Subaru Wide-Field AGN Survey (SWANS) with HSC

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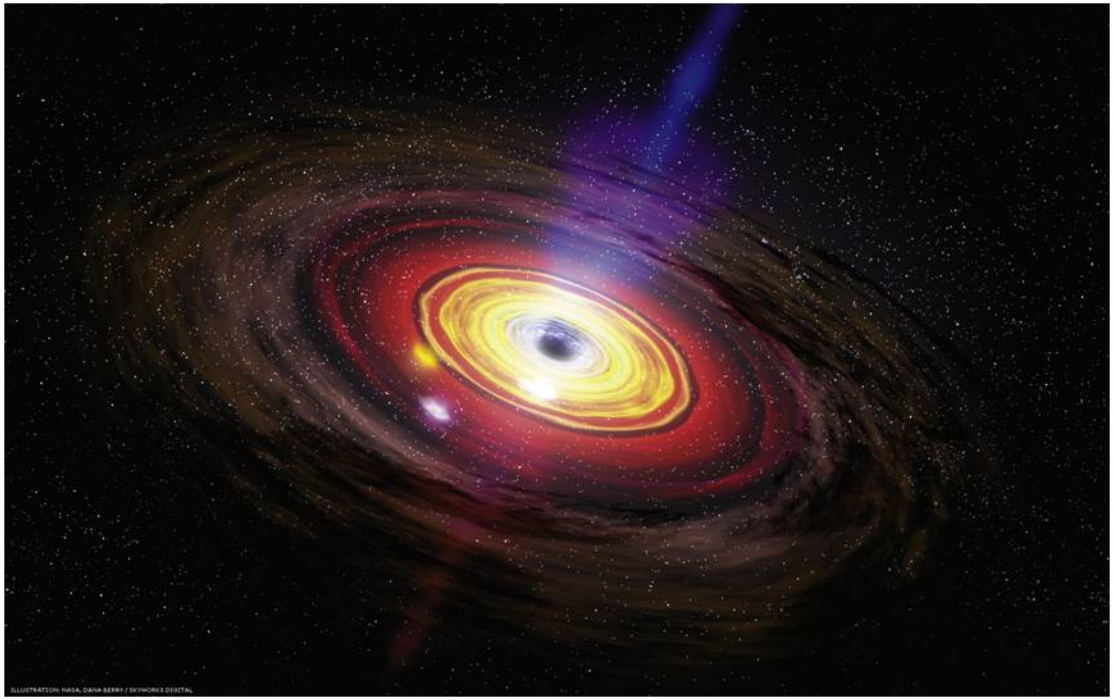
on behalf of the HSC-AGN WG

愛媛大学
EHIME UNIVERSITY

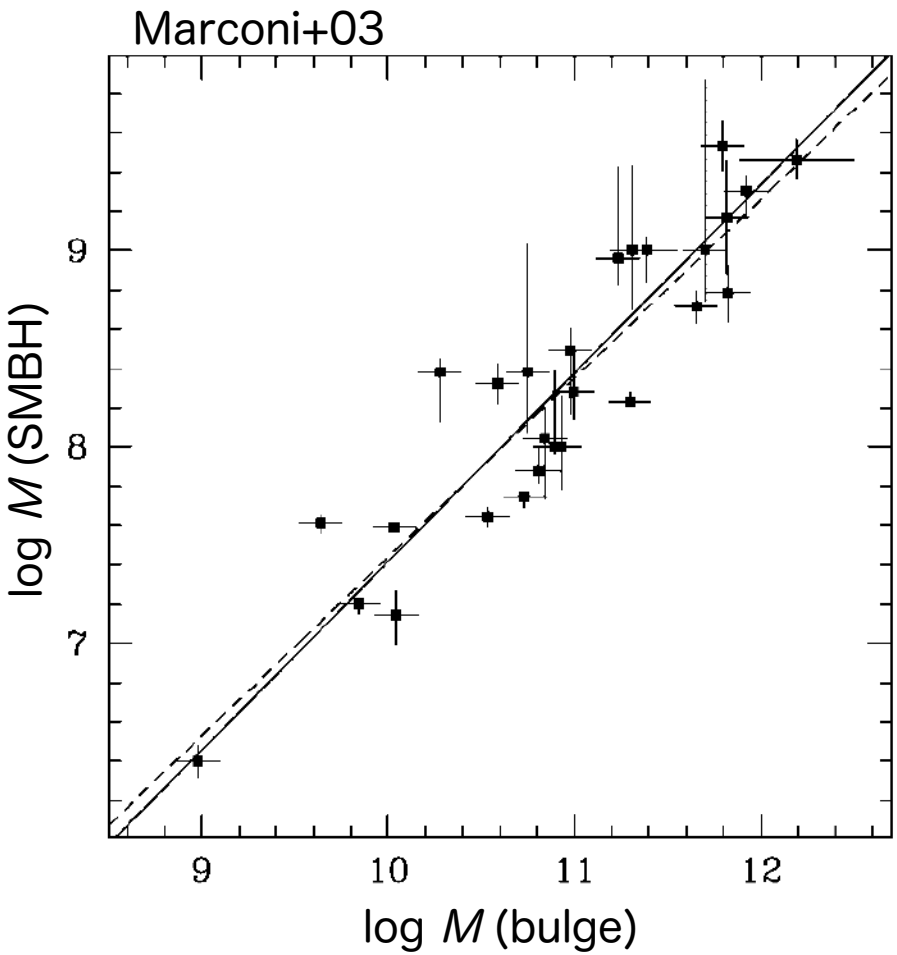
Subaru Seminar
26 Dec. 2014, Hilo Base Facility, Hawaii

Quasars, powered by supermassive black holes



The mass of SMBHs reaches up to $10^{10}\,M_{\rm sun}$,
but nobody knows how SMBHs formed and evolved.

Co-evolution of SMBHs and galaxies

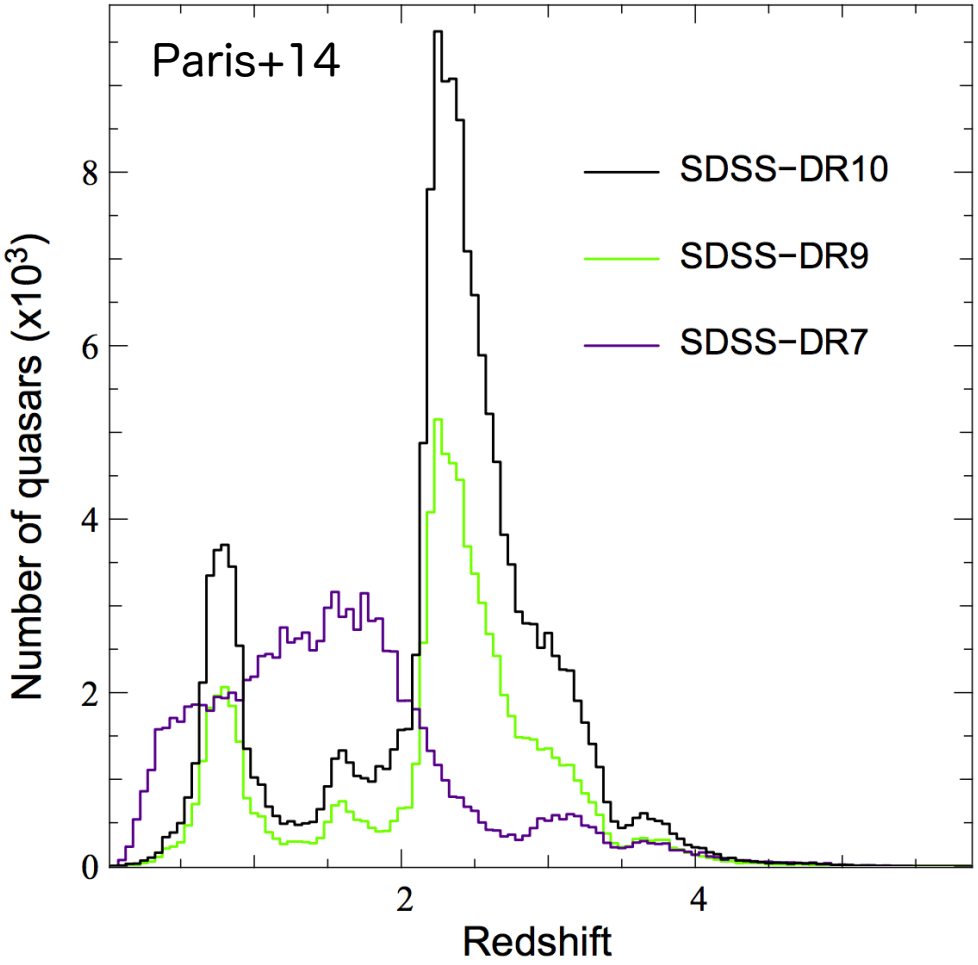


There is a tight correlation between the mass of SMBHs and their host galaxies, suggesting that there is a evolutionary link between SMBHs and galaxies (co-evolution).

Why? ...nobody knows.

Studies on the SMBH evolution is important, not only for quasars but also for understanding the galaxy formation.

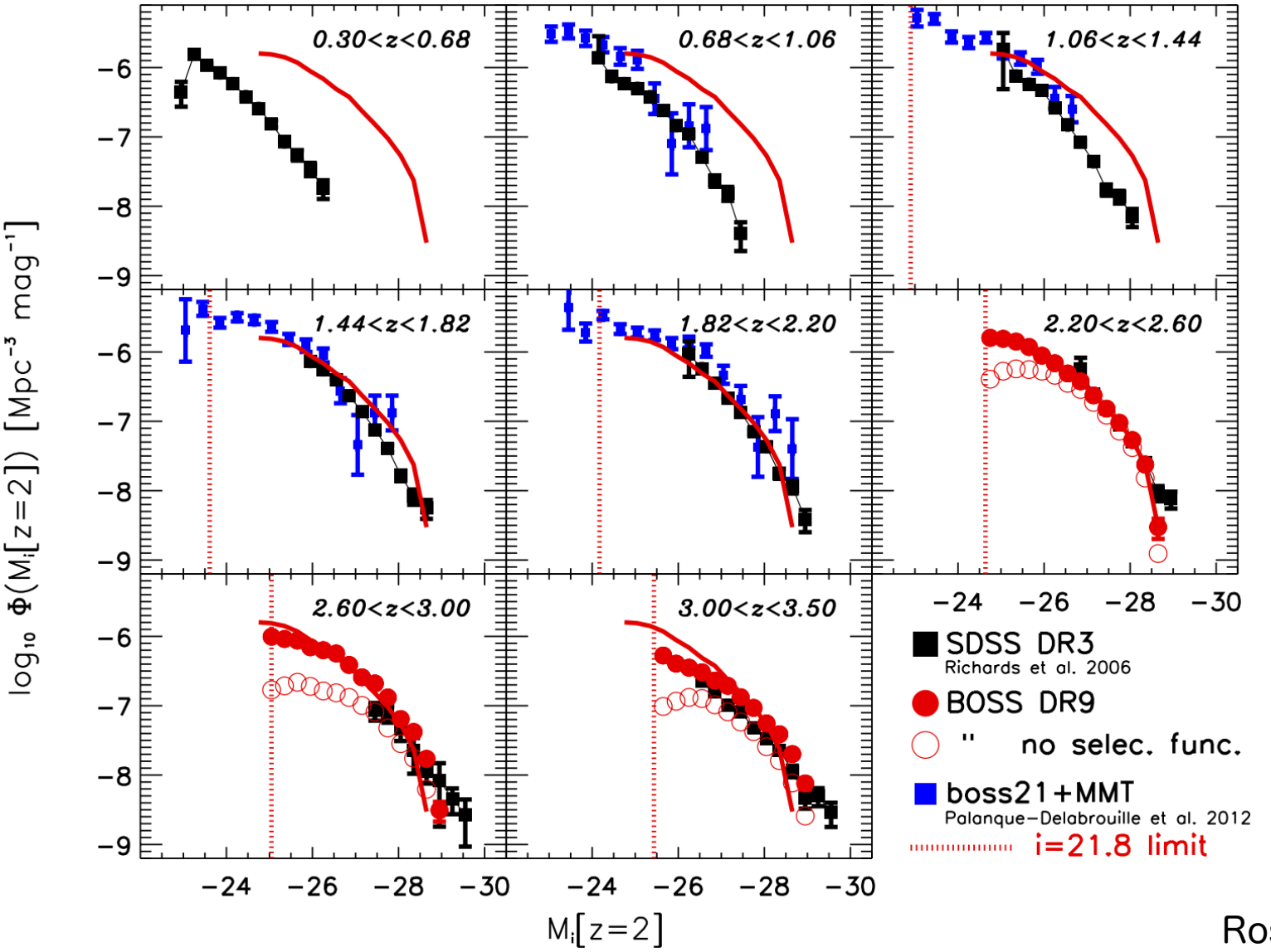
Why new quasar survey?



SDSS and BOSS have already discovered numerous quasars

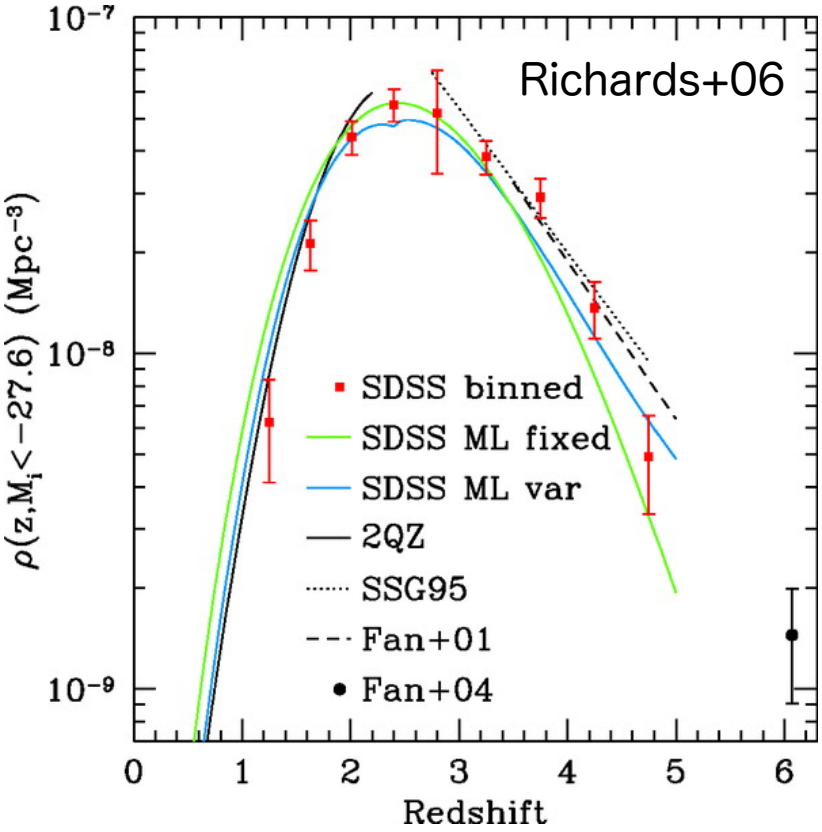
166,583 quasars in DR10

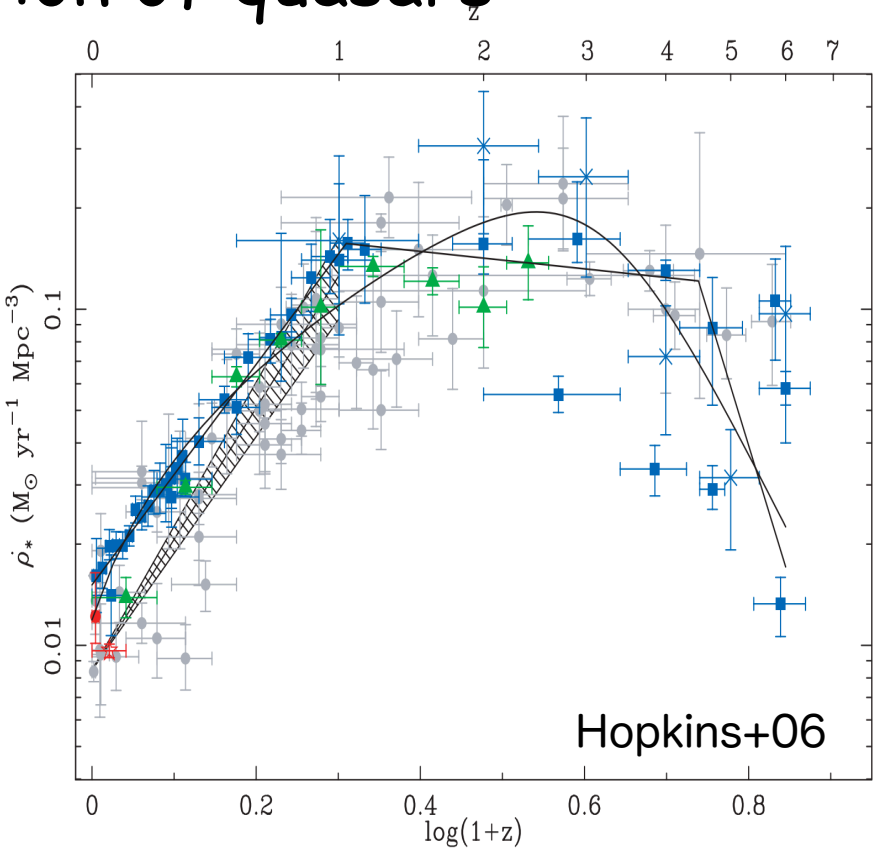
SDSS quasar luminosity function (QLF)



Ross+13

The number density evolution of quasars

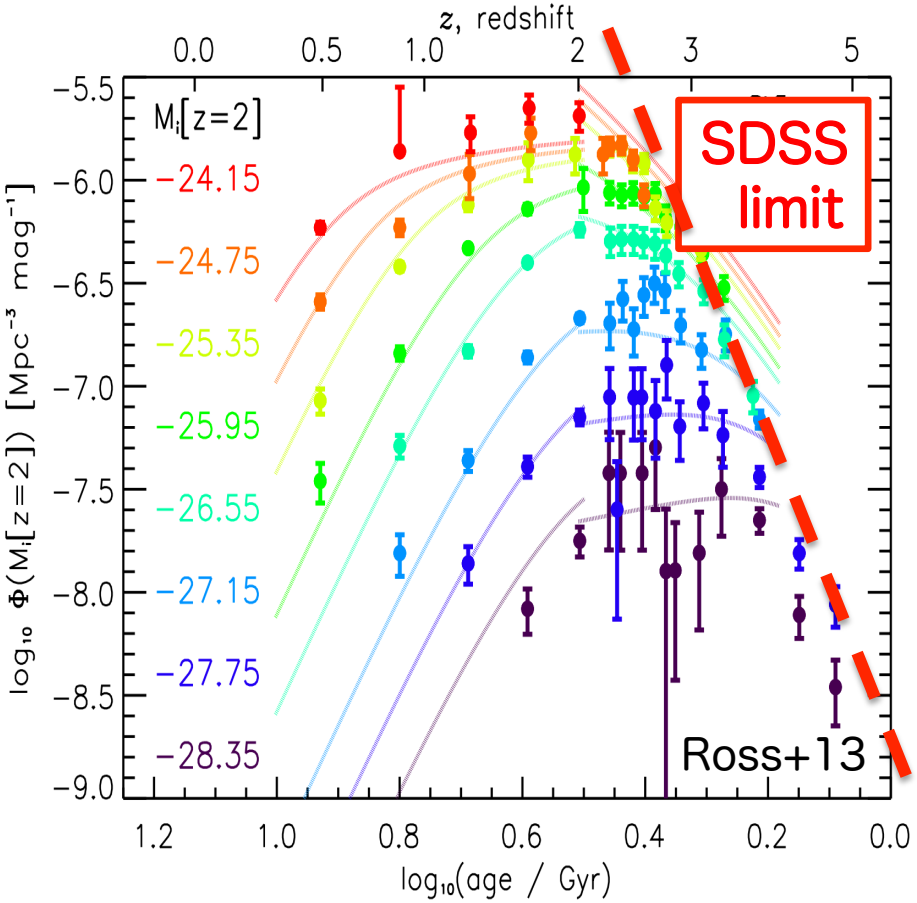




Number density of “luminous” quasars shows its peak at z~2-3. Similar to the evolution of cosmic star-formation rate density!

Indirect evidence of a close connection between the SMBH growth and the galaxy evolution

"Luminosity dependent" evolution of the QLF



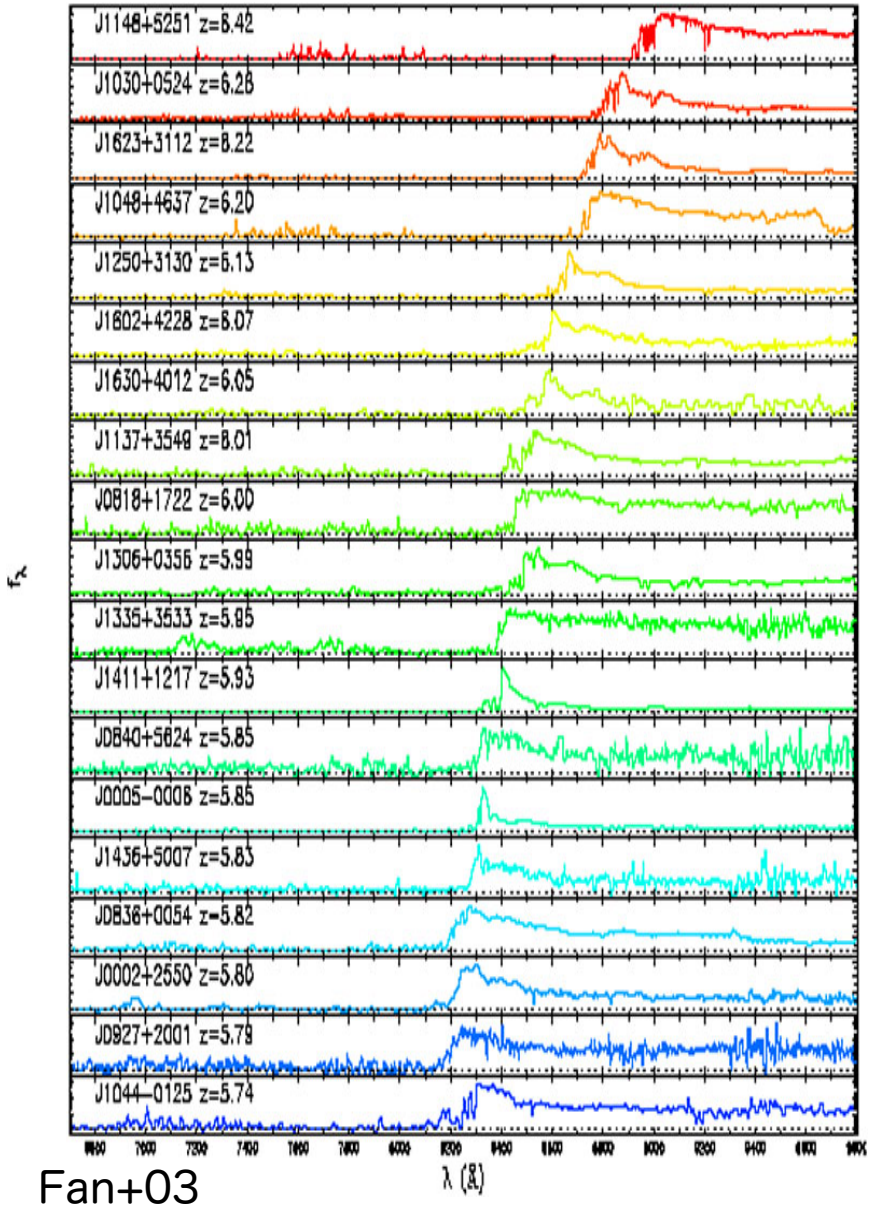
Number density evolution of SDSS III quasars. Different colors denote different luminosity ranges. See also, e.g., Croom et al. (2009); Ikeda, Nagao, et al. (2011, 2012).

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?

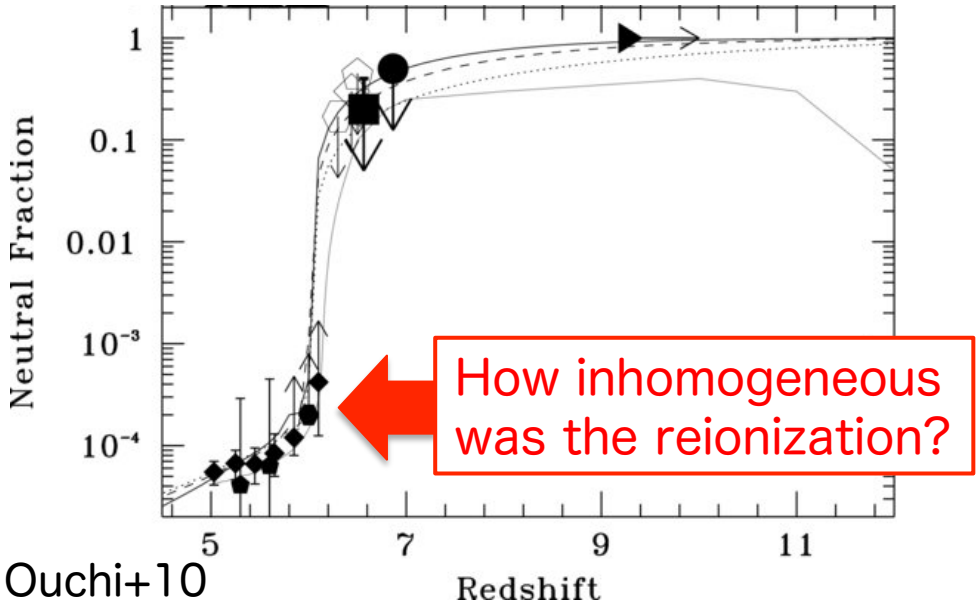
SDSS is NOT enough: also at z~6



Fan+03

A few dozens of quasars at z~5.7-6.5 have been found so far

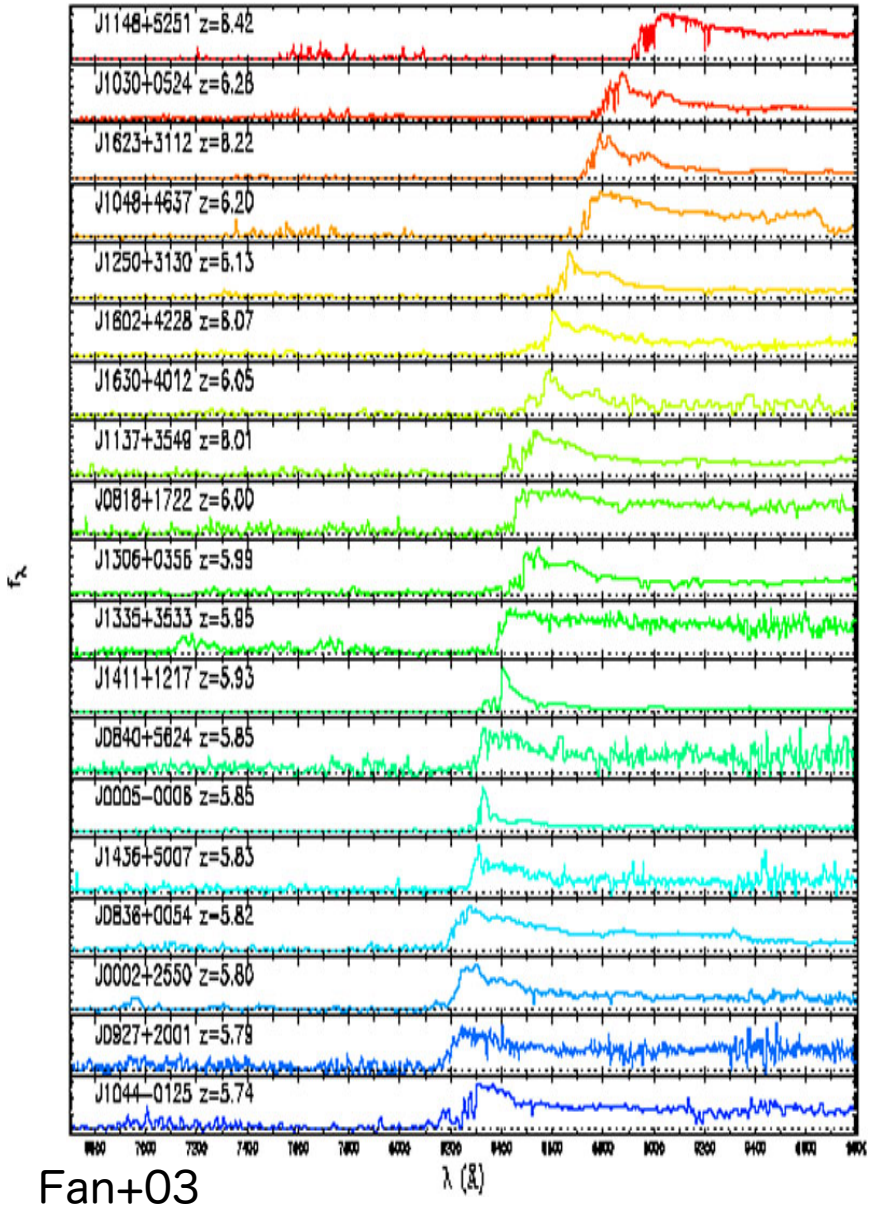
Cosmic reionization of hydrogen



Ouchi+10

More quasars at z~6 needed!

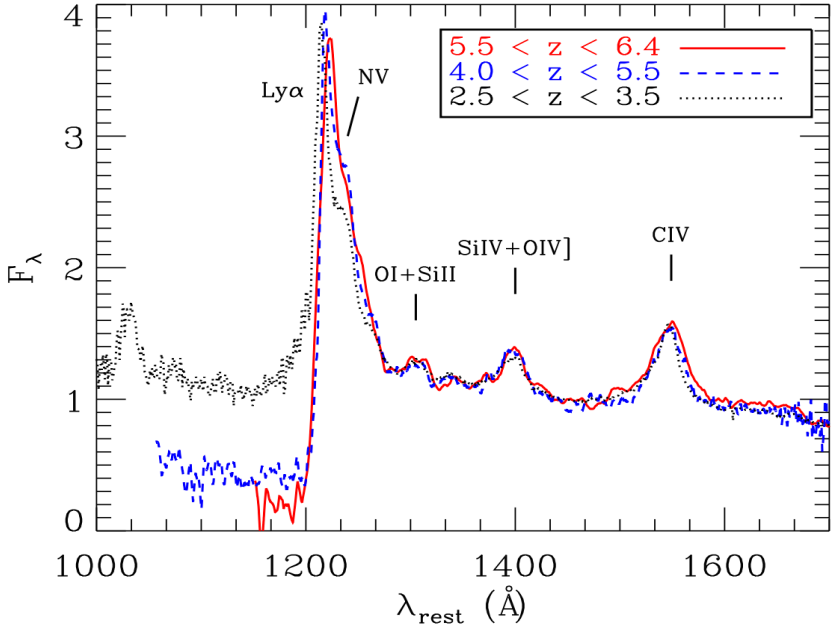
SDSS is NOT enough: also at z~6



Fan+03

Juarez et al. (incl. TN) 2009

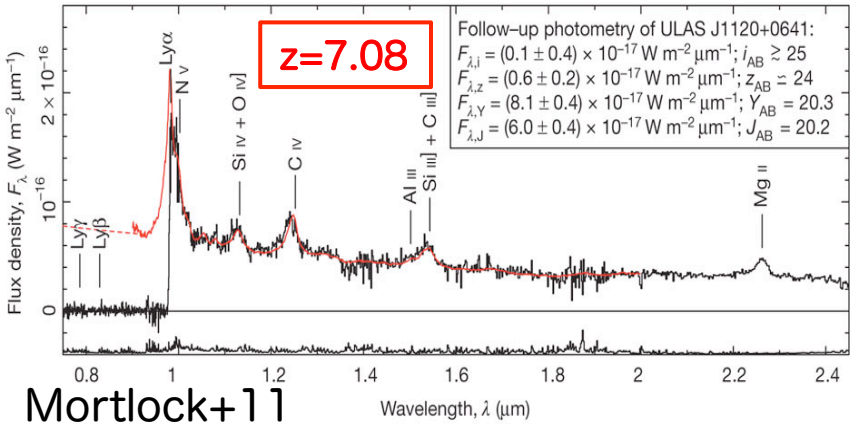
Stacked spectra of high-z quasars



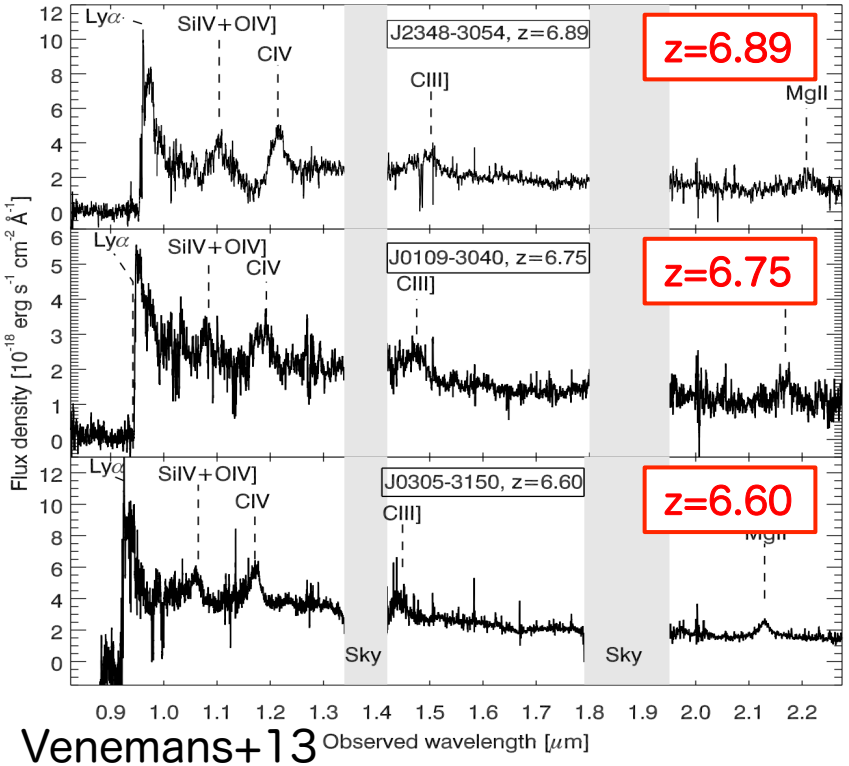
Even at z~6 (t_{age}~1 Gyr), the SMBH mass (~10^9 M_{sun}) and the metallicity are so high...

When the SMBH mass and the metals had increased??

Current NIR surveys are NOT enough: at z~7



Mortlock+11



Venemans+13

Only 4 quasars at 6.6<z<7.1, from UKIDSS & VIKING surveys

NEW Surprises:

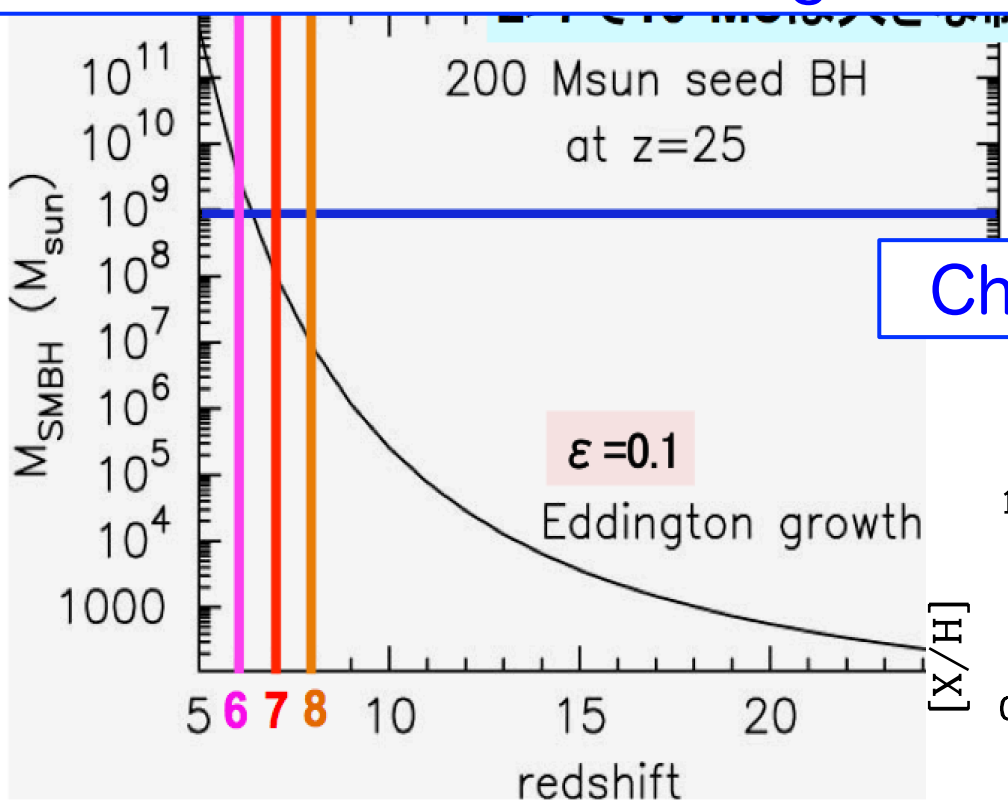
- $M_{BH} \sim (1\text{-}2)\times10^9\ M_{sun}$
- Strong metallic emission lines

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

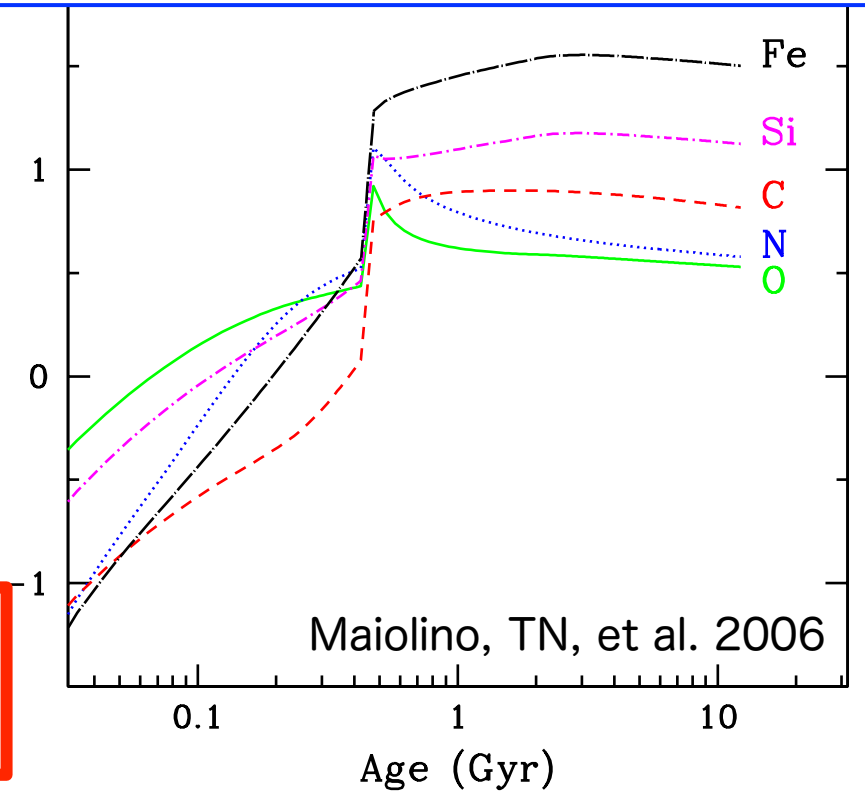
Current NIR surveys are NOT enough: at z~7

SMBH evolution at high-z



[Courtesy of Imanishi-san]

Chemical evolution at high-z



We need quasars at z > 7
for examining these issues!

Previous quasar survey: a brief summary

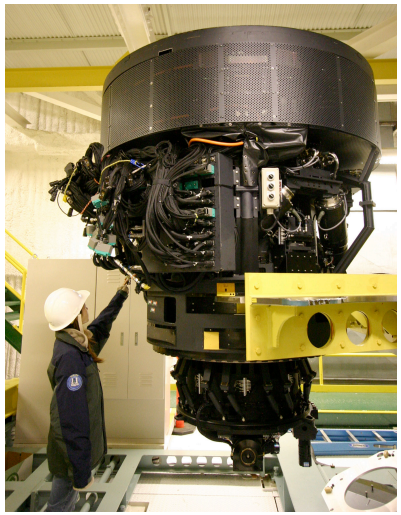
- Evolution of the quasar number density was examined
  - ~ the number density peak of luminous quasars at z~2-3
  - ~ luminosity dependent density evolution (or “down-sizing”)
  - ~ number density of low-luminosity quasars at z>3 still unknown

- A few dozen 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

- Only a few quasars were found at z~7 (UKIDSS, VIKING)
  - ~ 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 Suprime-Cam



Suprime-Cam
(1999-2015)
Miyazaki+02

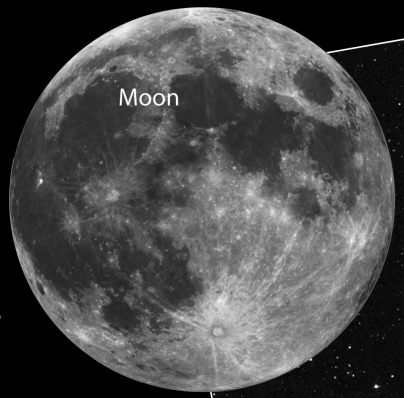
Suprime-Cam:
Prime-focus wide-field camera

Field-of-view: 27'x34'

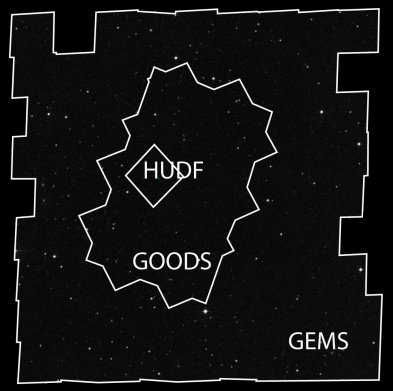
Good image quality:
instrumental degradation of the image profile is negligible for the whole of the FoV.

Extremely powerful in searching for rare and faint objects such as high-z quasars.

COSMOS



Relative Sizes of *HST* ACS Surveys

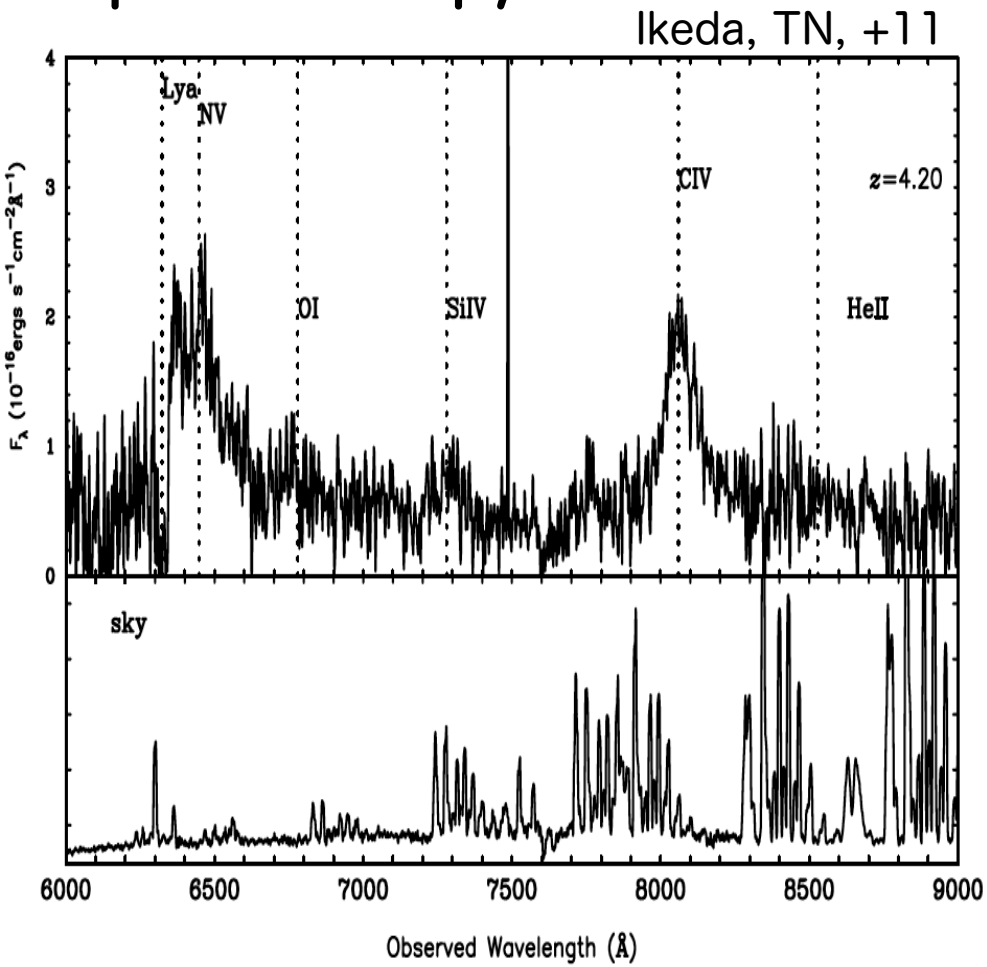


30′

Deep and wide (2 deg^2) multi-wav survey (incl. S-Cam)

We searched for high-z quasars in this COSMOS field.

Spectroscopy



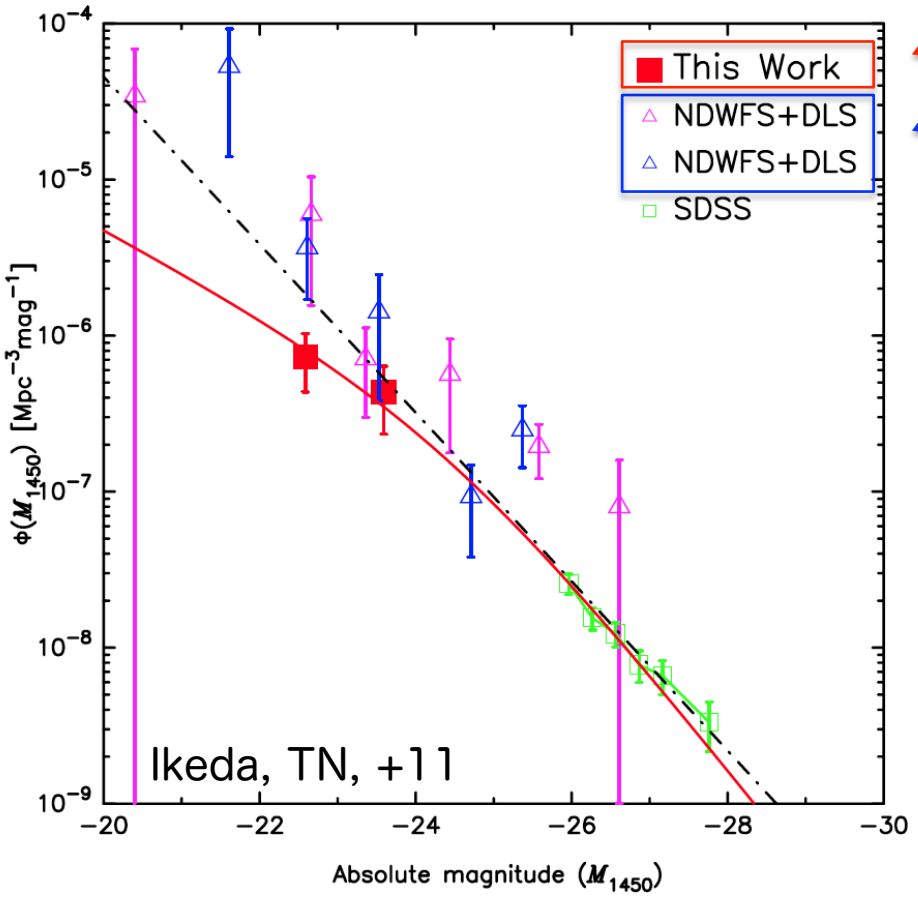
FOCAS spectrum of a quasar at z=4.20 (i=23.5), with 0.5 hr exposures.

Spectra of 28 candidates (among 31 candidates) were obtained with Subaru/FOCAS.

Typical exposure time:
0.5-2 hours for each targets

23 targets showed meaningful spectra, and 8 quasars were identified (remaining objects were late-type stars).

COSMOS QLF at z~4



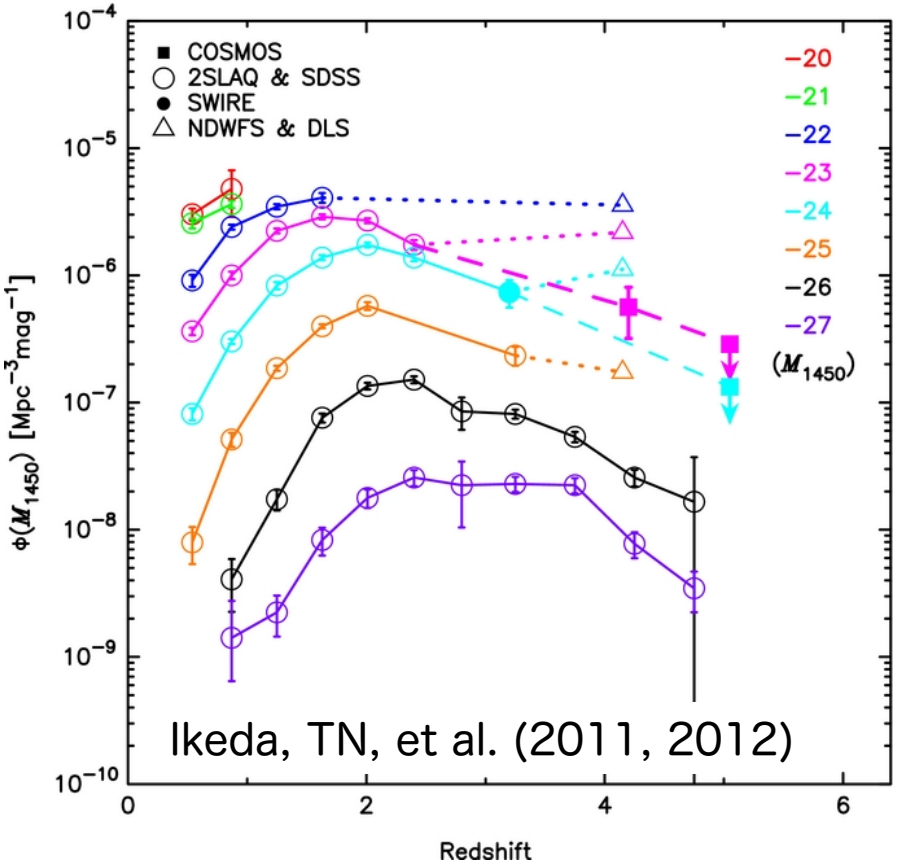
COSMOS results (Ikeda, TN, +11)

Results in NDWFS+DLS
(Glikman et al. 2010, 2011)

Derived QLF (+ SDSS QLF) is consistent to double power-law shape.

~0.5 dex lower than the number density derived by another quasar survey at similar redshift...??

Luminosity dependence of the number density

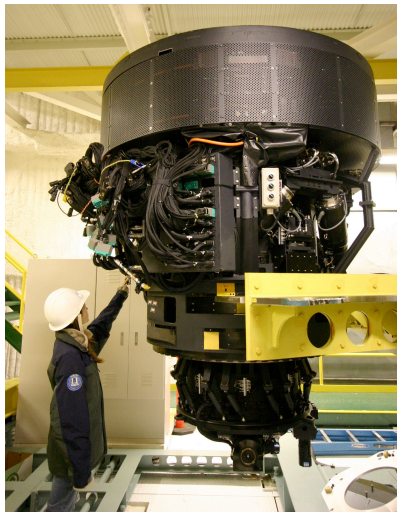


NOTE: quasars at z~5 were also searched in our COSMOS study but not identified (thus the upper limits are given at z~5).

Our results are consistent to the extrapolation of the downsizing evolutionary trend at lower z, while another survey show a different picture...??

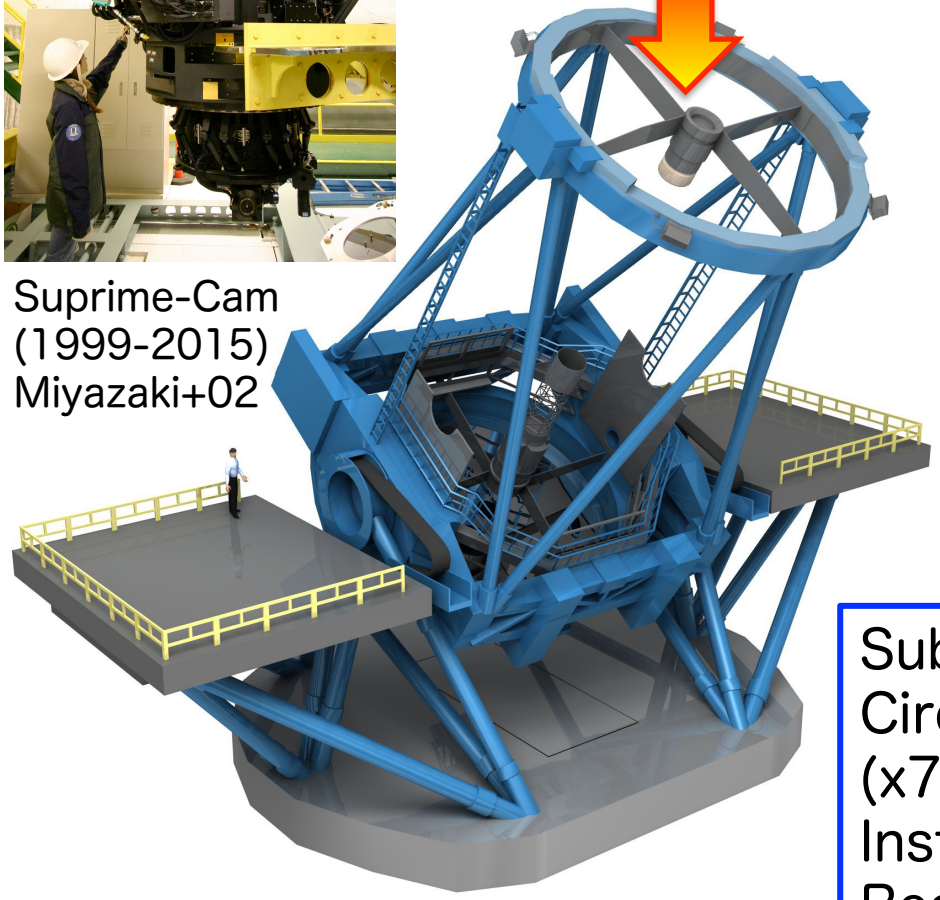
More intensive surveys for high-z low-luminosity quasars are needed !!

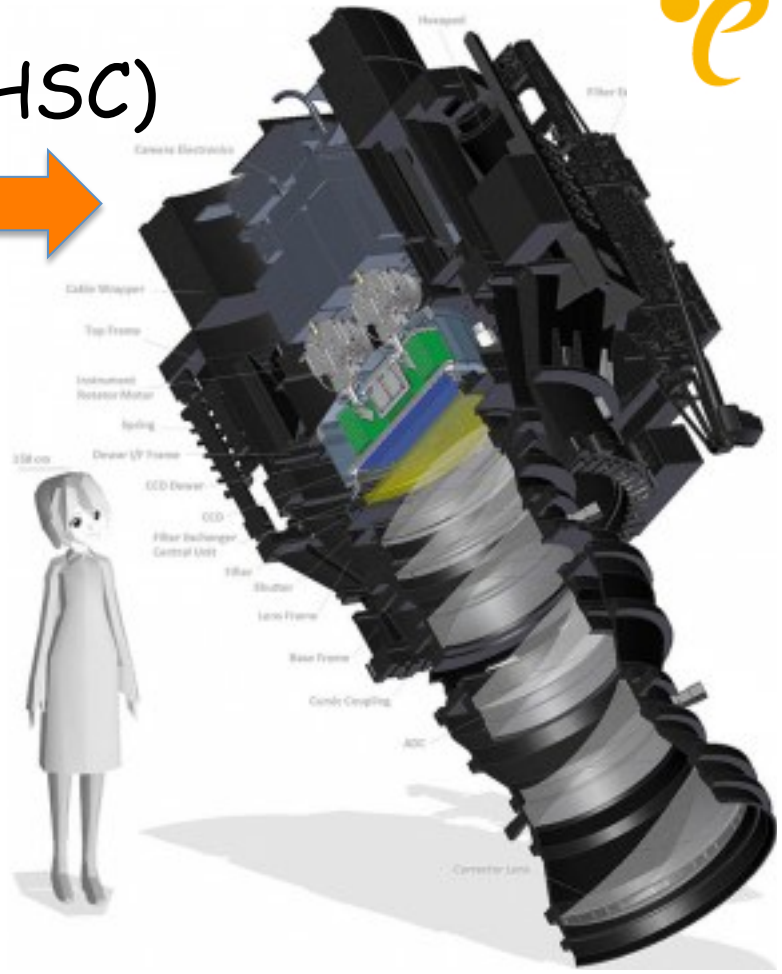
Subaru Hyper Suprime-Cam (HSC)



Suprime-Cam
(1999-2015)
Miyazaki+02

Prime Focus



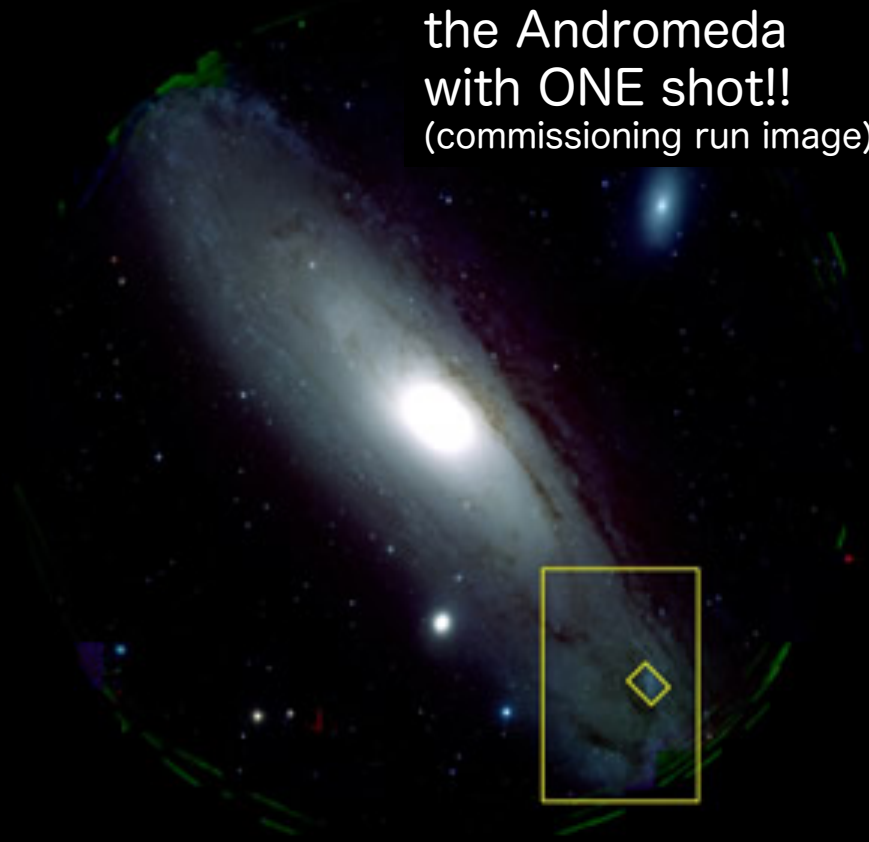


Subaru next-gen. wide-field camera
Circular FoV with a 1.5 deg diameter
(x7 wider FoV than Suprime-Cam)
Instrumental PSF: <0.1" (for the whole FoV)
Red-sensitive detectors

HSC: very wide field-of-view

FoV of a Cassegrain camera on Subaru

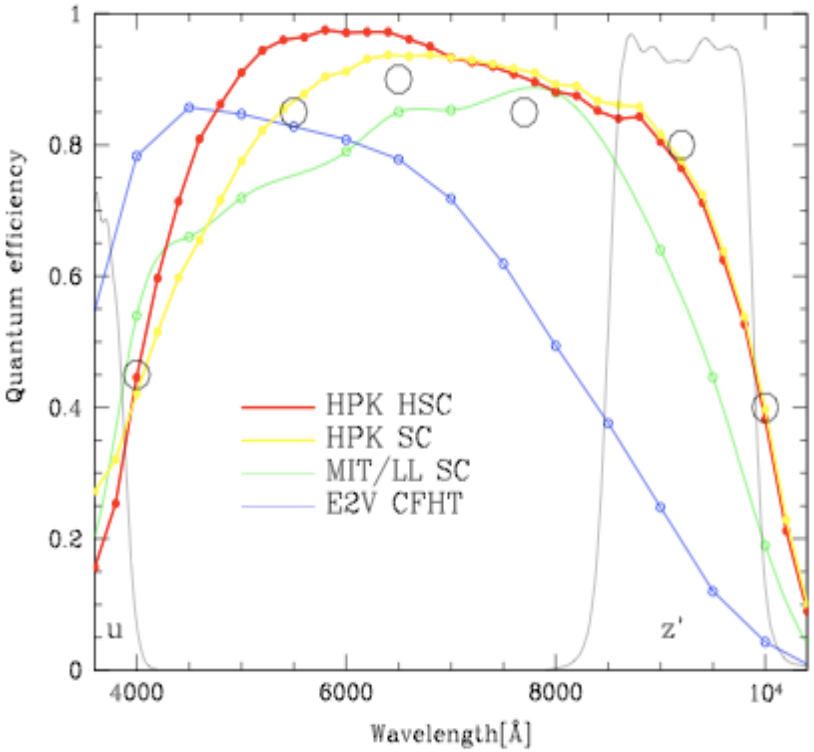
Suprime-Cam
FoV: 27'x34'



the Andromeda
with ONE shot!!
(commissioning run image)

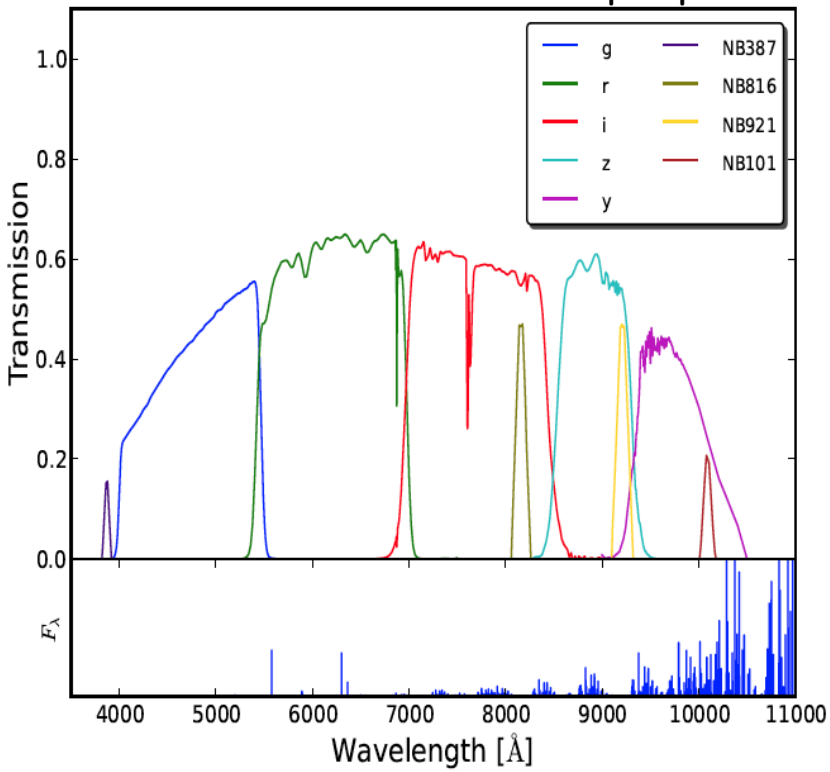
Hyper Suprime-Cam
1.5 degree diameter

HSC: red-sensitive detectors



Moderately sensitive even at 1um; x2 more sensitive than old Suprime-Cam detectors.

from the HSC-SSP proposal



Thanks to the sensitivity at red, HSC has y-band filter at the longer side of z-band.

Subaru strategic program (SSP) with HSC

HSC-SSP proposal

Wide-field imaging with Hyper Suprime-Cam: Cosmology and Galaxy Evolution

A Strategic Survey Proposal for the Subaru Telescope

PI: Satoshi Miyazaki (NAOJ)
Co-PI: Ikuru Iwata (NAOJ)

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(14) NNCT (15) Osaka Sangyo (16) Barcelona (17) NTU, Taiwan (18) Chic
(23) Kyoto (24) Las Vegas (25) KIAA, China (26) Hosei (27) JSGA (28) H
Konan (33) Kagoshima (34) Hiroshima (35) Kyoto Sangyo (36) JAXA

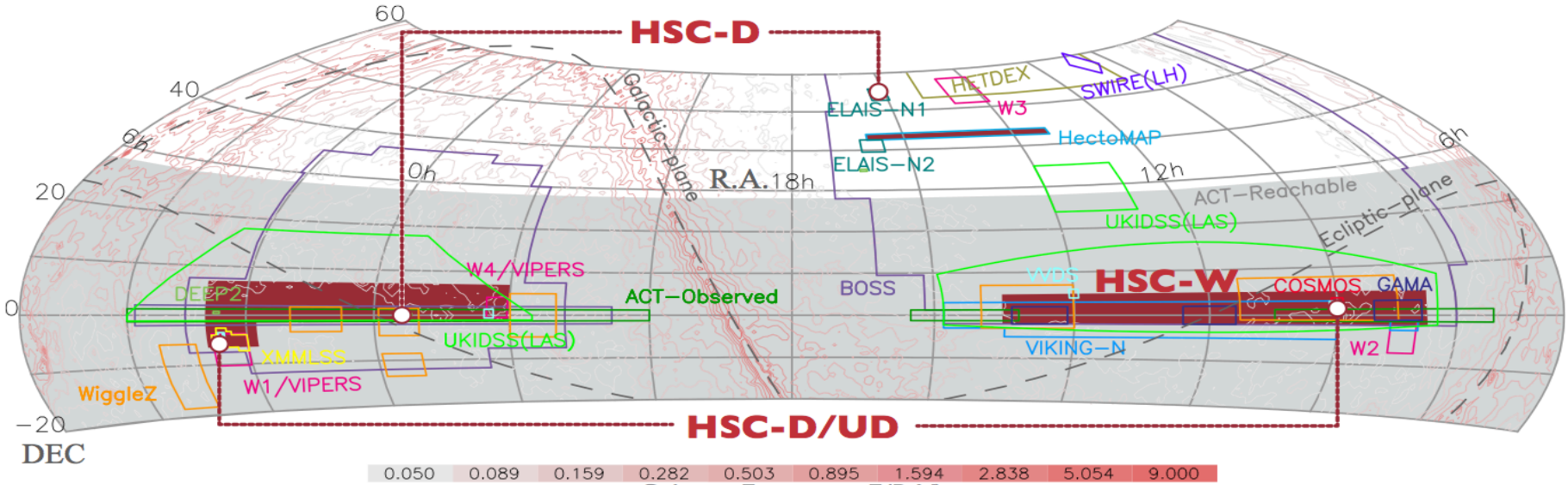
168 participants
from 36 institutes
on the proposal

Executive Summary

We propose to carry out a three-layered, multi-band (*grizy* plus narrow-band filters) imaging survey with the

from the HSC-SSP proposal

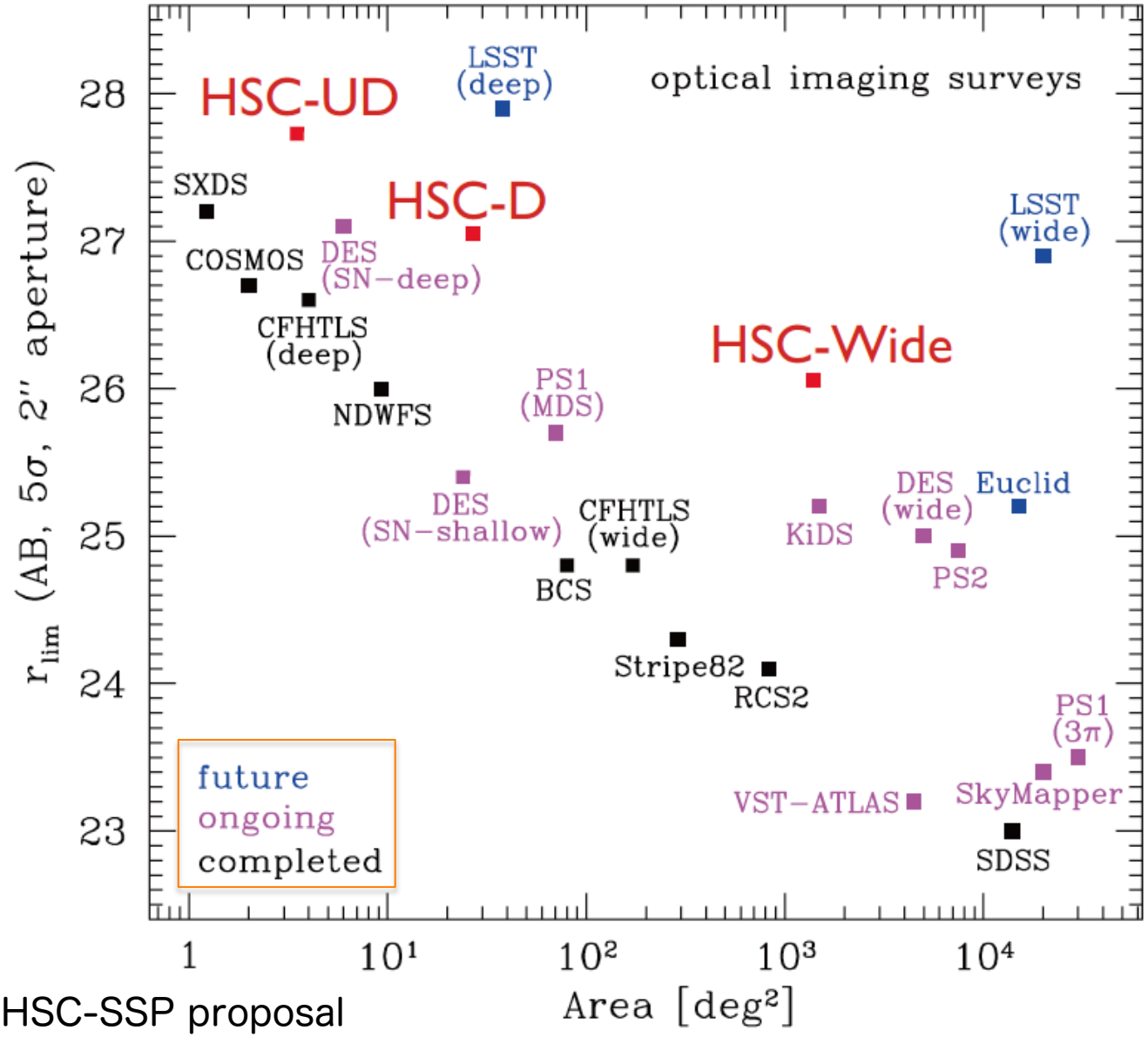
Subaru strategic program (SSP) with HSC



Layer	Filter	Exp.[a] (# of epochs)	Total[b] nights	Lim. mag.[c] (5σ, $2''$)	Moon[d] phase	Requirement(s)[e]	Main scientific driver(s)[f]
Wide	g,r	10 min (3)	53	26.5, 26.1	d	photo	photo-z, $z \lesssim 2$ gals, QSO
Wide	i	20 min (6)	53	25.9	d	FWHM $\lesssim 0.7''$	WL, $z \lesssim 2$ gals, QSO
Wide	z,y	20 min (6)	108	25.1, 24.4	g	photo	photo-z, clusters, $z \sim 1$ gals, $z \sim 6$–7 QSO
Deep	g,r	1.4 hrs (10)	7.3	27.5, 27.1	d	cadence	SNeIa
Deep	i	2.1 hrs (10)	5.4	26.8	d	FWHM $\lesssim 0.7''$, cadence	WL calibration, SNeIa
Deep	z	3.5 hrs (10)	9.1	26.3	g	cadence	$z \lesssim 2$ gals, ionization topology, SNeIa,
Deep	y	2.1 hrs (10)	5.4	25.3	g	cadence	$z \lesssim 2$ gals, SNeIa, QSO
Deep	$N387$	1.4 hrs ($\simeq$10)	3.6	24.5	d	photo	$z \simeq 2.2$ LAEs & LABs
Deep	$N816$	2.8 hrs ($\simeq$ 10)	7.2	25.8	g/d	photo	ionization topology, $z \simeq 5.7$ LAEs & LABs
Deep	$N921$	4.2 hrs ($\simeq$ 10)	11	25.6	g/d	photo	ionization topology, $z \simeq 6.6$ LAEs & LABs
UD	g,r	7 hrs (20)	4.8	28.1, 27.7	d	cadence	$z \gtrsim 2$ gals, SNeIa
UD	i	14 hrs (20)	4.8	27.4	d	cadence	$z \gtrsim 2$ gals, SNeIa, QSO
UD	z,y	18.9 hrs (20)	13	26.8, 26.3	g	cadence	$z \gtrsim 2$ gals, SNeIa, QSO
UD	$N816$	10.5 hrs ($\simeq$ 10)	3.6	26.5	g/d	photo	$x_{\rm HI}(5.7)$, $z \simeq 5.7$ LAEs & LABs
UD	$N921$	14 hrs ($\simeq$ 10)	4.8	26.2	g/d	photo	$x_{\rm HI}(6.6)$, $z \simeq 6.6$ LAEs & LABs
UD	$N101$	17.5 hrs ($\simeq$ 10)	6.1	24.8	g/d	photo	$x_{\rm HI}(7.3)$, $z \simeq 7.3$ LAEs

300 nights in total
2014.02 – 2019.01
(already approved and started !!)

Subaru strategic program (SSP) with HSC



from the HSC-SSP proposal

Subaru strategic program (SSP) with HSC

Defined working groups

(from the HSC collaboration policy document)

working group	chair	vice-chair
Galactic Evolution	Gunn	
AGN	Nagao	Strauss
Weak Lensing	Takada	Hamana
Galactic Structure	Chiba	
Solar System	Yoshida	
Variables/transients	Morokuma	Huang
Very high redshift	Ouchi	Shimasaku
Clusters	Lin	Oguri
Supernovae	Yasuda	Urata
Photometric Calibration	Gunn	Furusawa
Hardware	Miyazaki	
Software and Data Distribution	Lupton	Furusawa

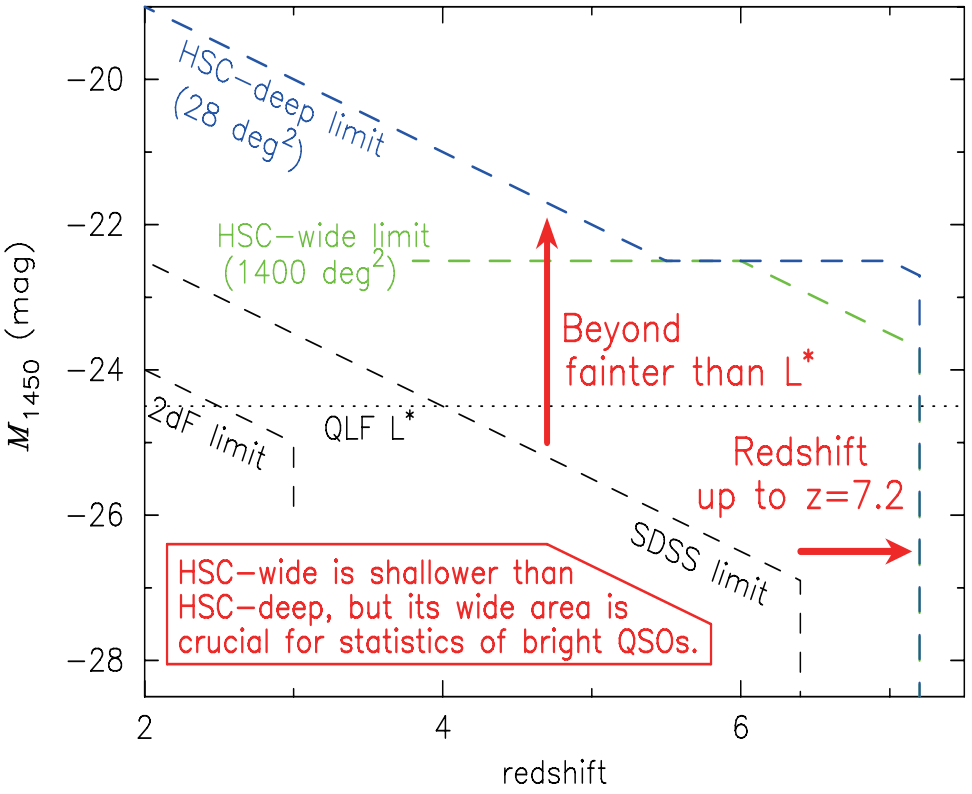
Some focused topics, including:

~ Cosmology, through weak lensing, cluster statistics, SNIa

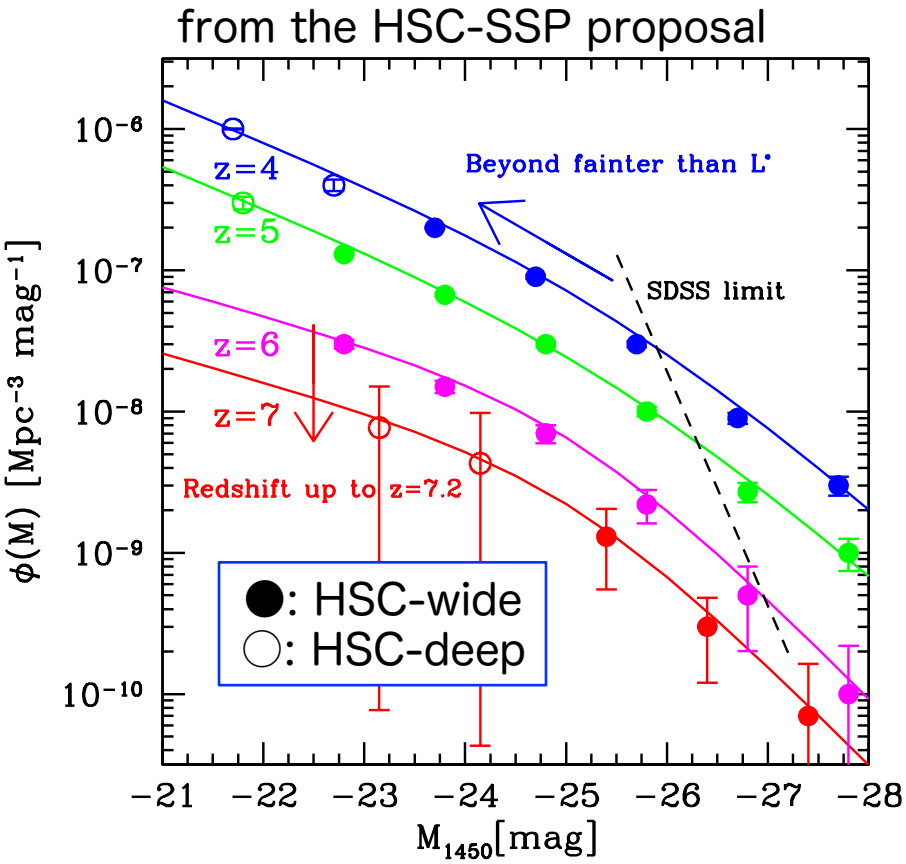
~ Galaxy evolution, by observing LBGs/LAEs up to z~7

~ Quasars !!

Quasar survey with HSC

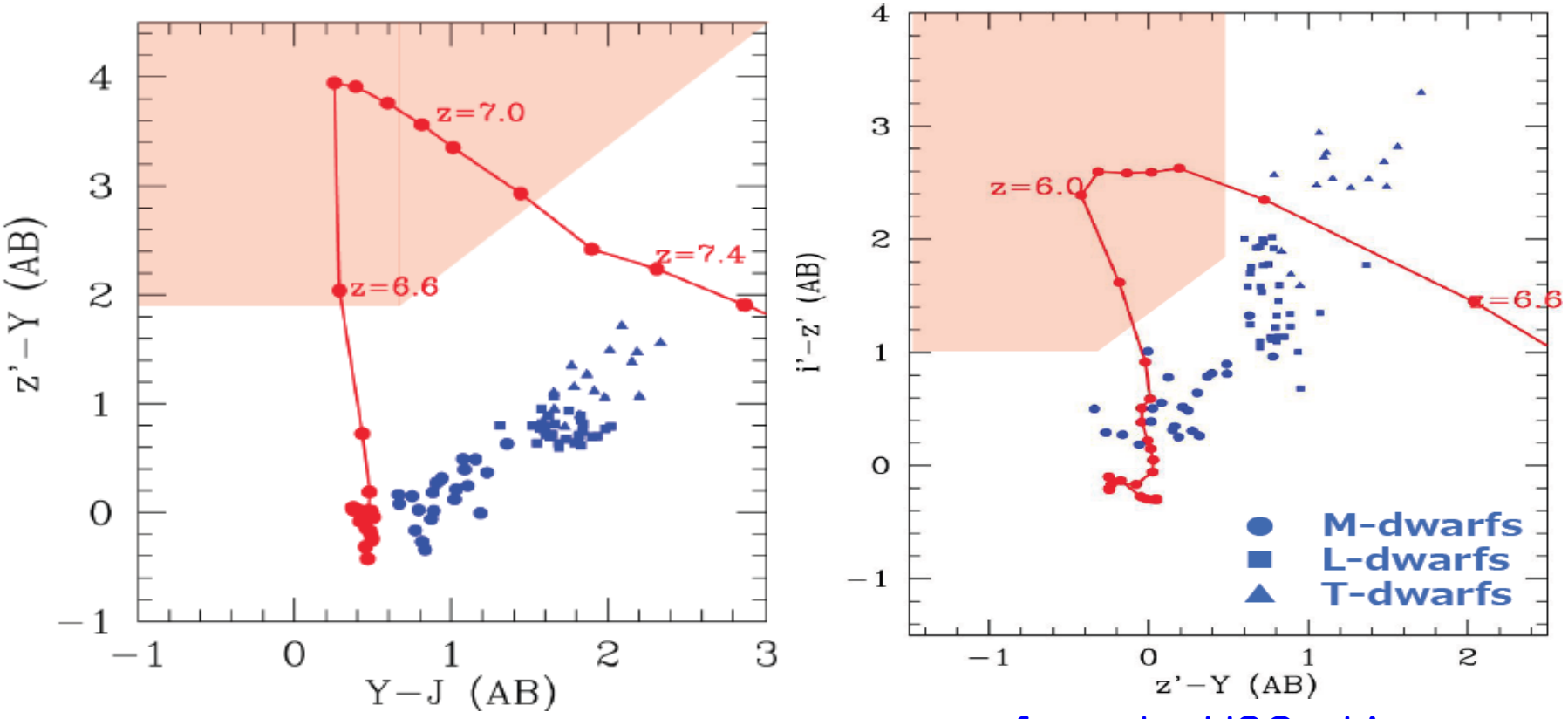


from the HSC-SSP proposal



A caveat: simple color selections cannot find quasars that are fainter than M_{UV} ~ -22.5, since LBGs dominate the selected objects. → variability selection in HSC-deep

Quasar survey with HSC at z ~ 6-7

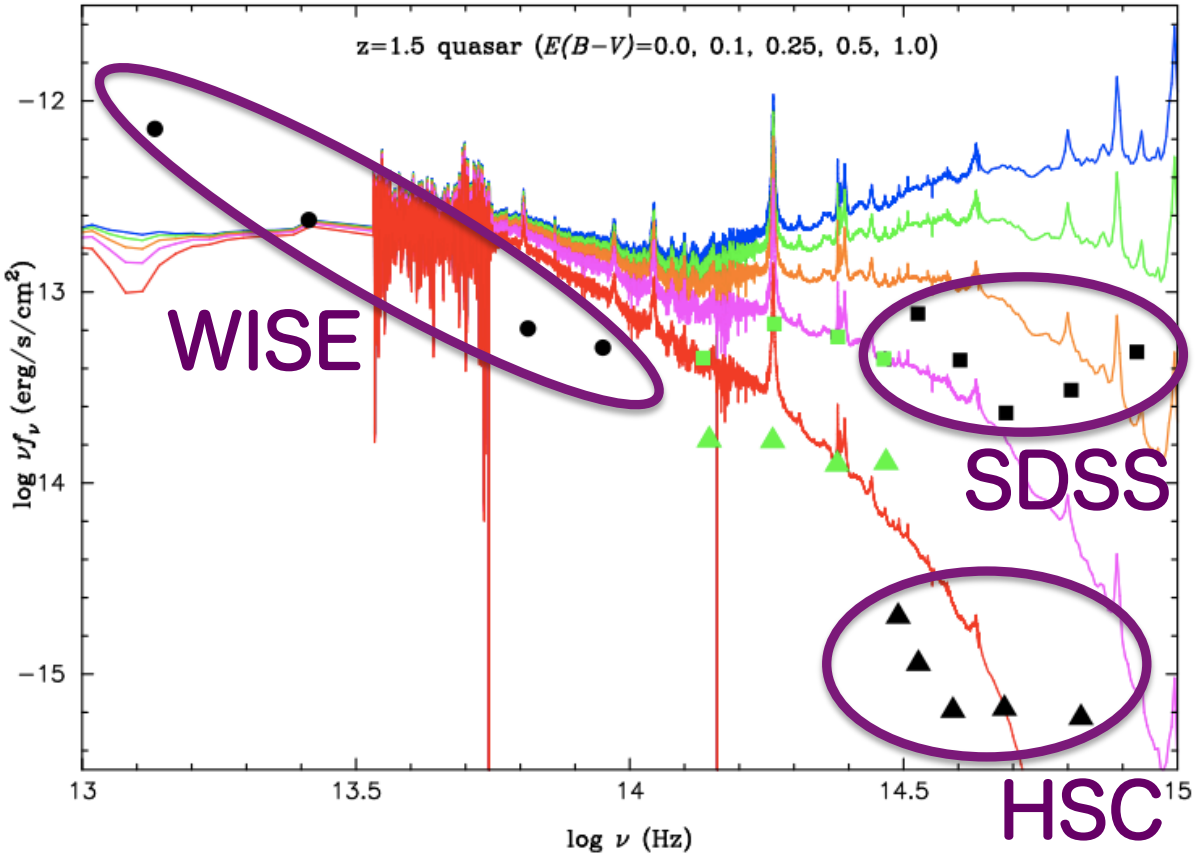


from the HSC white paper

J-band image is needed to select z~7 quasars
→ Most of the target area is in the VIKING or UKIDSS fields
No additional NIR images are needed to select z~6 quasars
→ Much more efficient survey than SDSS (that has no y-band)

Synergy with multi-wavelength data: MIR

- identifying red quasars with HSC & MIR all-sky data
  - ~ AKARI & 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)

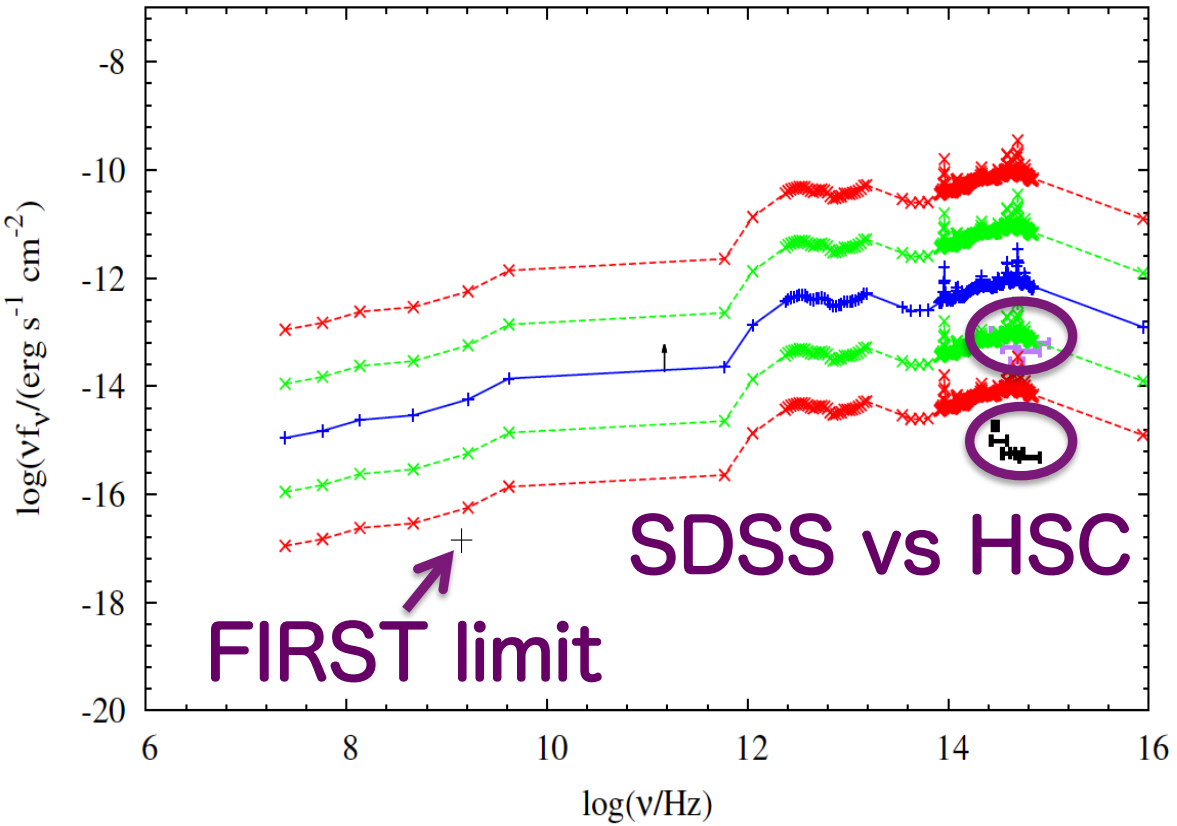
Red WISE-detected quasars cannot be detected in SDSS

HSC is deep enough to detect them!

from the HSC white paper

Synergy with multi-wavelength data: radio

- Optical counterparts of FIRST wide-sky survey sources
  - ~ FIRST catalog contains 10^7 radio sources
  - ~ 40% of FIRST sources have no SDSS optical counterparts
  - ~ many missing radio-loud populations? HSC can address this!



z=4 radio-loud quasar spectrum with various luminosity

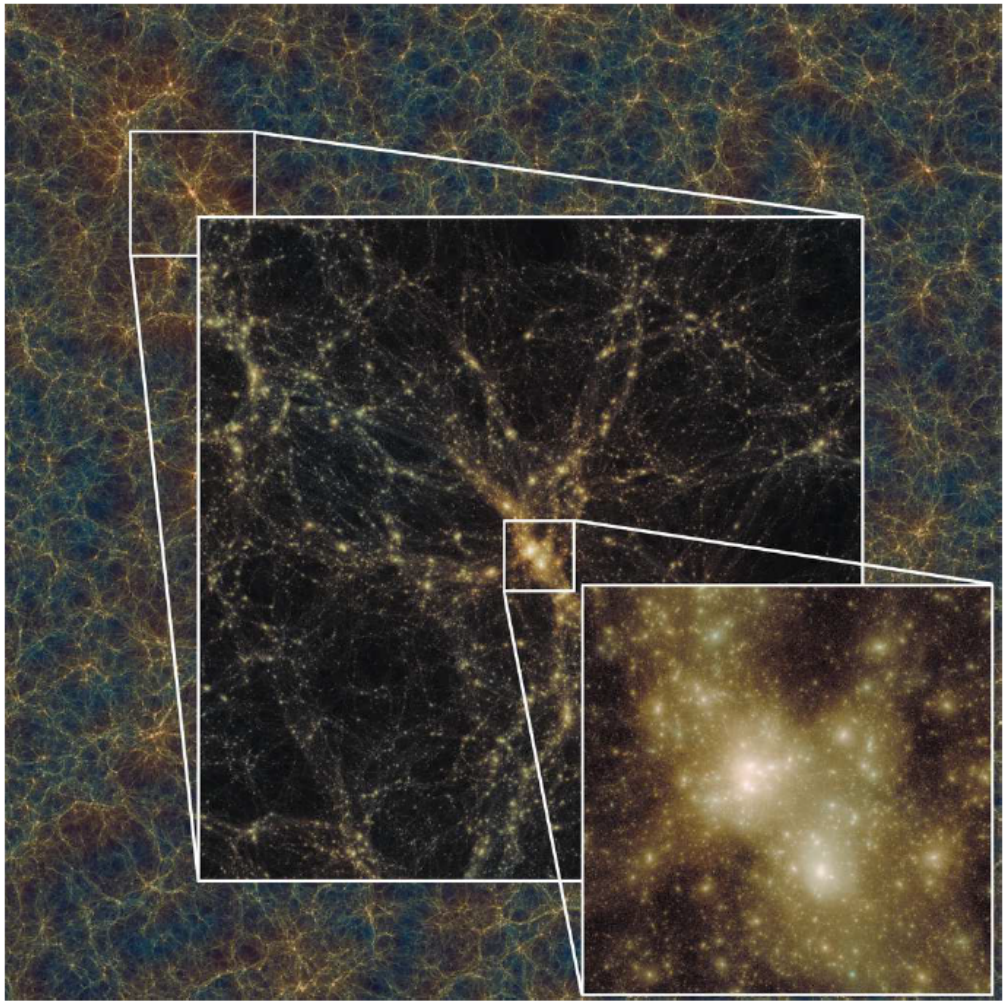
High-z low-L radio-loud quasars are detected in the FIRST data but not in the SDSS data

HSC is deep enough to detect them!

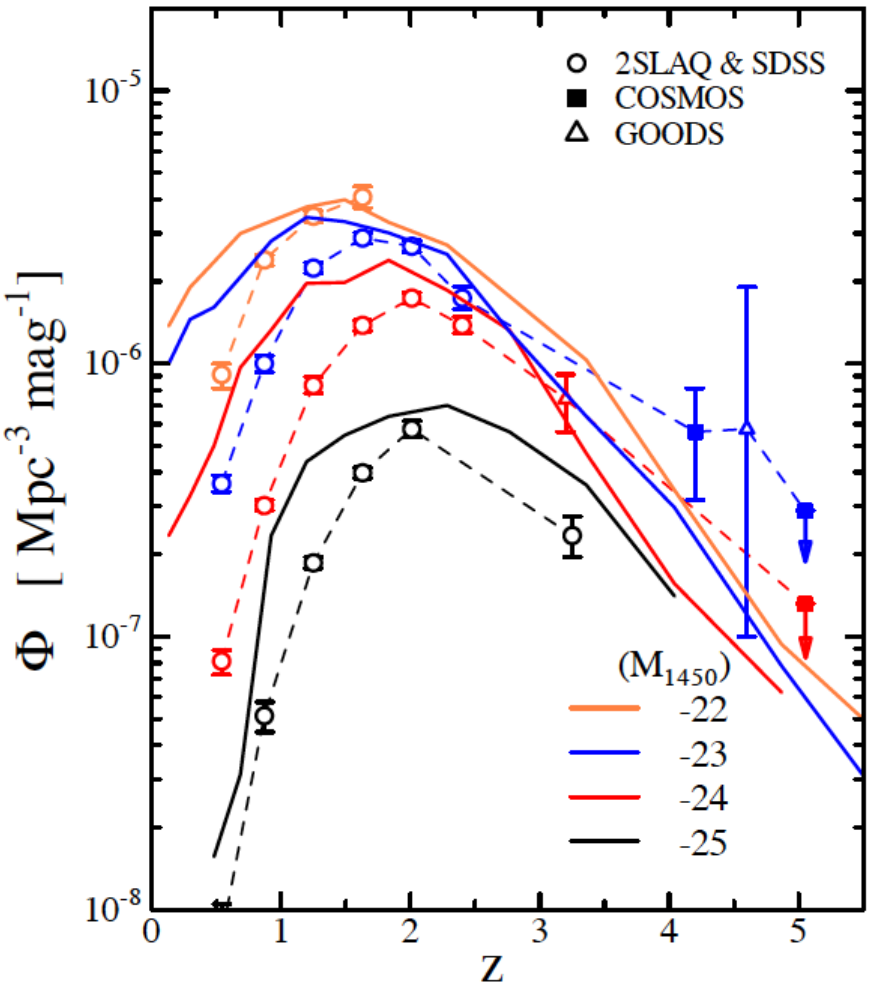
from the HSC white paper

Theoretical models

Ishiyama+14 (arXiv:1412.2860)



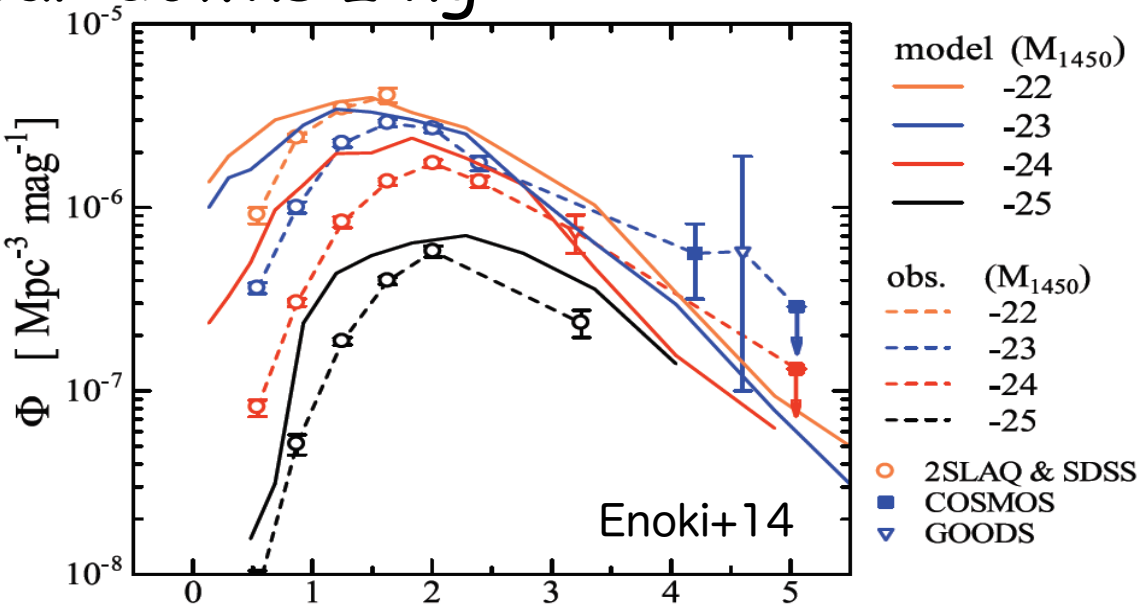
Enoki+14

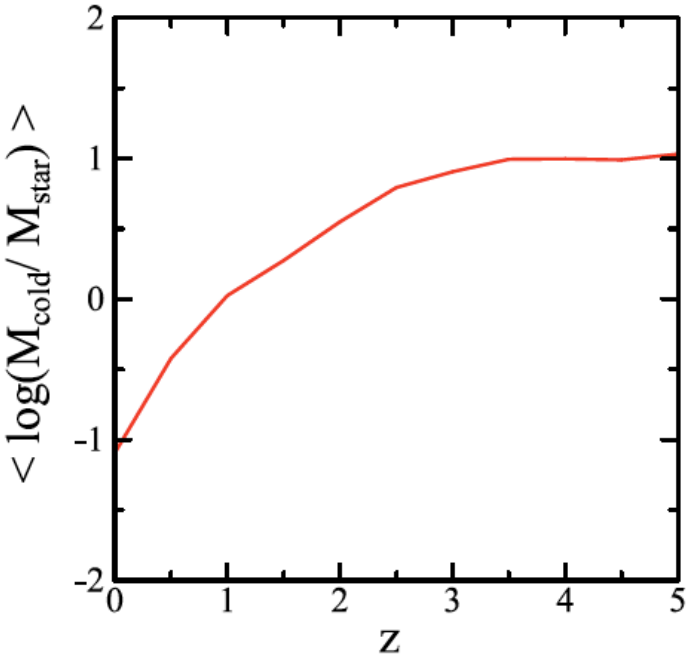


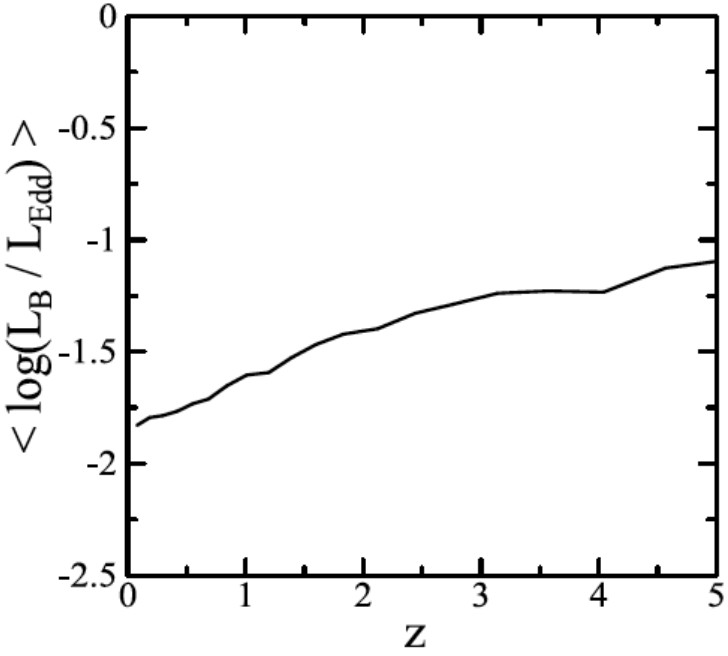
Models for the quasar downsizing

Enoki+'s AGN semi-analytic model well reproduces the quasar downsizing evolution.

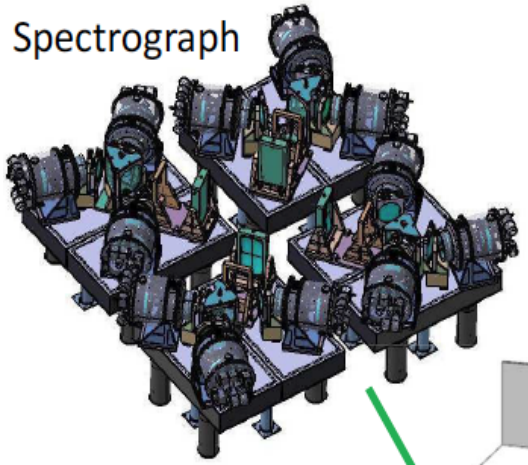
Lower gas fraction at lower-z → lower luminosity

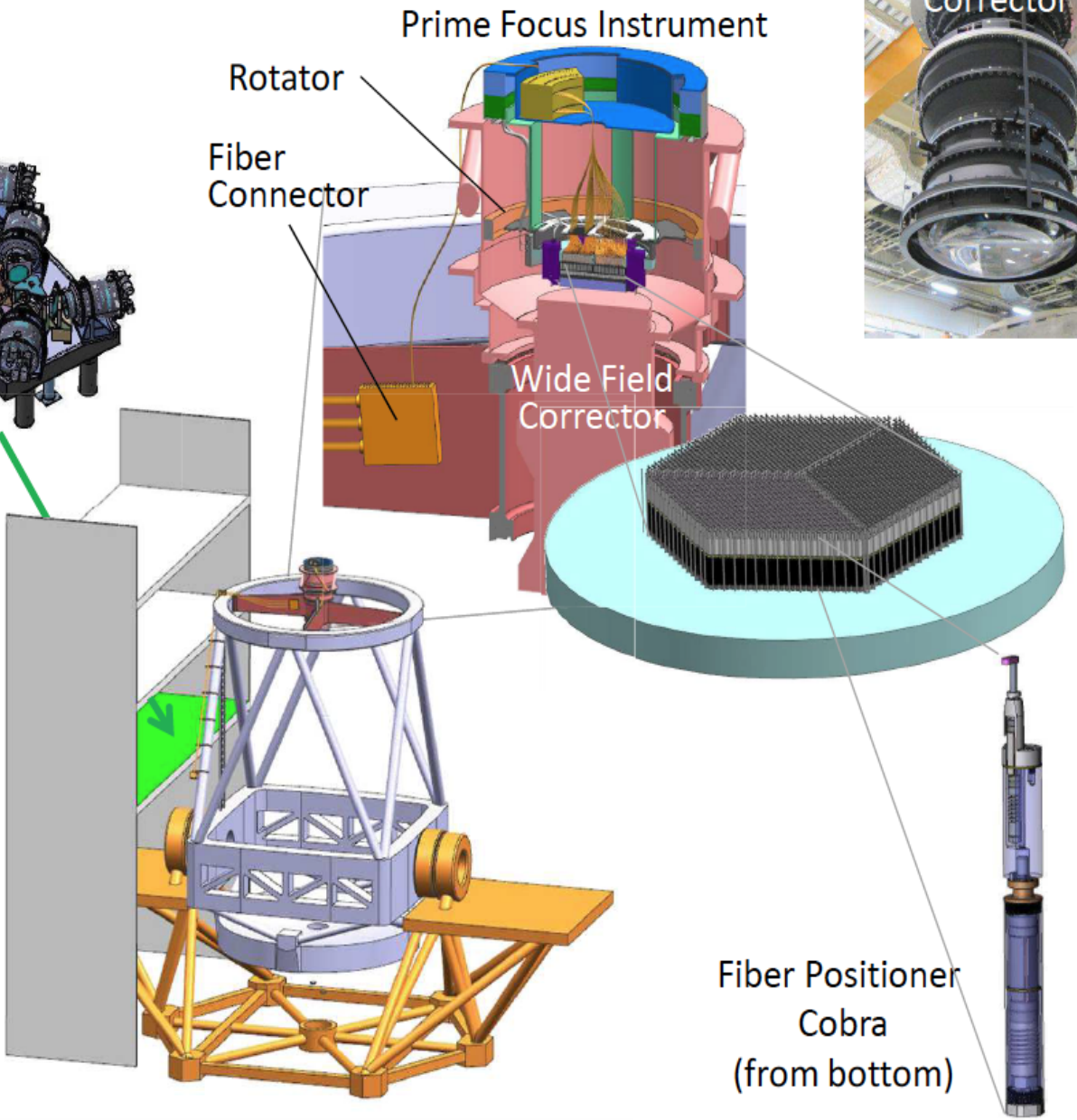






Subaru Prime Focus Spectrograph (PFS)





PFS Partners:

- ~ NAOJ/U.Tokyo
- ~ Princeton U.
- ~ ASIAA (Taiwan)
- ~ Caltech/JPL
- ~ Johns Hopkins U.
- ~ Marseille
- ~ Brazil
- ~ Max Planck

Takada, Ellis, et al. (2014)

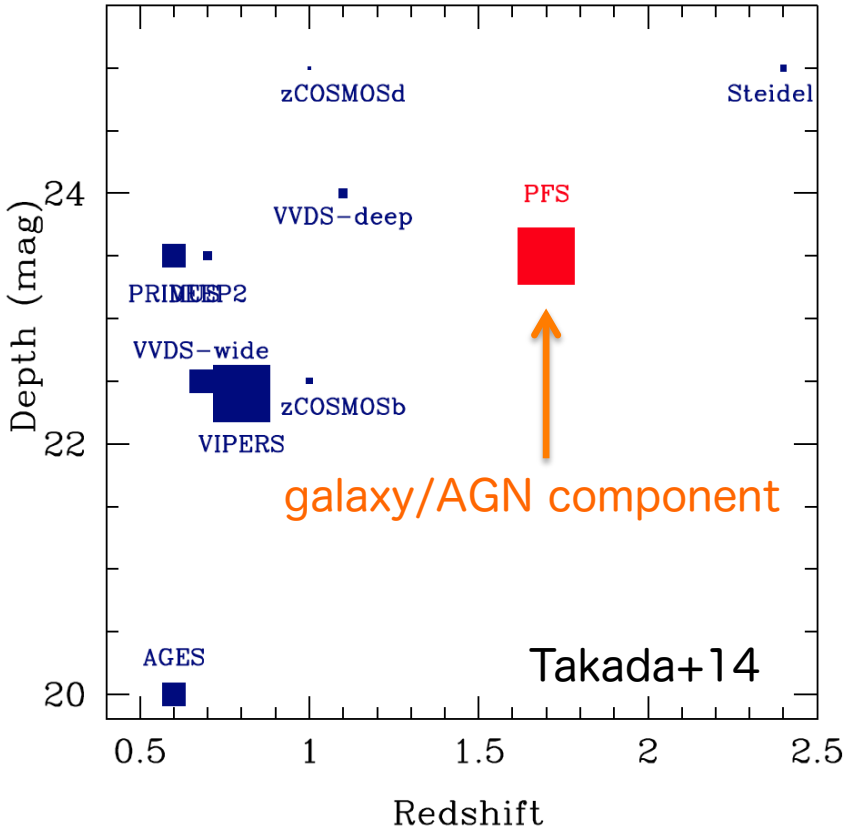
PFS parameters

Takada+14

Number of fibers	2400 (600 for each spectrograph)		
Field of view	1.3 deg (hexagonal – diameter of circumscribed circle)		
Field of view area	1.098 deg^2		
Fiber diameter	1.13″ diameter at the field center; 1.03″ at the edge		
	Blue arm	Red arm	IR arm
Wavelength coverage [nm]	380–670	650–1000	970–1260
Spectral resolution $\lambda/\Delta\lambda$	1900	2400	3500
Pixel scale [Å/pix]	0.71	0.85	0.81
Read-out noise [e^- rms/pix]	3	3	4[a]
Detector type/read-out mode	CCD	CCD	HgCdTe/SUTR
Thermal background [e^-/pix/sec]	None	None	0.013
Dark current [e^-/pix/sec]	3.89×10^{-4}	3.89×10^{-4}	0.01
Spectrograph image quality [μm rms/axis]	14	14[b]	14

IR arm, not only blue & red arms
→ no “redshift desert” ([OII] for z<2.3, Lyα for z>2.2)
Multi-layer survey (not yet fixed)
~ cosmology component (15 min x 2 visits for >1000 deg^2)
~ galaxy/AGN component (longer exposure for 10-30 deg^2)
~ Galactic archaeology component (for specific fields)

Subaru/PFS survey plan (still under discussing)



Comparison with other large spectroscopic surveys. The symbol size corresponds to the area of the target fields.

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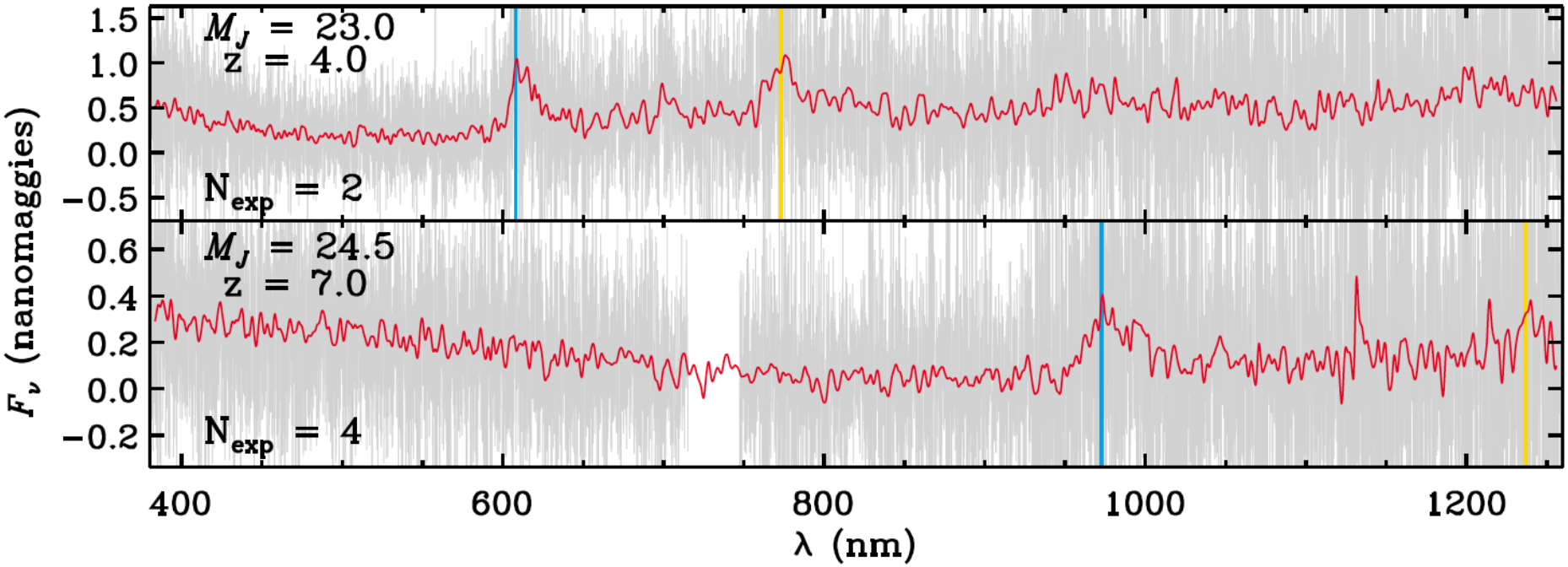
Simulated PFS spectra of quasars

Takada+14



Top: 15 min x 2 exposures for a z=4.0 quasar with J_{AB}=23.0
Bottom: 15 min x 4 exposures for a z=7.0 quasar with J_{AB}=24.5
Gray: simulated PFS spectra, before the binning (R~2000-3500)
Red: after the binning (effective resolution of R~300)

Subaru Wide-Field AGN Survey: summary

- HSC has come!!
  - ~ under collaboration among Japan, Taiwan, and Princeton
  - ~ wide FoV (1.5 deg diameter), good image quality, red sensitive
  - ~ SSP and common-use observations have started in Feb. 2013
- HSC-SSP legacy survey
  - ~ 300 nights in 5 years (approved, already started)
  - ~ multi-layer survey (wide, deep, ultradeep)
  - ~ multi-purpose survey (cosmology, galaxy evolution, SNe, ...)
  - ~ you can join in this consortium now (or even later)
- Quasar survey with HSC
  - ~ searching for z~7 quasars and low-luminosity ones at z~3-6
  - ~ by combining the color-selection and variability-selection
  - ~ combination with multi-wavelength datasets also interesting
  - ~ theoretical model preparations also on going
  - ~ and forthcoming PFS will get their spectra