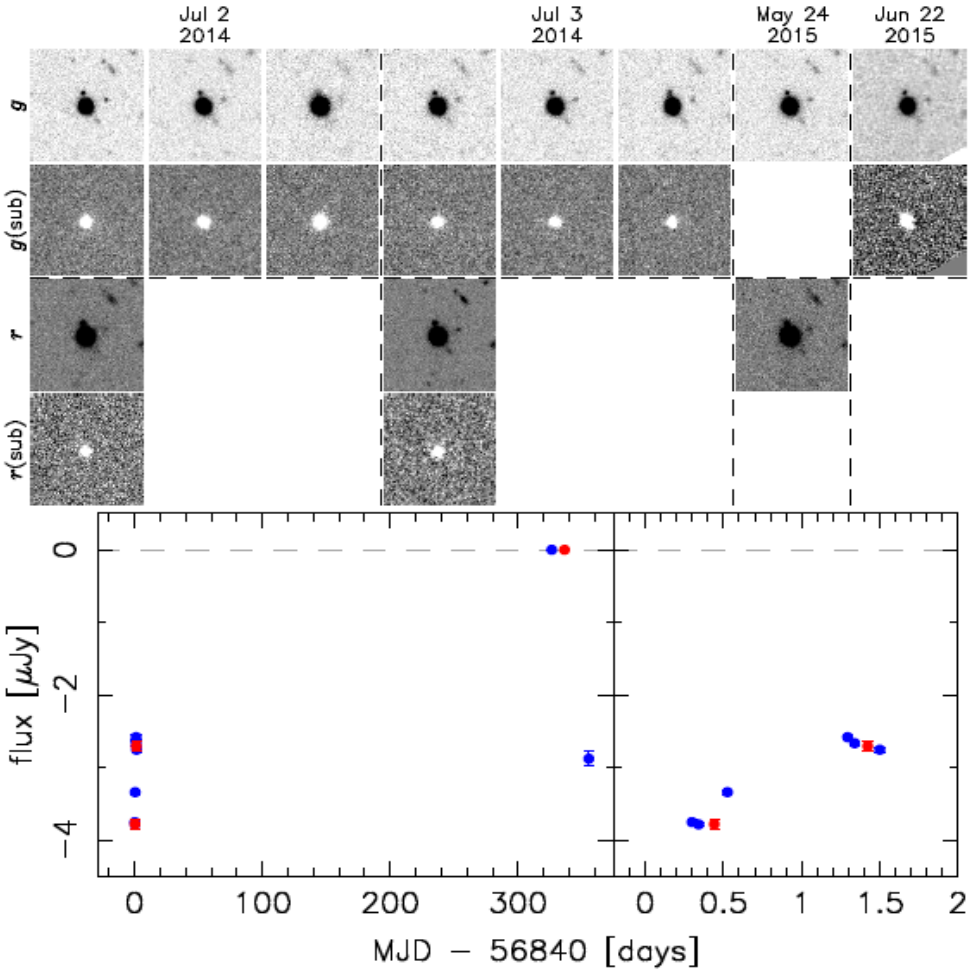
Number/luminosity density of HSC DOGs





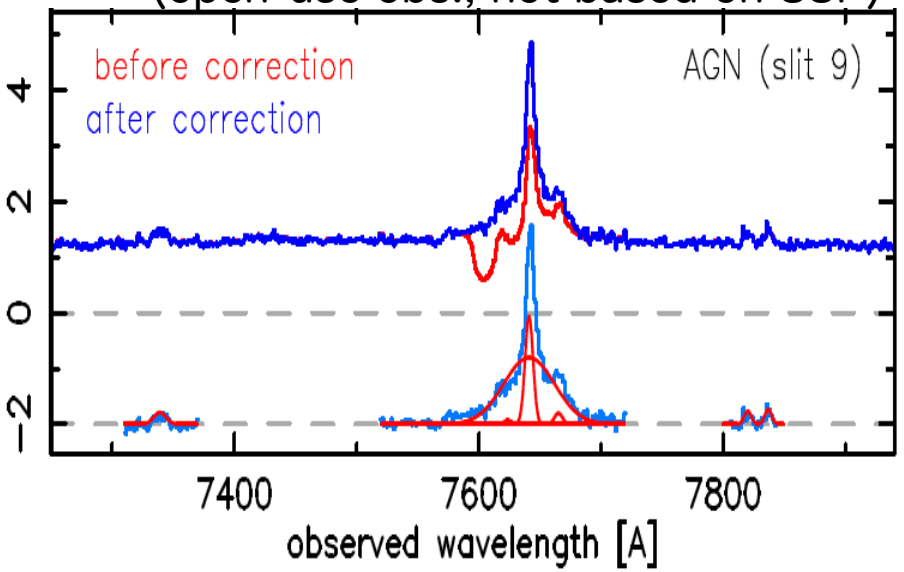
- The bright end of DOGs LF has been determined for the first time → The DOGs LF is characterized by double power law, not Schechter-like shape.
- The contribution of DOGs to the IR luminosity density is estimated to be >3 %.
- Latest DR contains x10 larger number of DOGs → ACF of DOGs & CCF with galaxies → $M_{\rm DMH}$, environment, ...

Variability-selected AGNs



HSC variability info
→ identifying objects with objects with a quick variability

Morokuma et al. incl. TN (2016)
(open-use obs., not based on SSP)



Follow-up spectroscopy
→ AGN with a small SMBH
(M_{BH} ~ 2.6 x 10^6 M_{sun})

HSC-SSP will discover many low-M_{BH} AGNs (like this) soon
(HSC projects 56, 57, 72, 99)

Summary and possible synergy with eROSITA

➢Initial results of the HSC AGN survey

- ~ Extremely efficient selection of z~6-7 quasars results in the spectroscopic confirmation of ~10 quasars at z~6-7
- ~ Successful selection of WISE-HSC DOGs using VIKING data
- ~ Low-M_{BH} AGNs through variability selection with HSC images

➢Possible synergy with eROSITA

- ~ Combination of HSC and eROSITA will be powerful for searches of "obscured" AGNs at high-z
- ~ HSC is not so powerful to select quasars at z~1-3 due to the lack of u-band; eROSITA will help to select z~1-3 quasars among numerous HSC sources
- ~ eROSITA data for WISE-HSC DOGs will tell us the AGN power and mass accretion rate, that cannot be assessed with HSC
- ~ Combination of the time-variability data in HSC and eROSITA will tell us physics of the variability
- ~ and many more