HSC-SSPを用いたz>6低光度クェーサー探査

尾上匡房 (総研大D3)

With the great helps of HSC-SSP collaborators
from project #47 (SHELLQs) , #18, and #222

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  - – High redshift (z>6) quasar, z>6 quasar survey
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  (MO+ in prep., Kashikawa+15)
  - – z~6 QLF and photon budget
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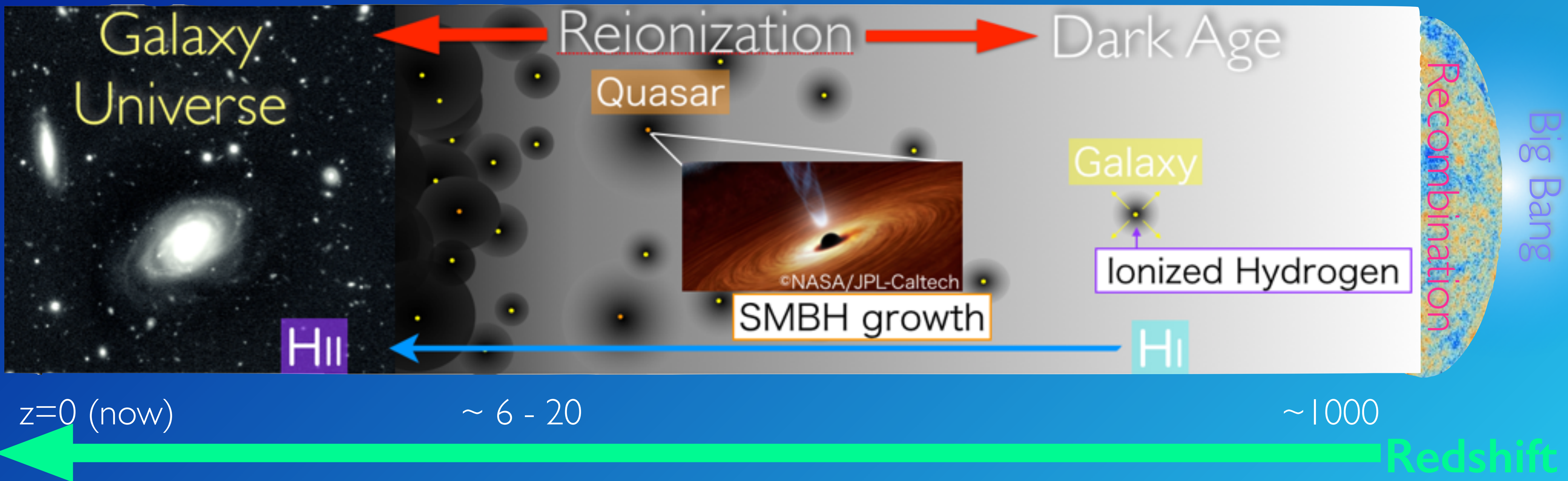
  - – MBH estimate of one z~6 quasar
- ✦ **SHELLQs view on JWST**

- Introduction

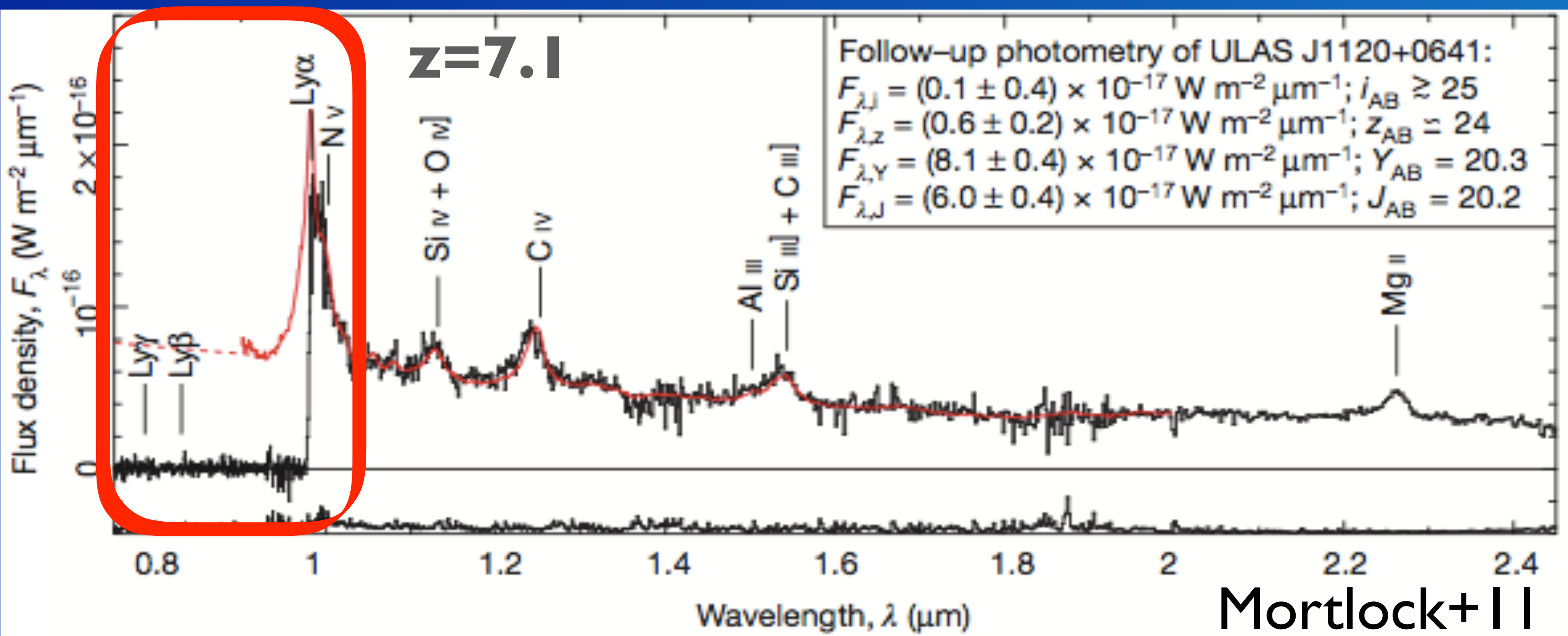
Why we care high-z (z>6) quasar ?

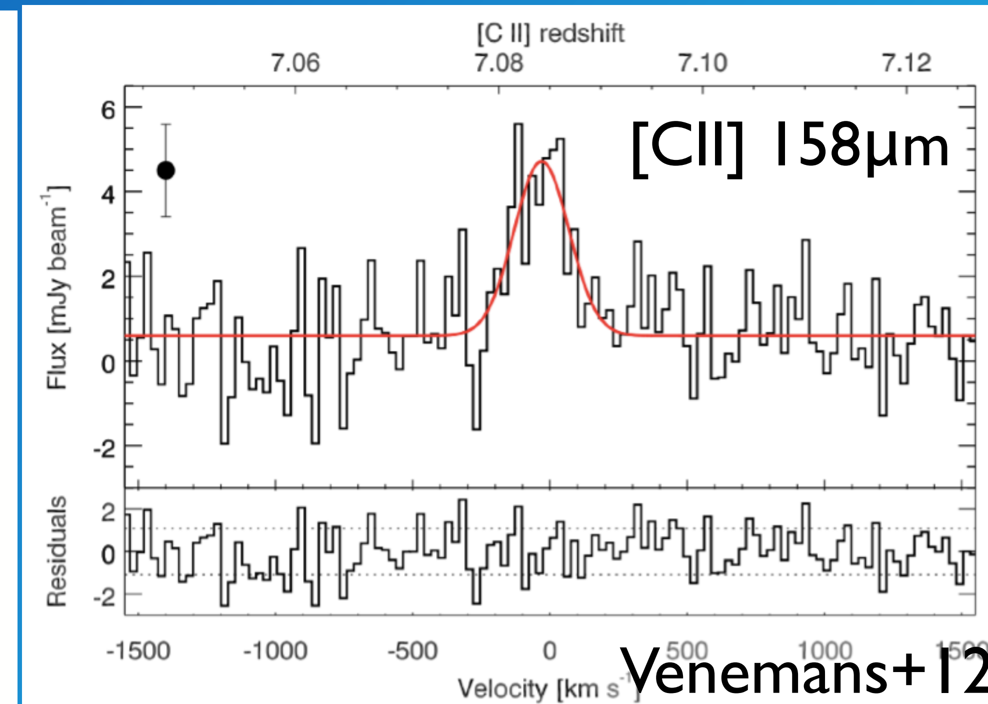


- ✦ IGM opacity during cosmic reionization
- ✦ SMBH evolution/formation scenario
- ✦ Co-evolution with host galaxy → Izumi-san's talk
- ✦ Chemical enrichment of broad line region

Unique probe of the early Universe !!

Why we care high-z (z>6) quasar ?





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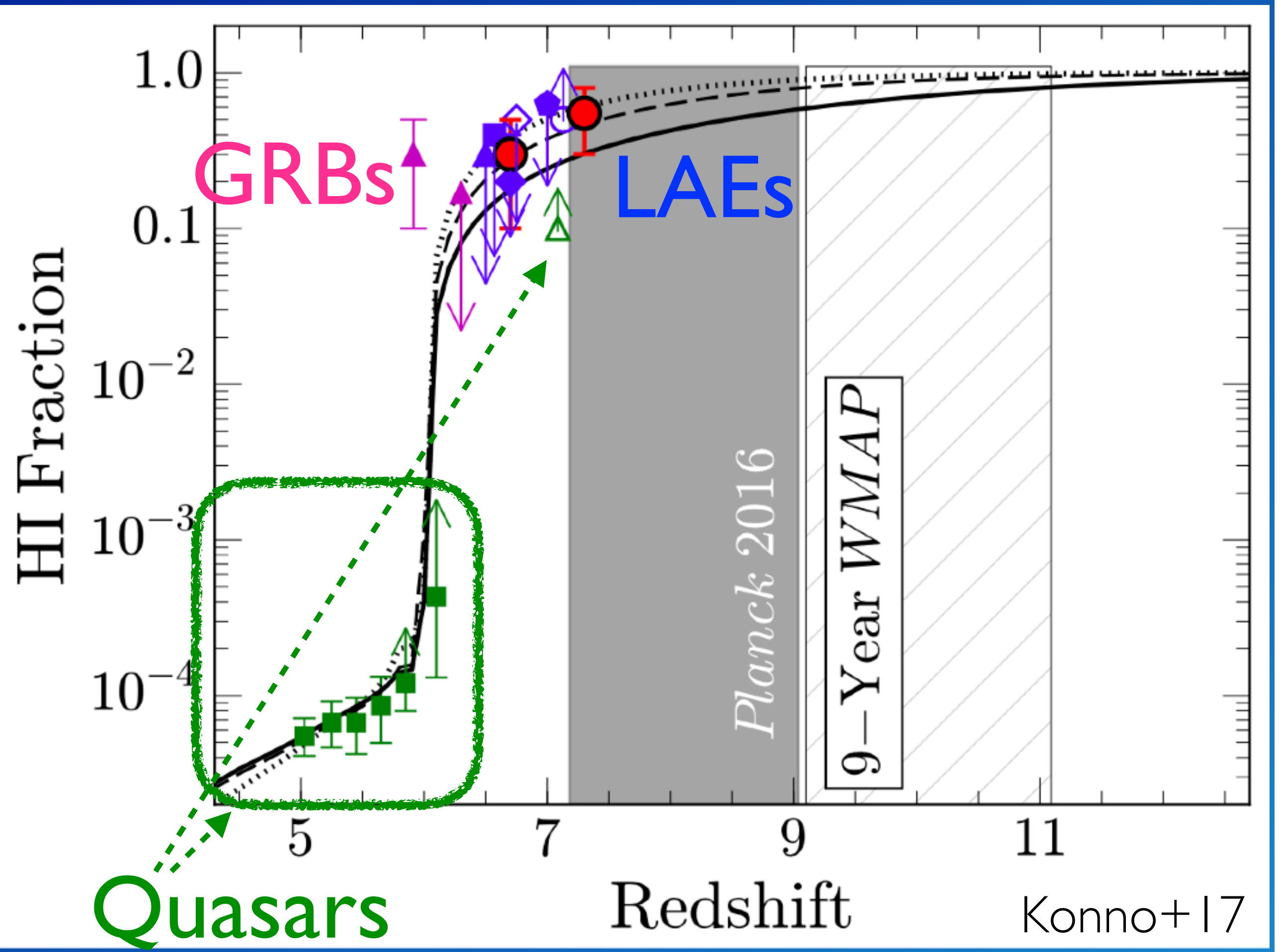
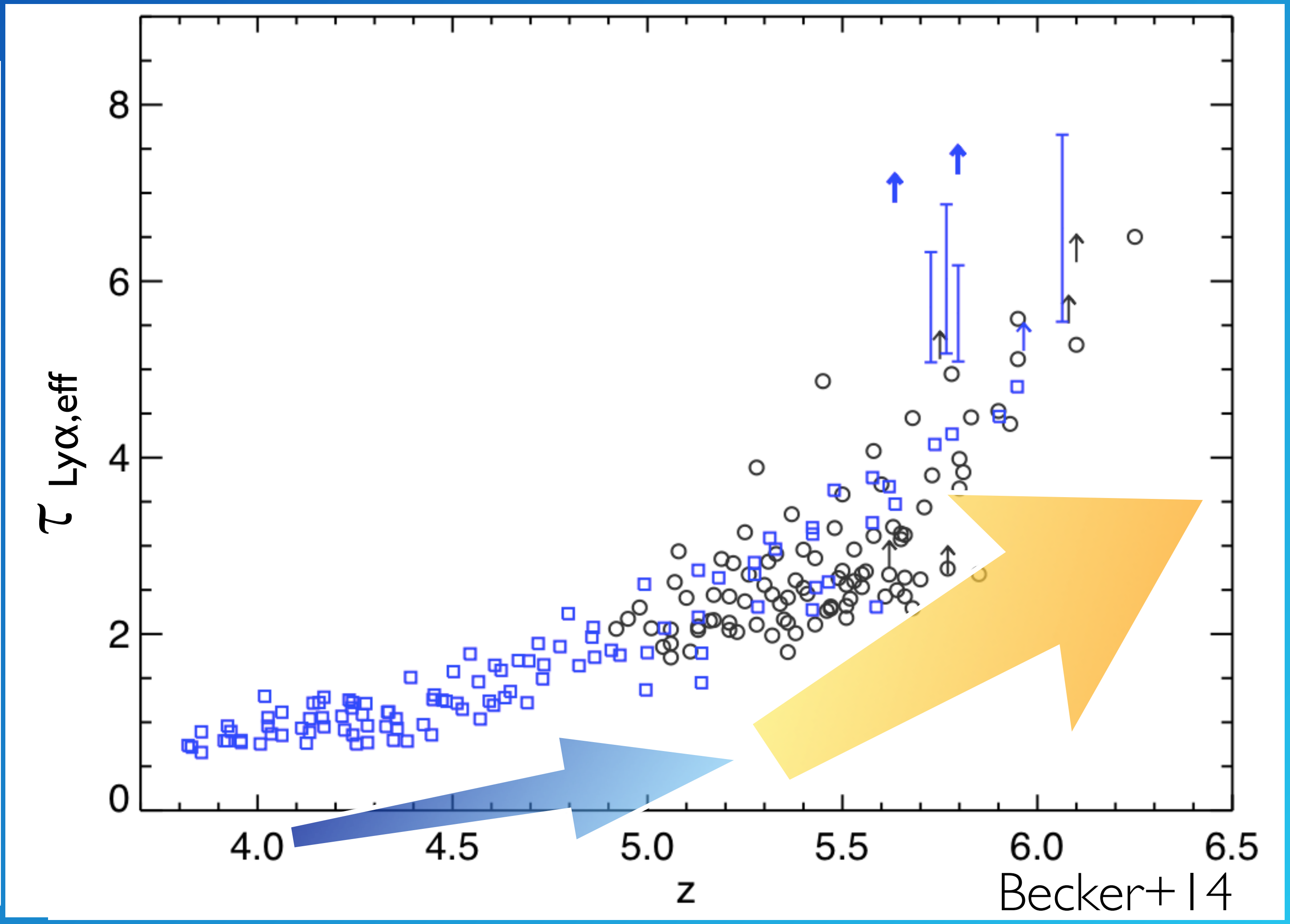
Unique probe of the early Universe !!

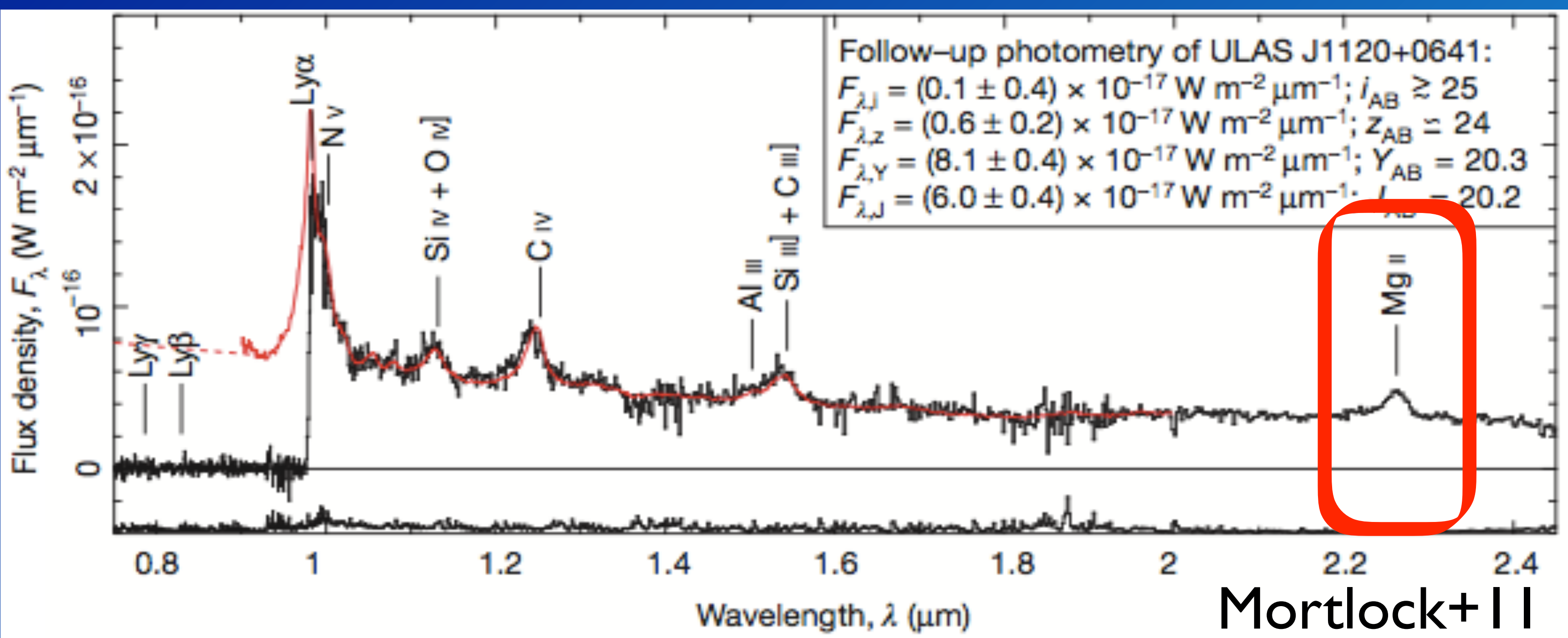
IGM Opacity

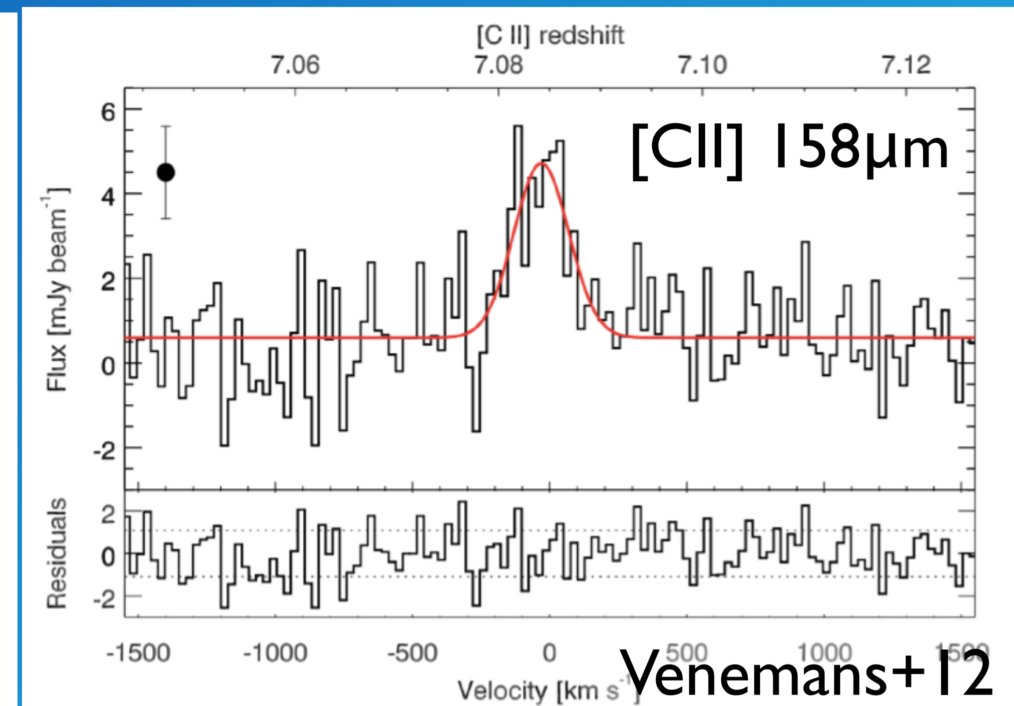




- ✦ Redshift evolution of IGM neutral fraction during EoR
- ✦ Spatially patchy reionization process suggested

Why we care high-z (z>6) quasar ?





- ✦ IGM opacity during cosmic reionization
- ✦ SMBH evolution/formation scenario
- ✦ Co-evolution with host galaxy → Izumi-san's talk
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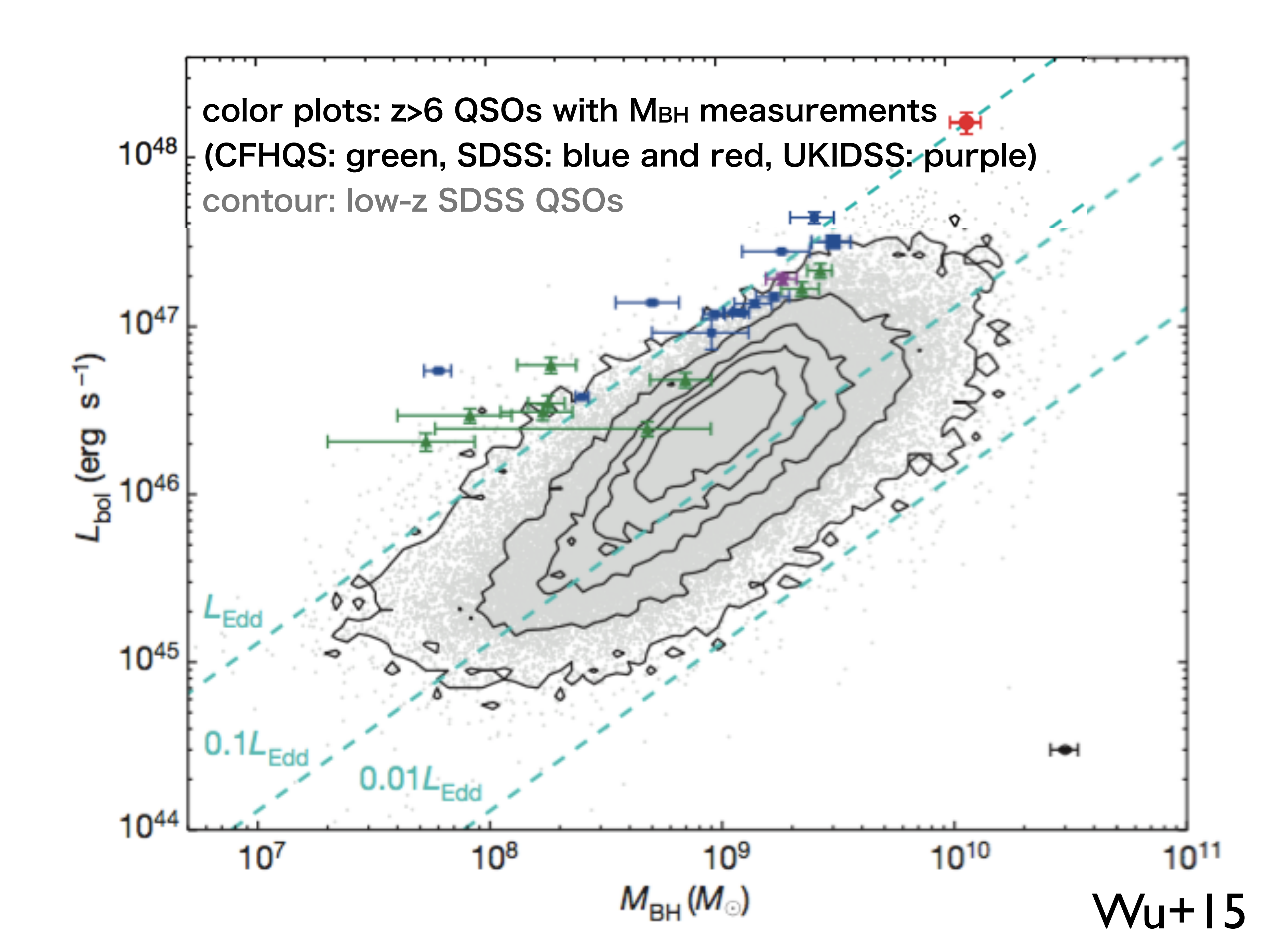
Unique probe of the early Universe !!

M_{BH} vs L_{bol} of Luminous z>6 Quasars



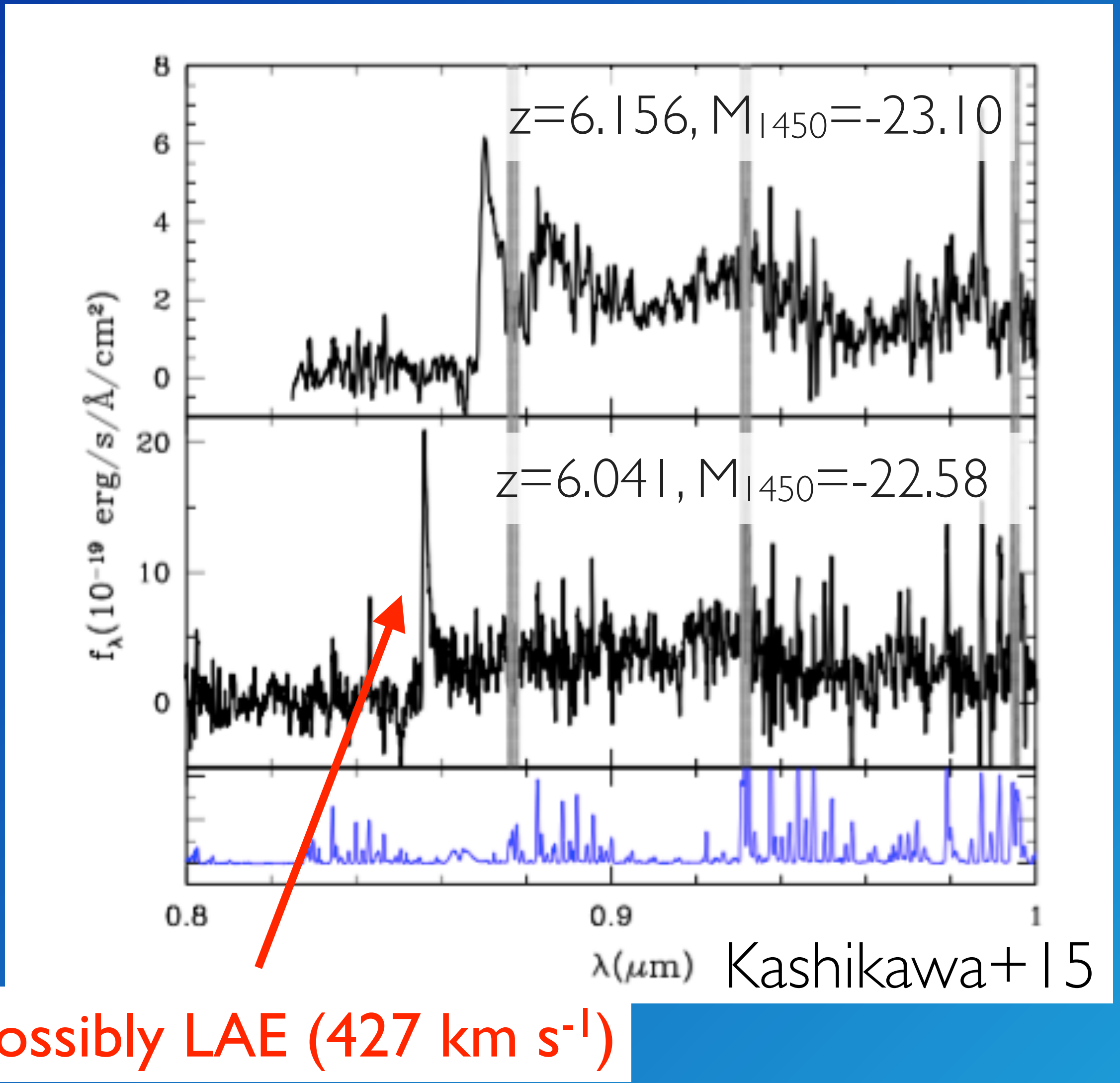
Currently known z>6 quasars are powered by
the most massive and active BHs

- S-Cam search of z~6 low-luminosity quasar (MO in prep., Kashikawa+15)

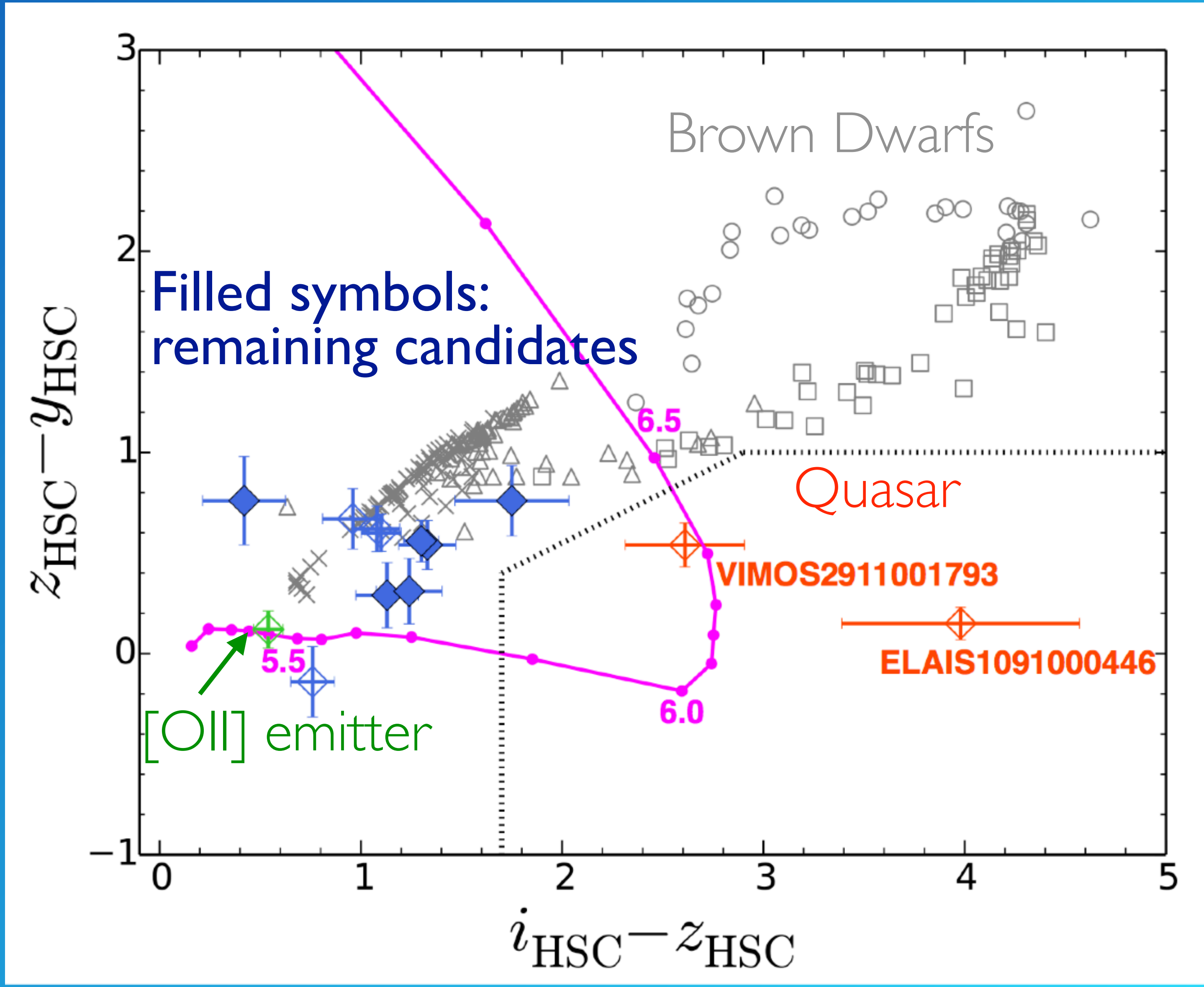
S-Cam Observation and Follow-up

✦UKIDSS-DXS field (6.56 deg^2), $z_{R,3\sigma}$=24.15
- 17 candidates (z_R=23.6-24.1) from i-z_B and z_B-z_R color selection

Subaru/FOCAS spectroscopy (11 candidates)

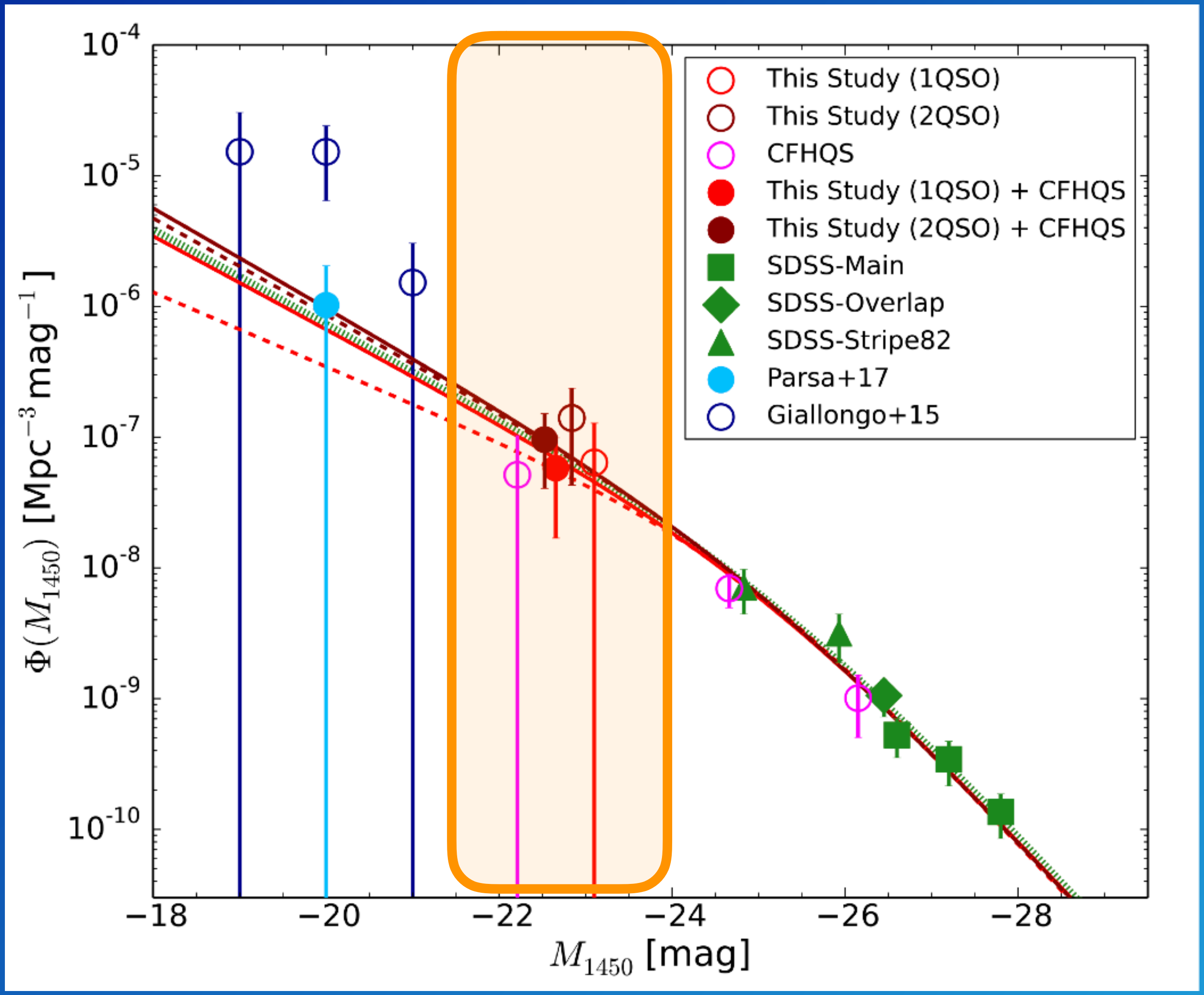


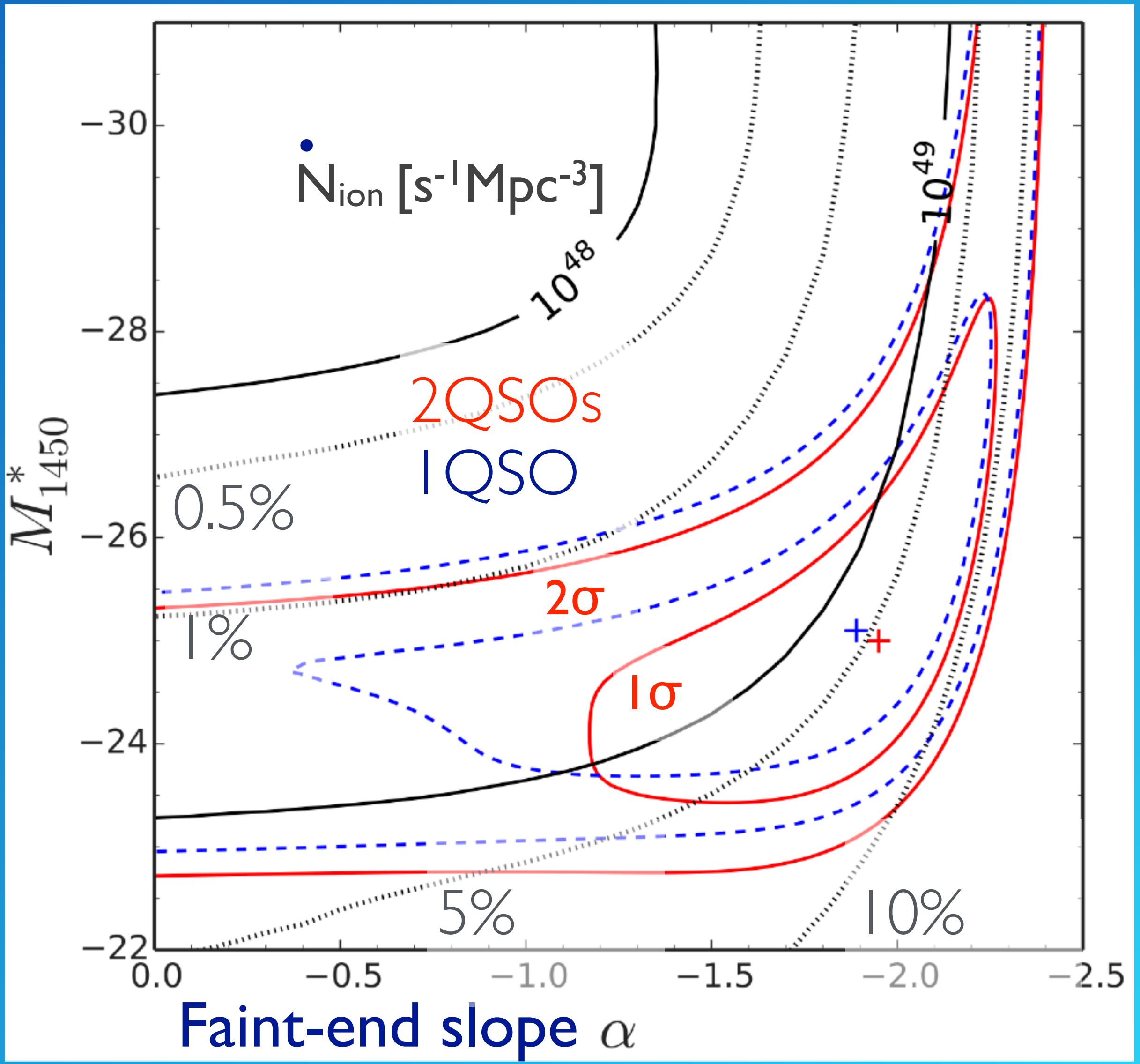
HSC-SSP photometry (Deep and Wide)



Two (or one) quasars found. No additional quasars from Kashikawa+15.

z~6 Quasar Luminosity Function





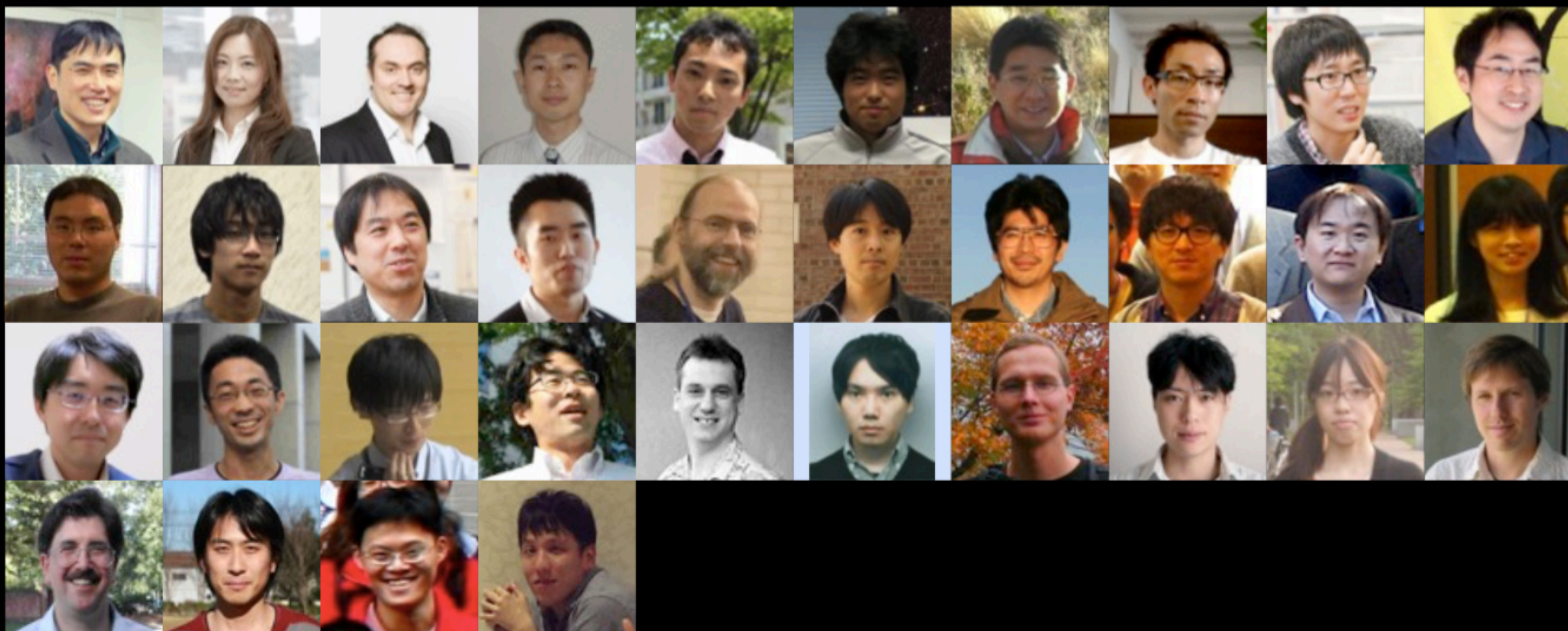
1-12% contribution to ionizing photons (95.4% confidence)

-> Quasars are minor contributors of reionization

- HSC-Wide search of z~6 quasar
  (Matsuoka, MO, Kashikawa+16, 17)

SHELLQs

Subaru High-z Exploration of Low-Luminosity Quasars



Members

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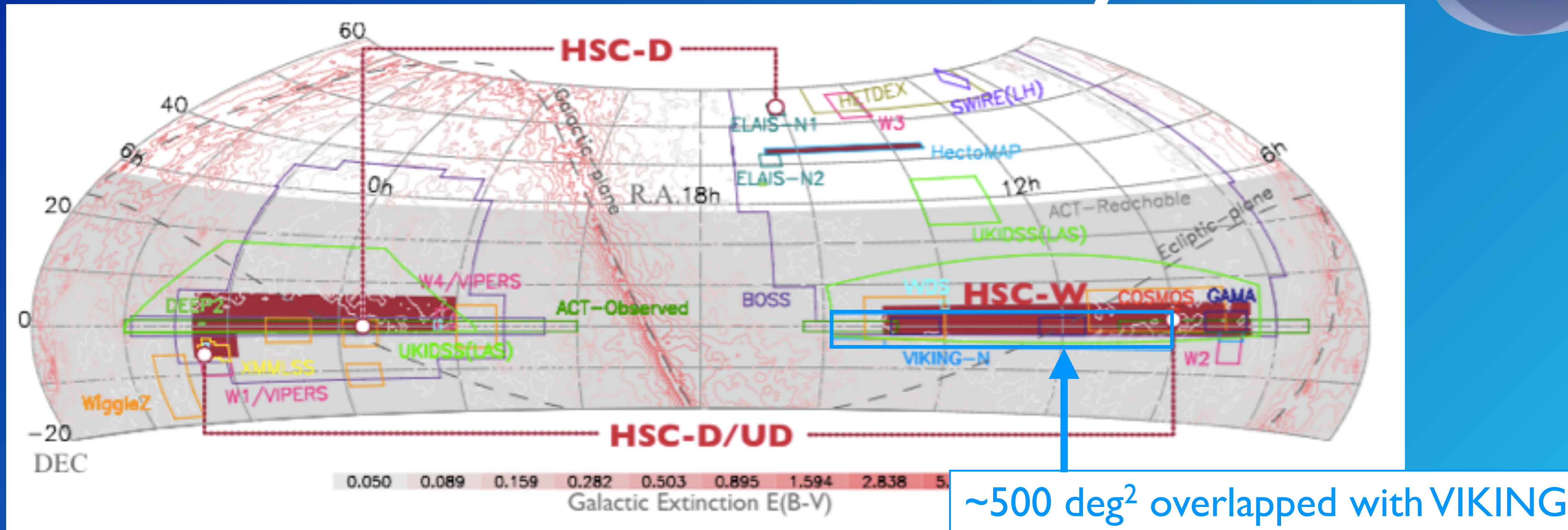
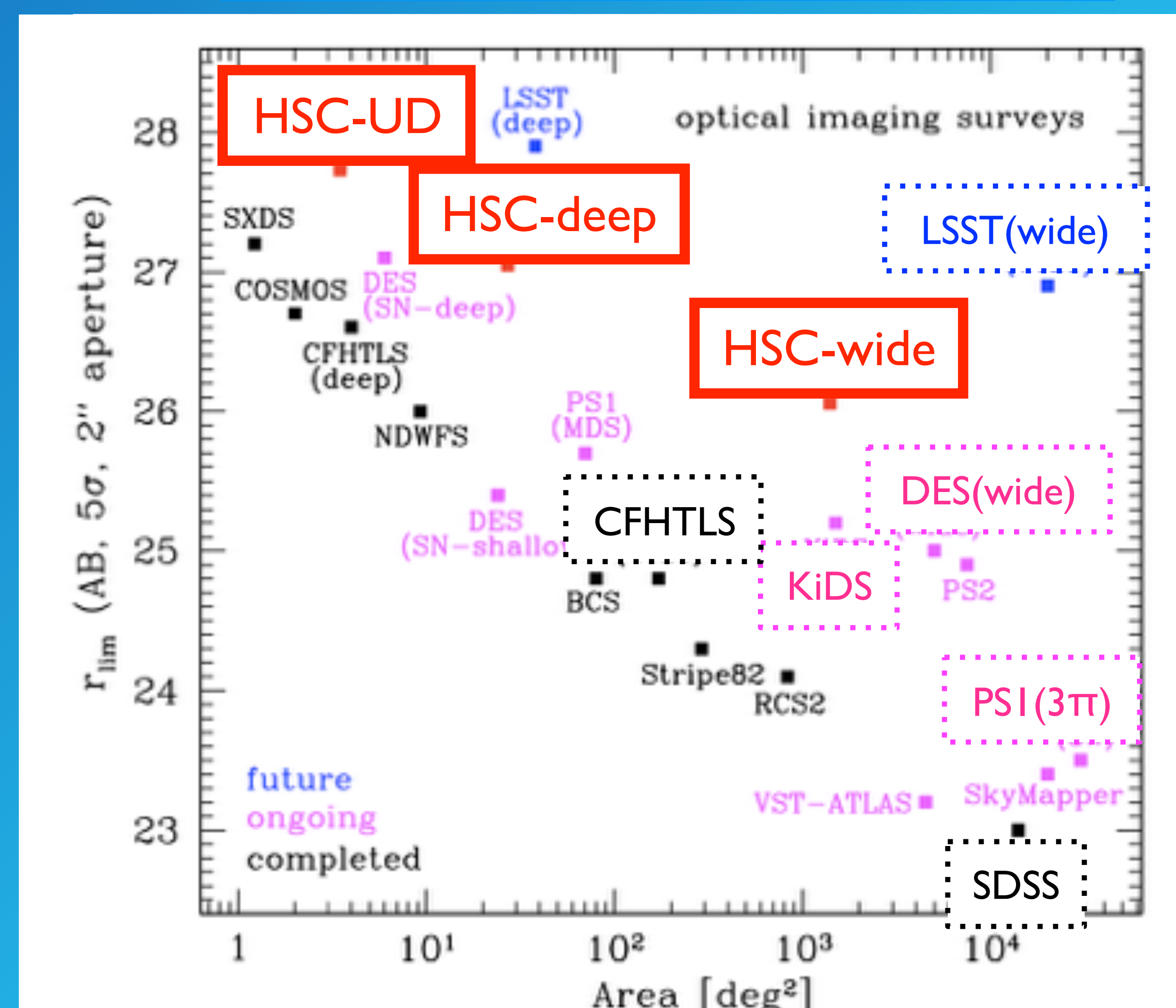
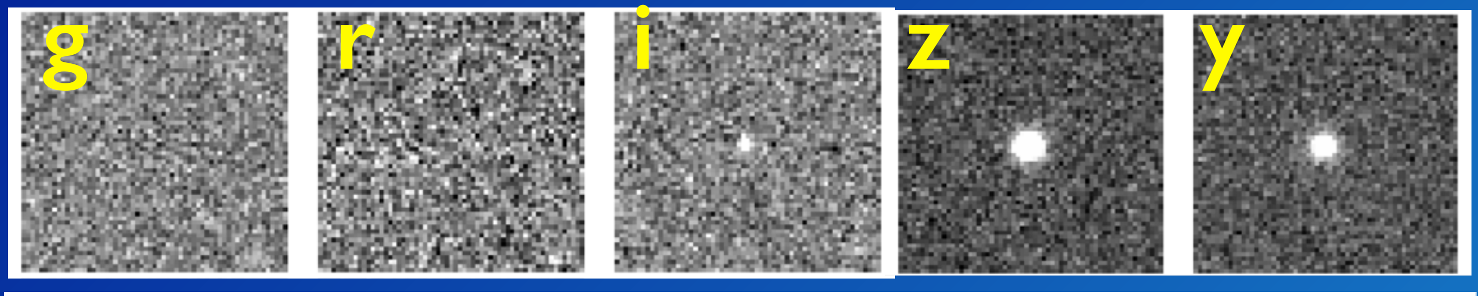
HSC-SSP Survey

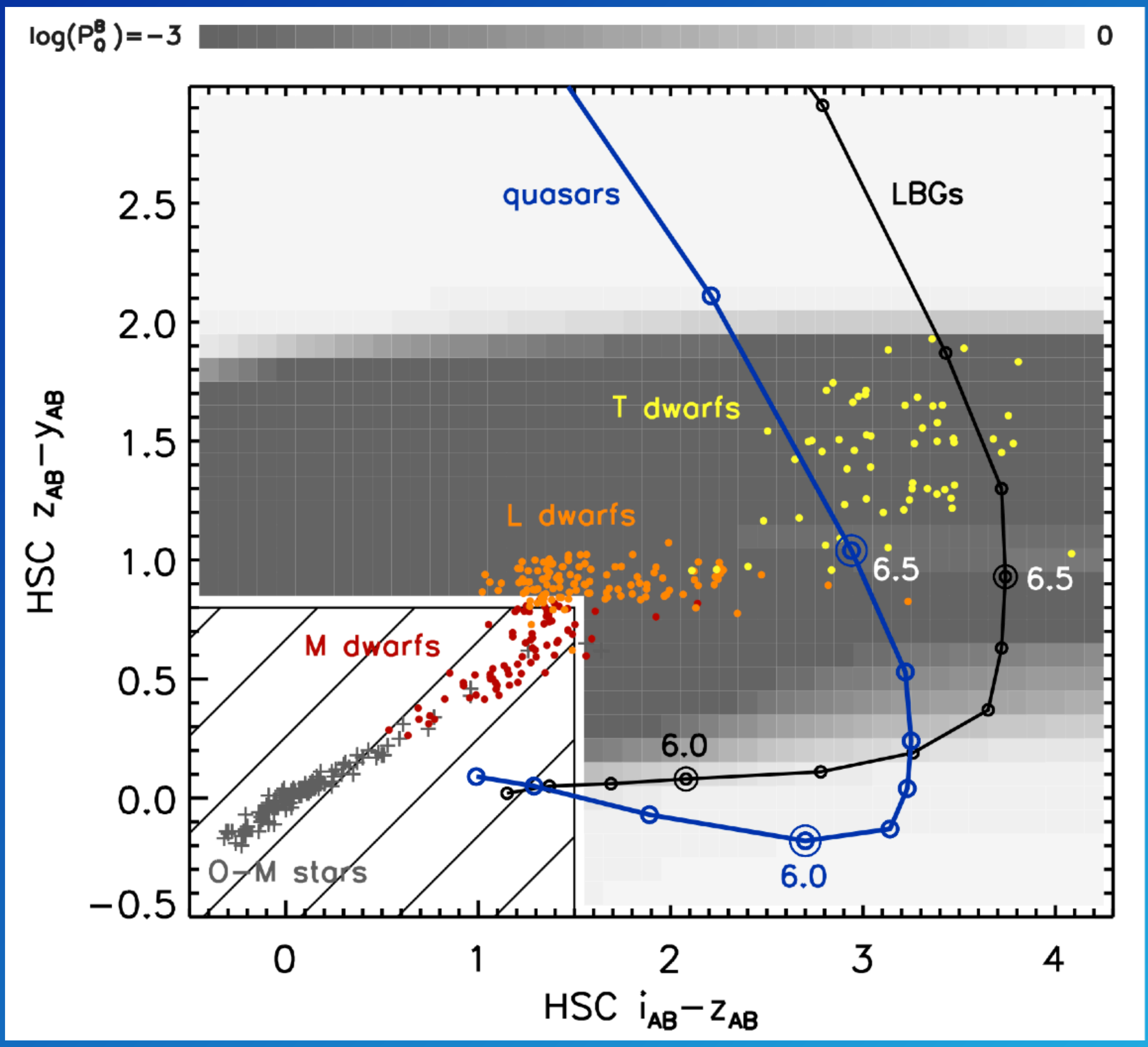


- ✦ Optical multi-band survey with Subaru/HSC (5years, 300nights)
  - Wide: 1400 deg², $r_{lim,5\sigma}$~26
  - Deep: 27 deg², $r_{lim,5\sigma}$~27
  - UD: 3.5 deg², $r_{lim,5\sigma}$~28
- ✦ Most powerful optical survey before LSST



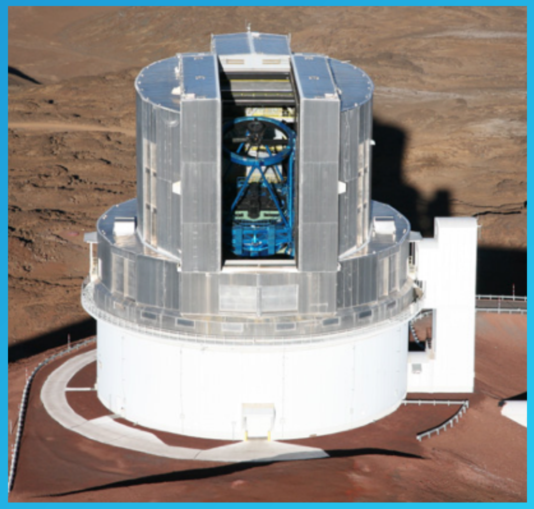
Candidate Selection





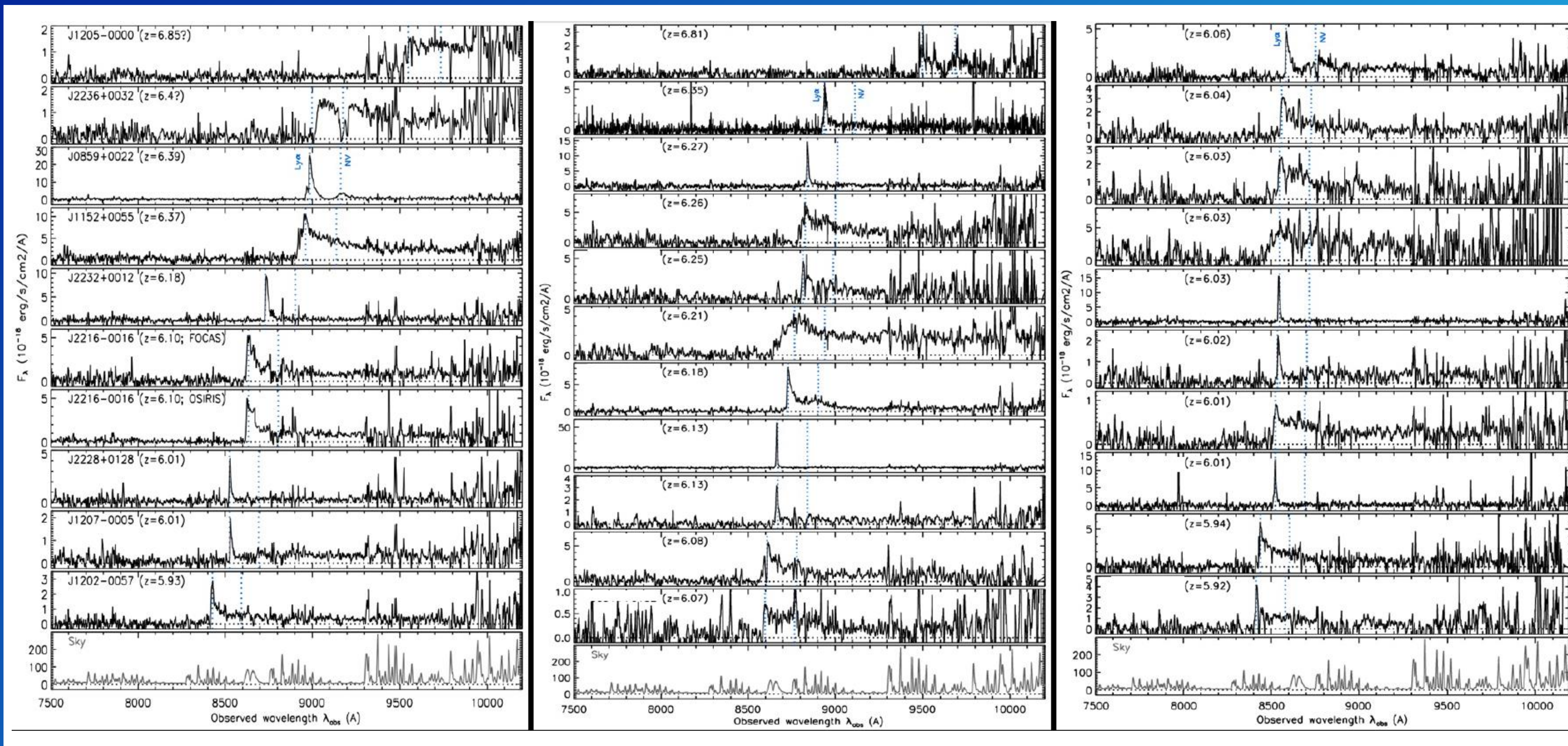
- ✦**Efficient selection is necessary (300@z~6, 50@z~7)**
  - –Based on quasar probability using an Bayesian framework
  - –Evidence of being quasar/brown dwarfs is calculated from the observed HSC colors with surface density $\rho_{Q/D}(\mathbf{m}, z)$ as a prior
- ✦**Optical spectroscopy**

Subaru/FOCAS



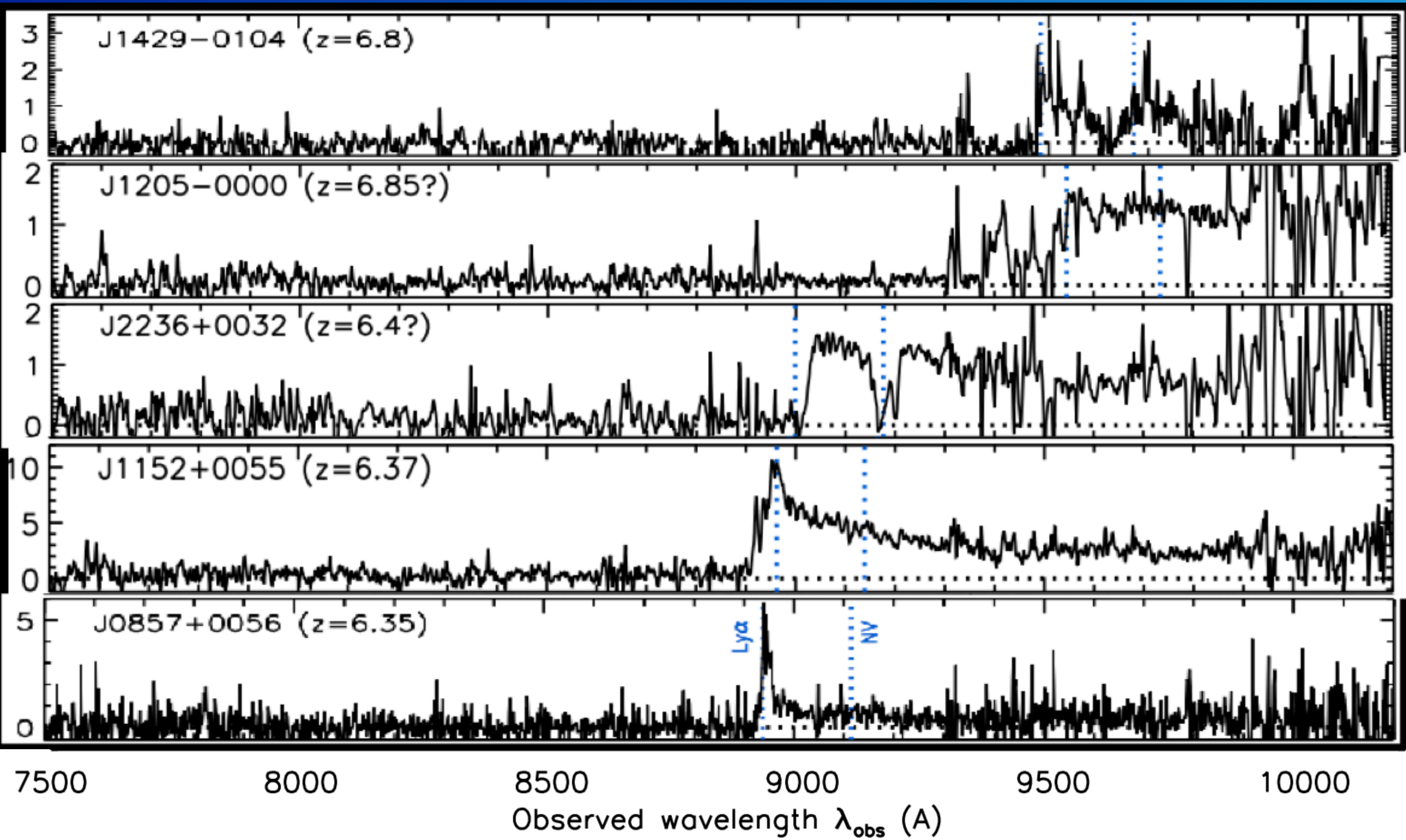
GTC/OSIRIS

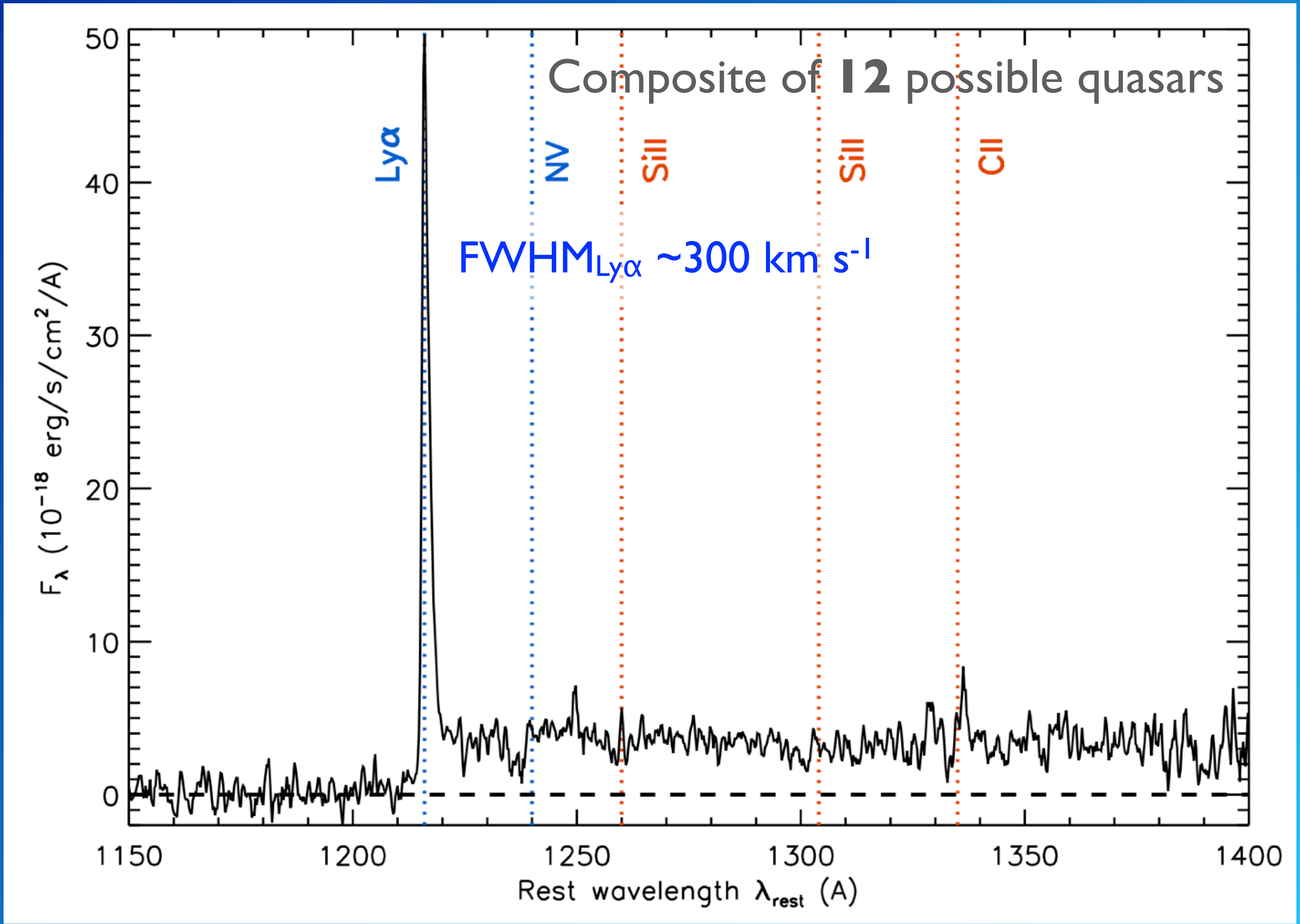
Initial Discovery



Matsuoka+16, 17

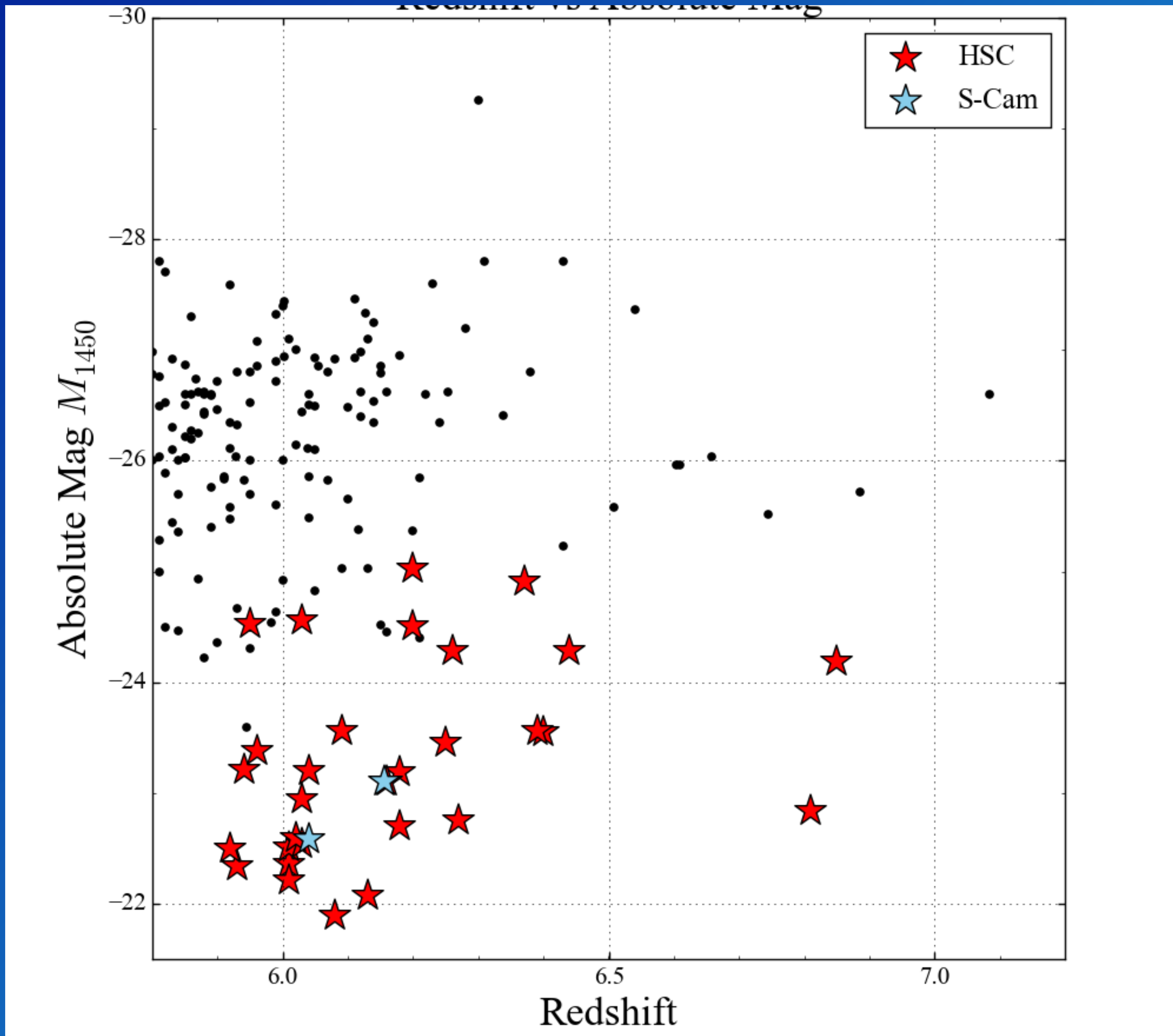
33 quasars found at 5.9<z<6.8 in ~400 deg²

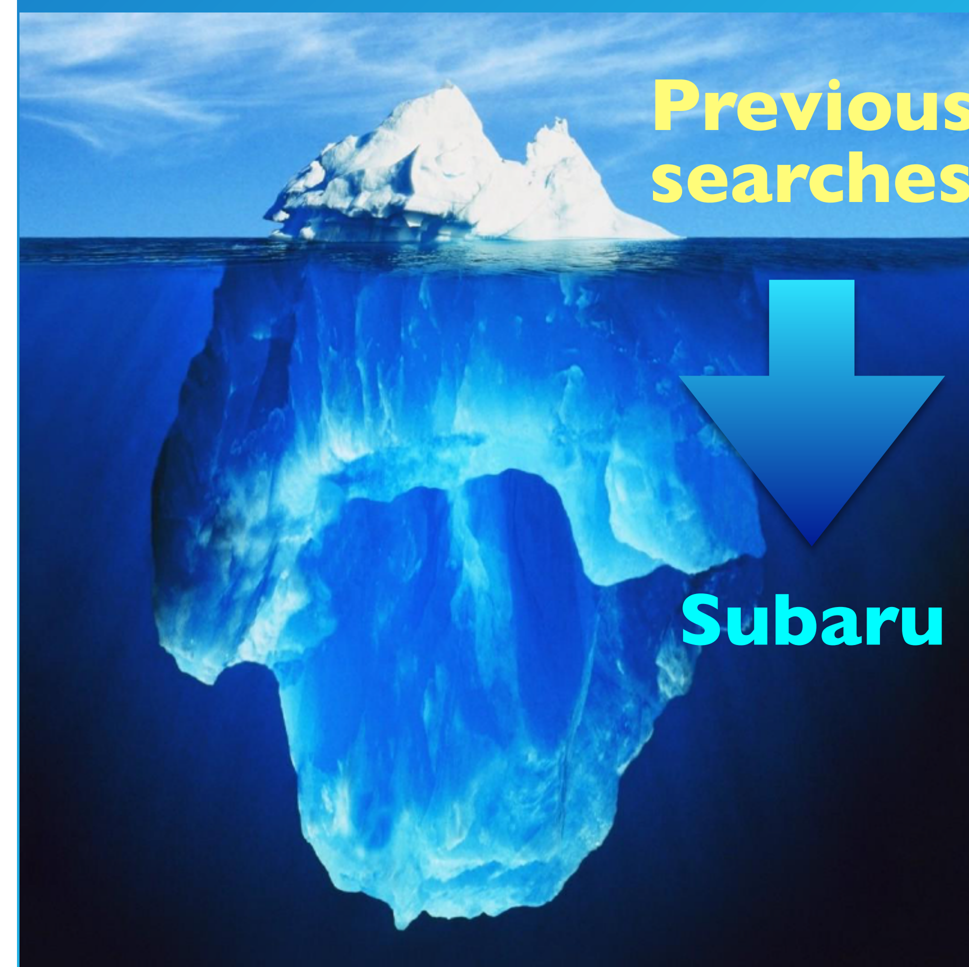

J1429−0104 (z=6.8)
J1205−0000 (z=6.85?)
J2236+0032 (z=6.4?)
J1152+0055 (z=6.37)
J0857+0056 (z=6.35)
Lyα
NV
7500
8000
8500
9000
9500
10000
Observed wavelength λ_{obs} (A)



Type-II quasars? Galaxy & type-I composite?

z vs M_{1450} distribution





We are exploring beyond the tip of iceberg!

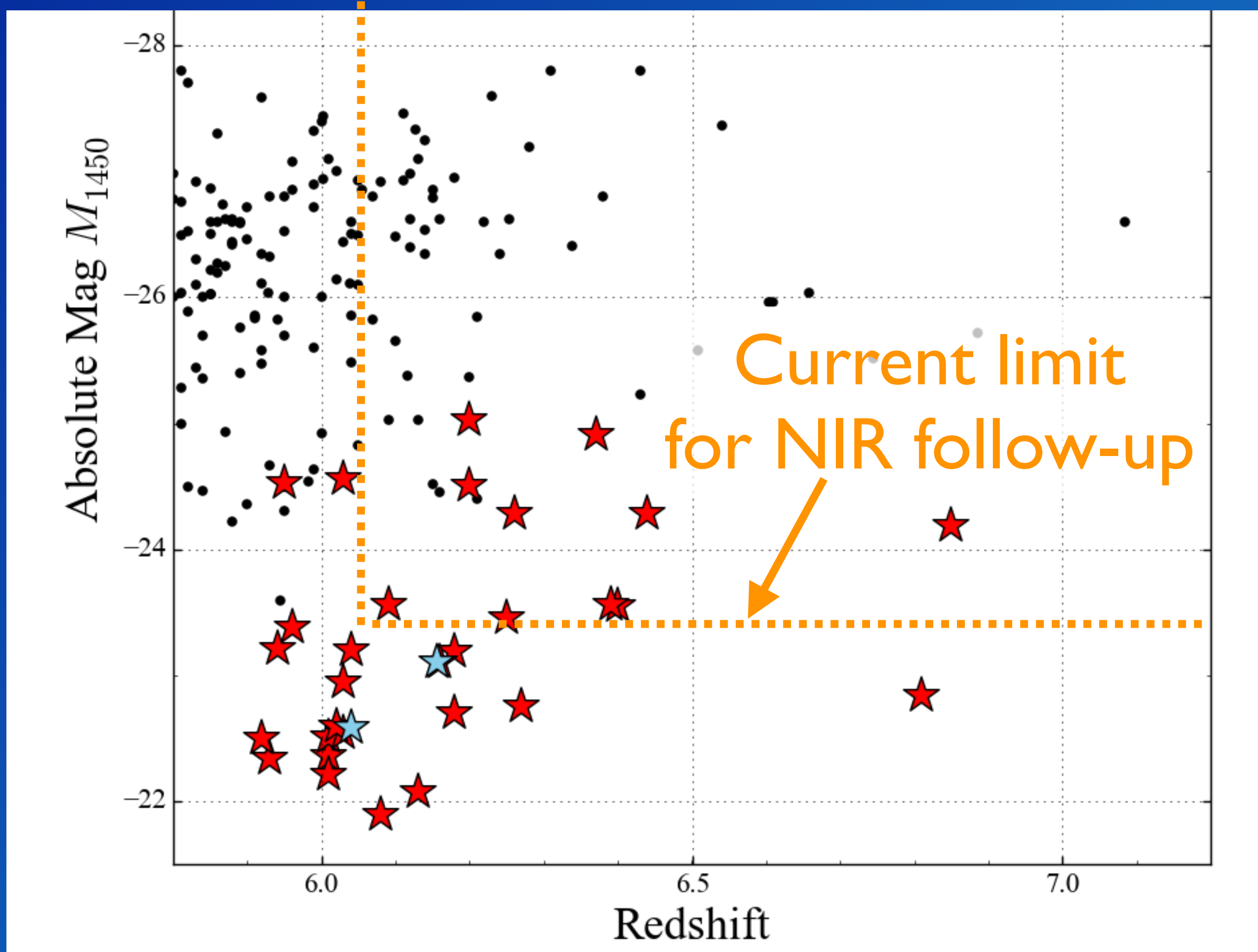
Follow-up Observation of SHELLQs

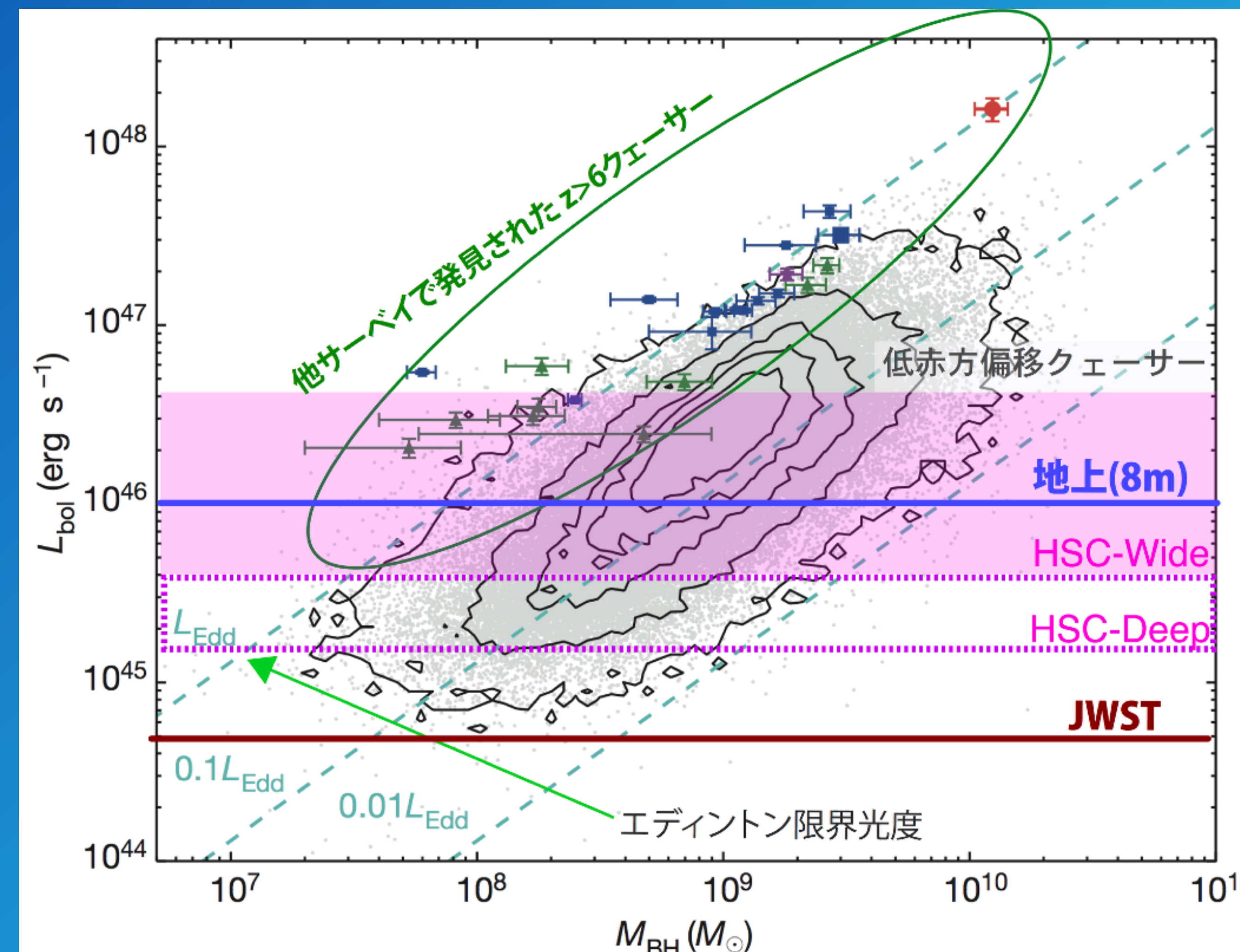
Preliminary

- SHELLQs view on JWST

Synergy with JWST

JWST/NIRSpec, R=1000





Our NIR follow-up is limited to bright sample

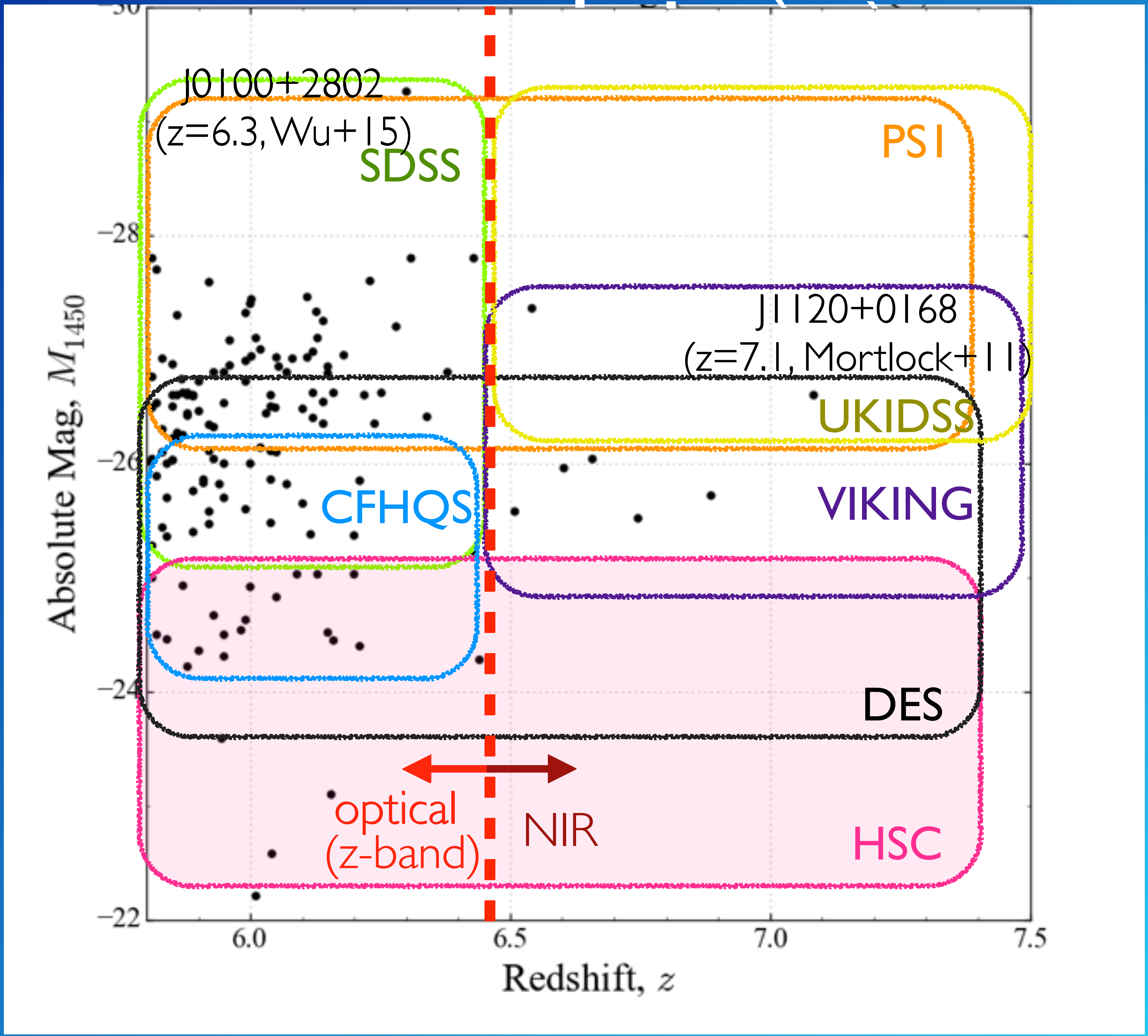
JWST enables M_{BH} measurements of the whole HSC sample down to ~10^7 M_{sun} at z~6

Summary

- High redshift quasar is an important tracer of cosmic reionization
- From our S-Cam project, we found quasars have only moderate (1-12%) contribution on the UV photon during the reionization
- SHELLQs project has been quite successful in the 1st year, discovering >30 QSOs in ~400deg^2
- From the first NIR follow-up, the target quasar is found to be a ~10^8 M_{sun} BH with Eddington accretion
- JWST will probe further down the BHMF at z>6

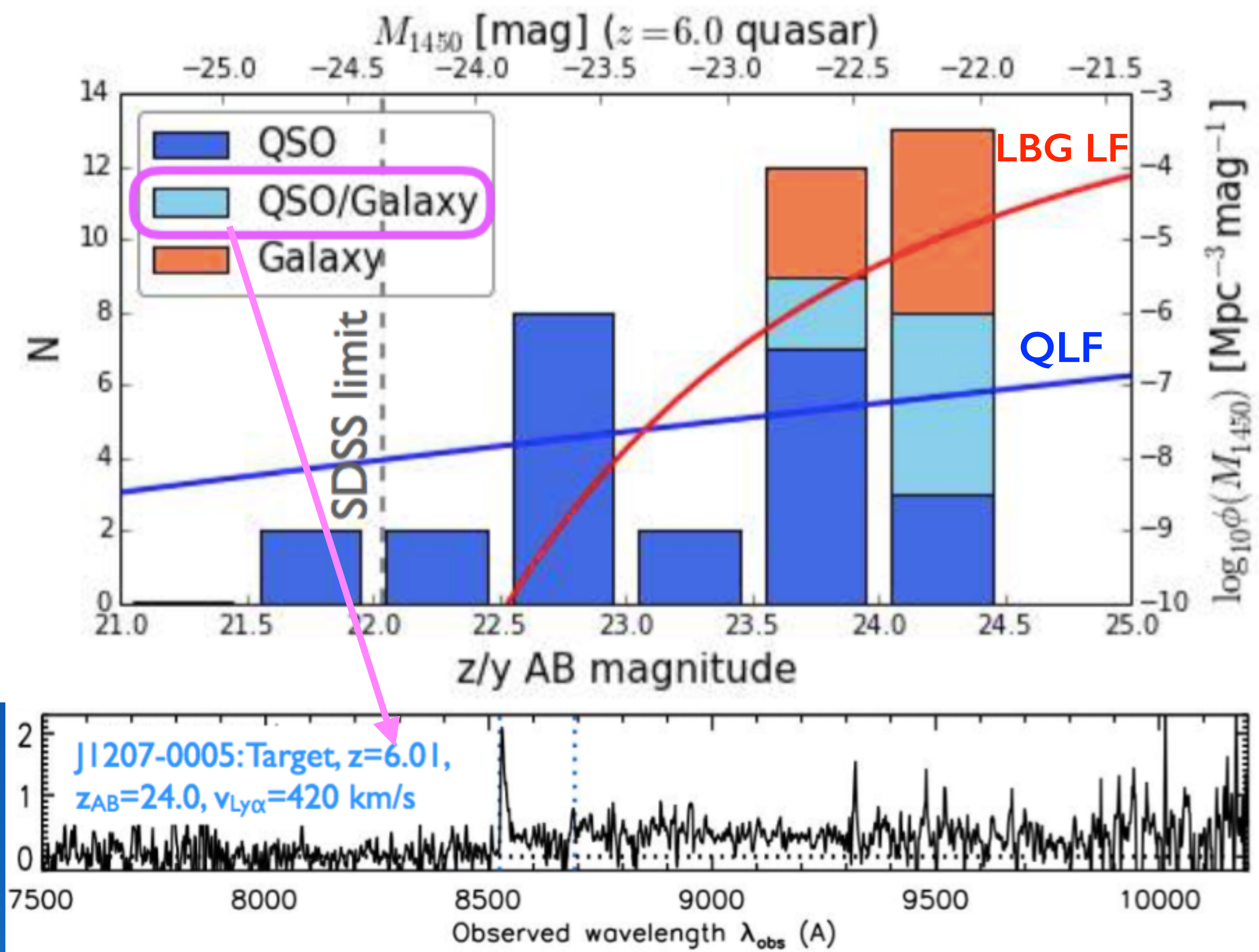
- Additional Slides

Published z>6 qsos (Oct. 2016)



Now, we should go deeper & higher-z (z>7)

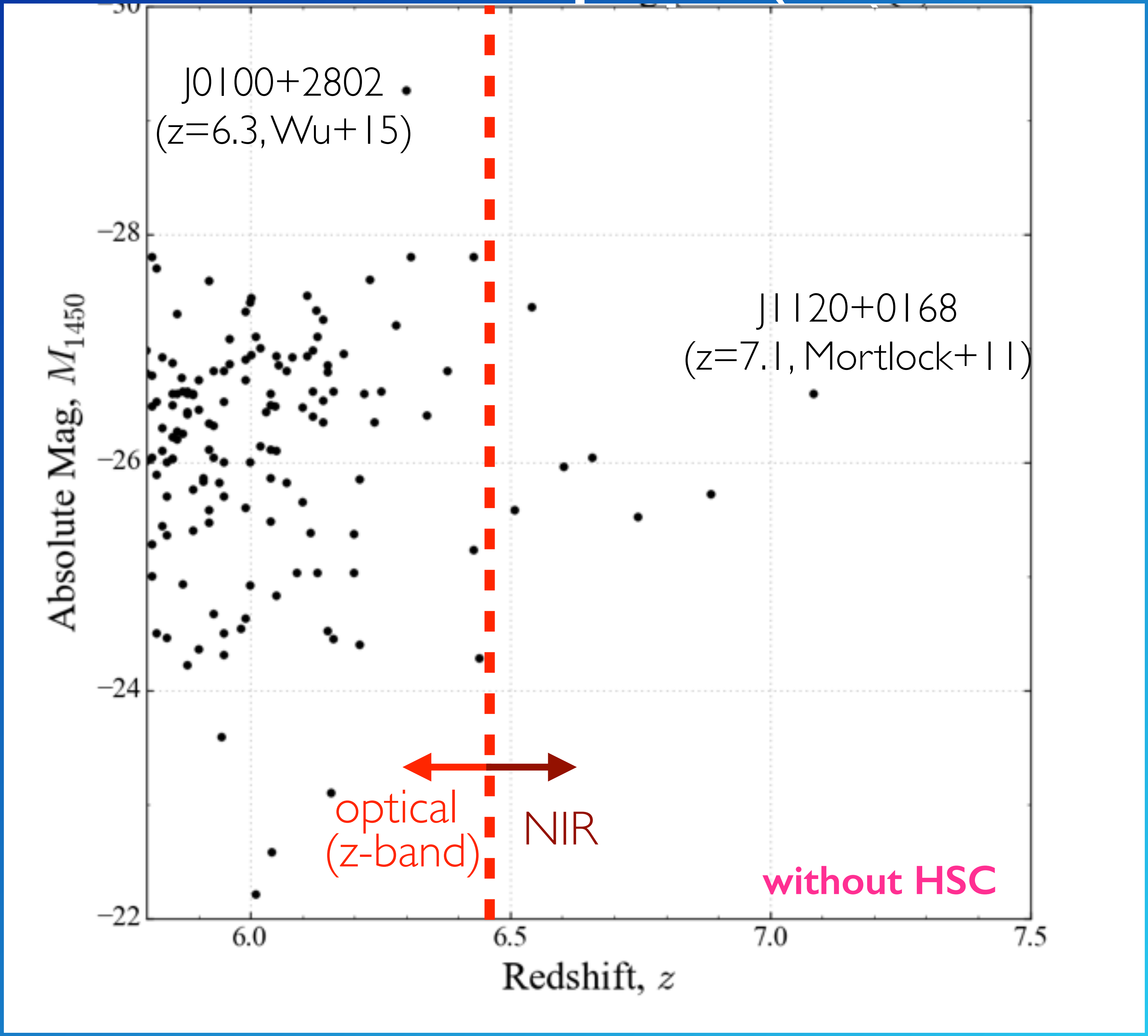
Our New Quasars & Galaxy



Candidates (z_{AB} < 24.5, y_{AB} < 24.0)	80
Known z ≥ 6 quasars	5
Spectroscopy done	55
Quasars at z ≥ 6	31
Galaxies at z ~ 6	8
[O III] emitters at z ~ 0.8	2
Brown dwarfs	8
Moving/transient	6

Lyα emitter with type-I AGN contribution?
or type-II quasar?

Published z>6 qsos (Oct. 2016)



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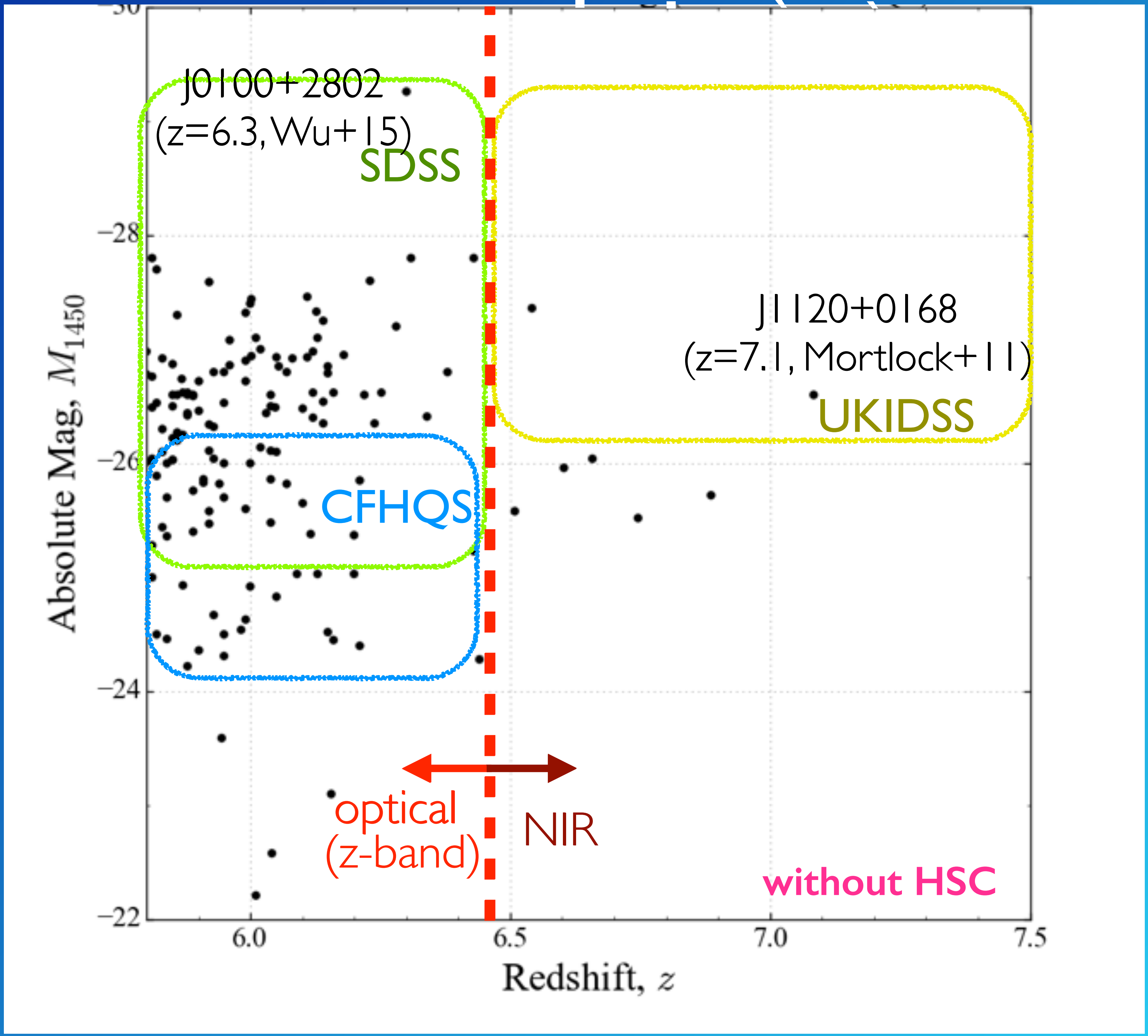

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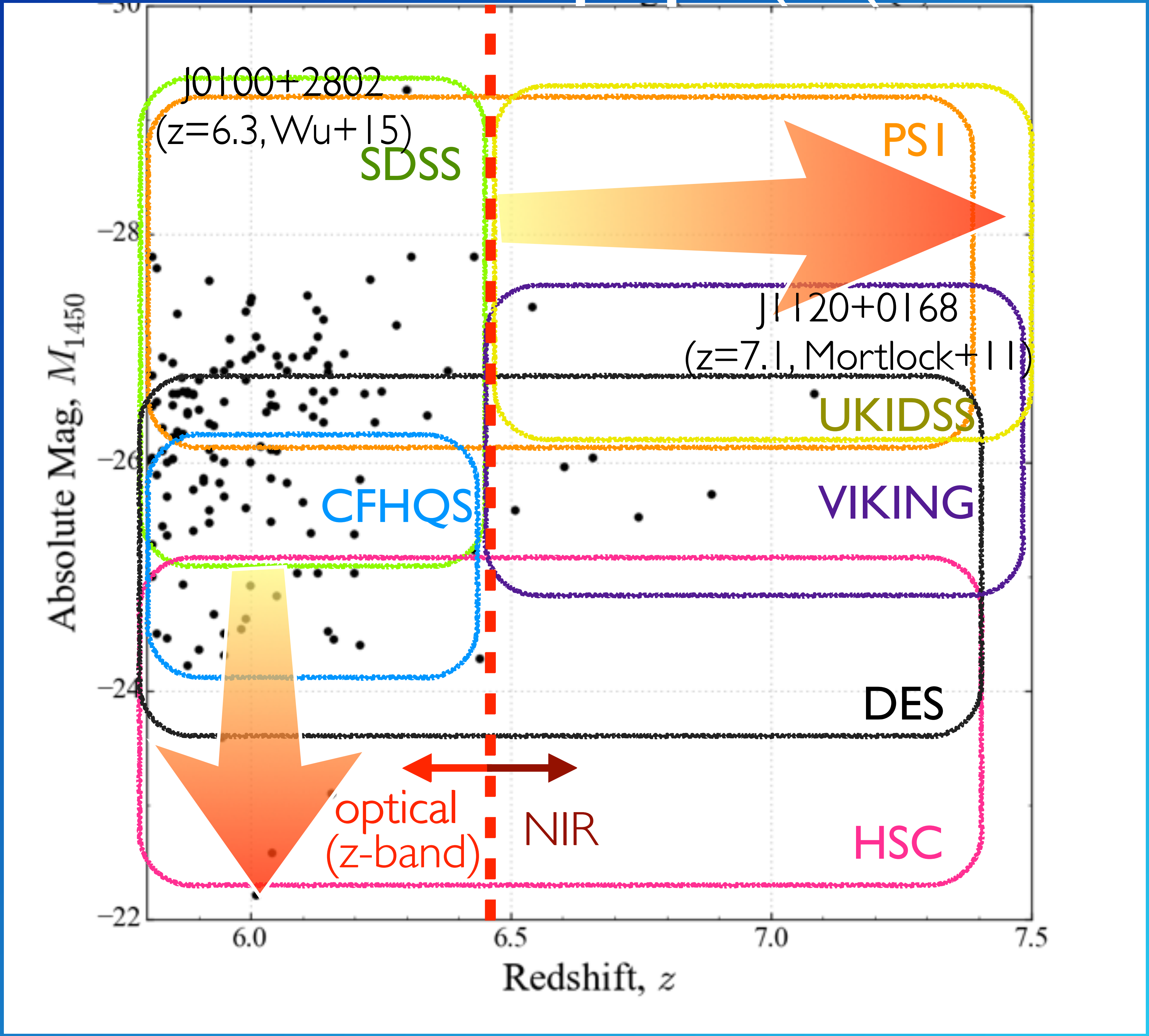
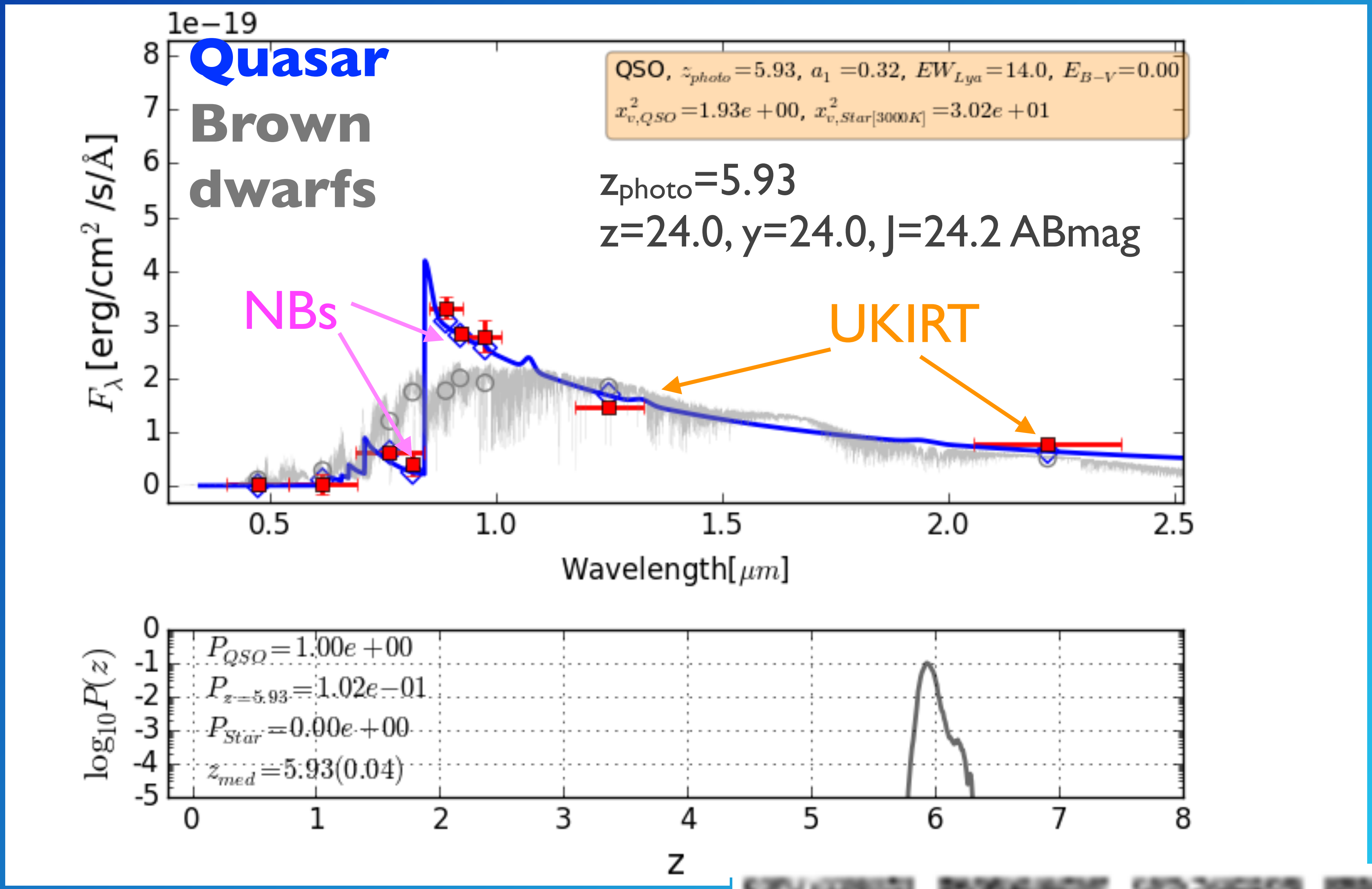
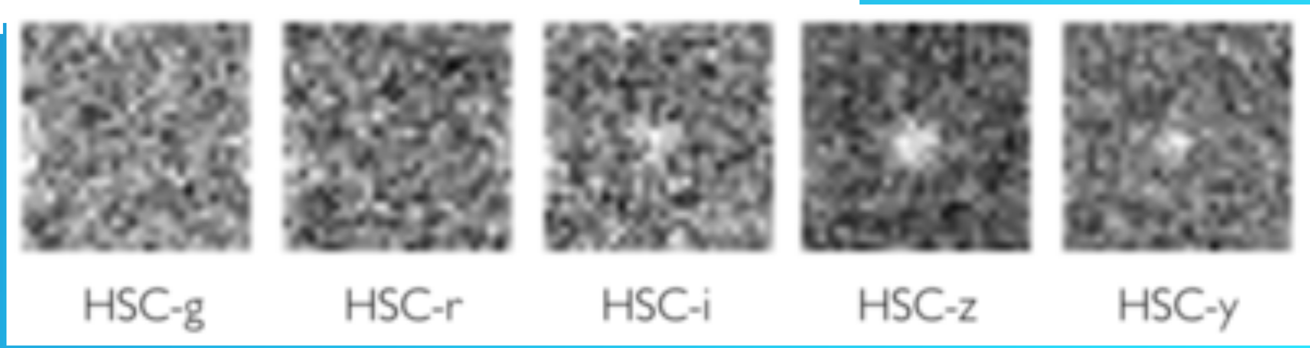


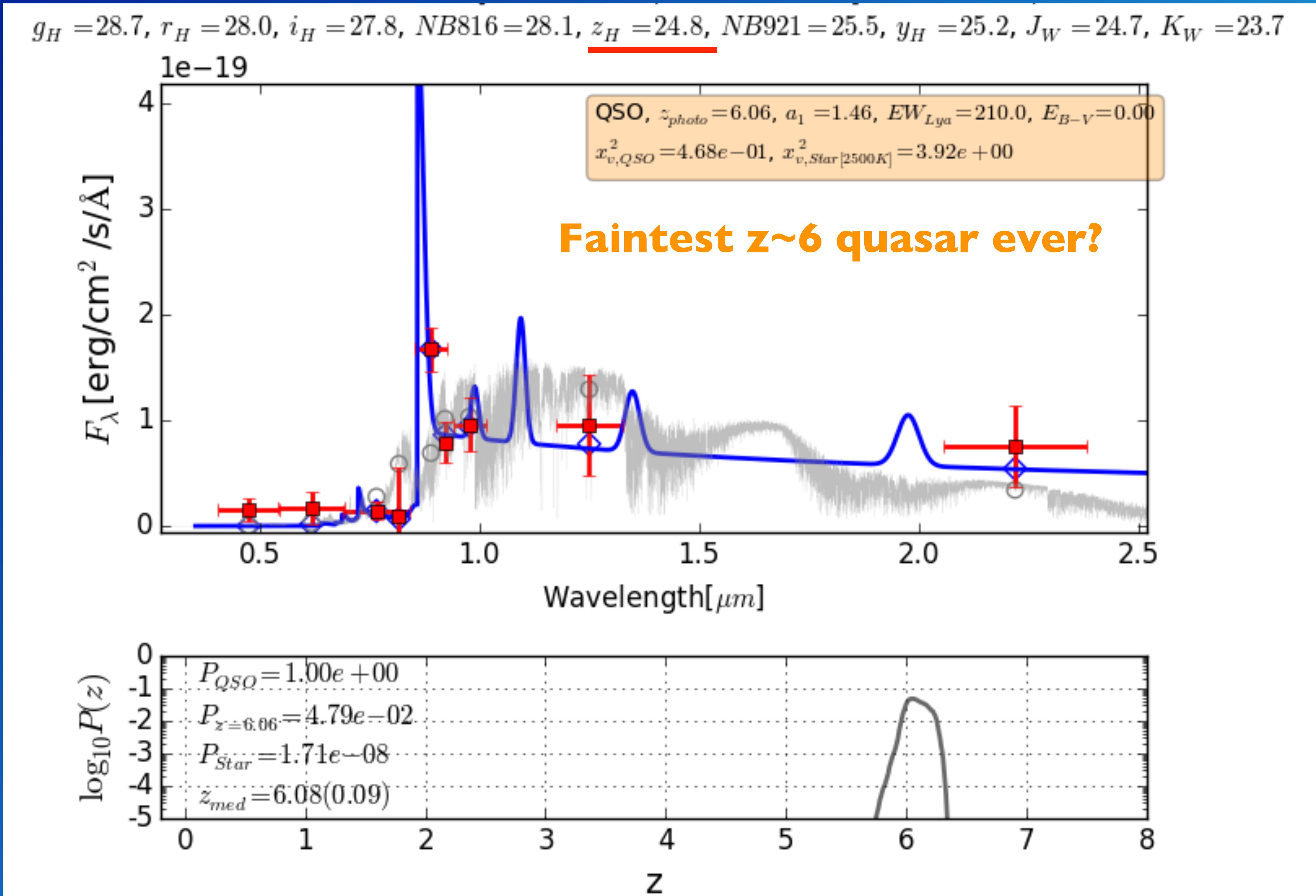
Now, we should go deeper & higher-z (z>7)

Fainter QSO Search with HSC-Deep (Elais-N1)

- ~1 mag deeper than HSC-Wide ($y_{lim,5\sigma}$=25.3)
- HSC NBs & UKIRT NIR photometry are available!







HSC-Deep probes down the quasar LF to M_{UV}~-21
First follow-up in next Mar. & Apr.

Data Flow

HSC
(z/y detected, point source)

VIKING & UKIDSS

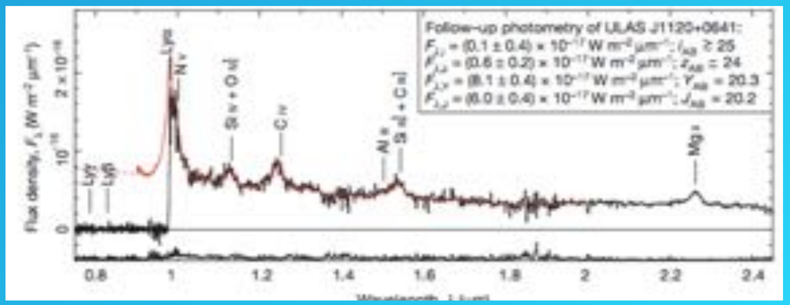
Initial Color Selection
(no g,r detection,
red color in i-z / z-y)

Multi-color Selection
1. Bayesian (CORE)
2. SED-fitting (BONUS)

Junk Removal &
Visual Inspection

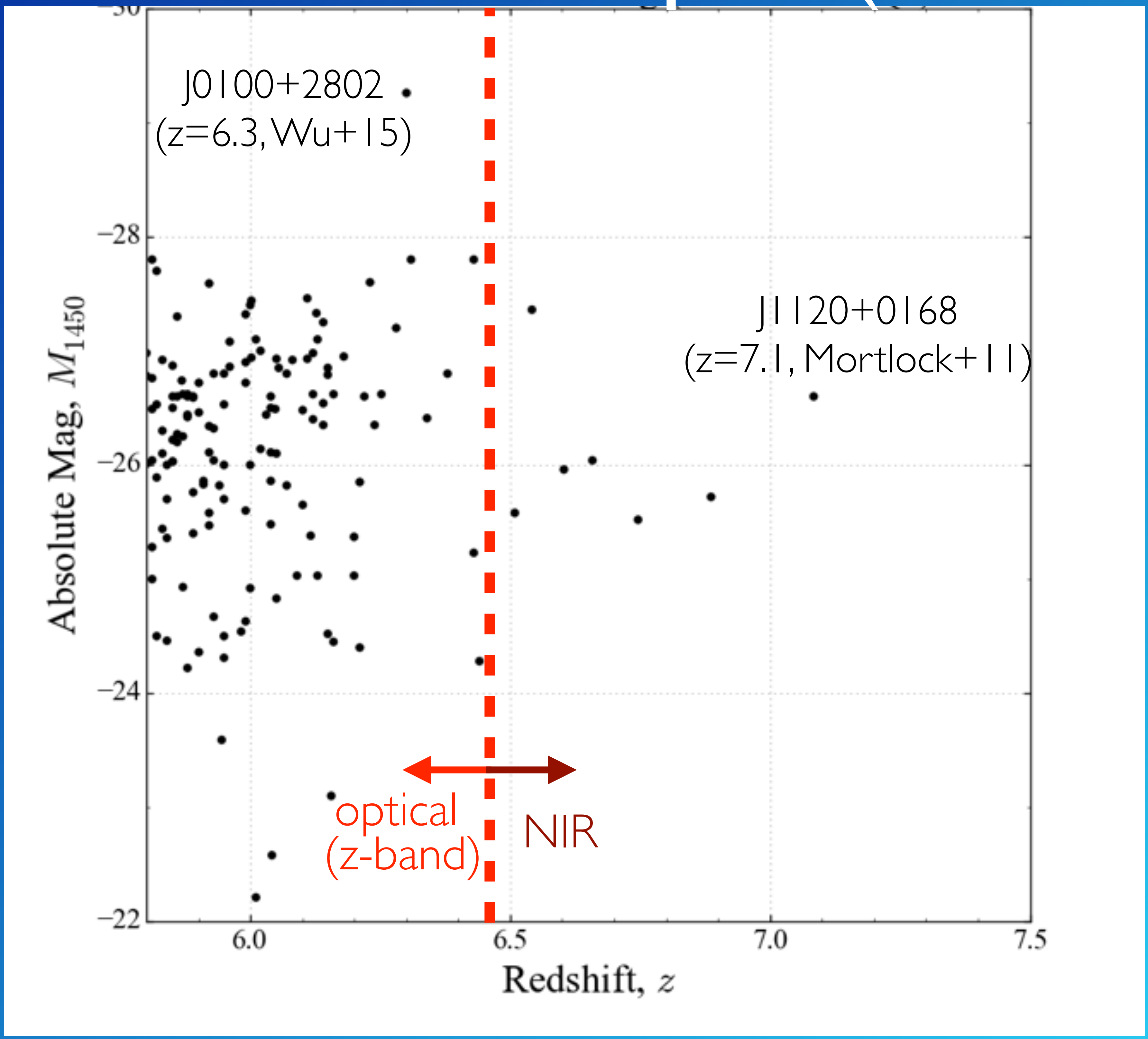
Spectroscopic Follow-up

Discovery!



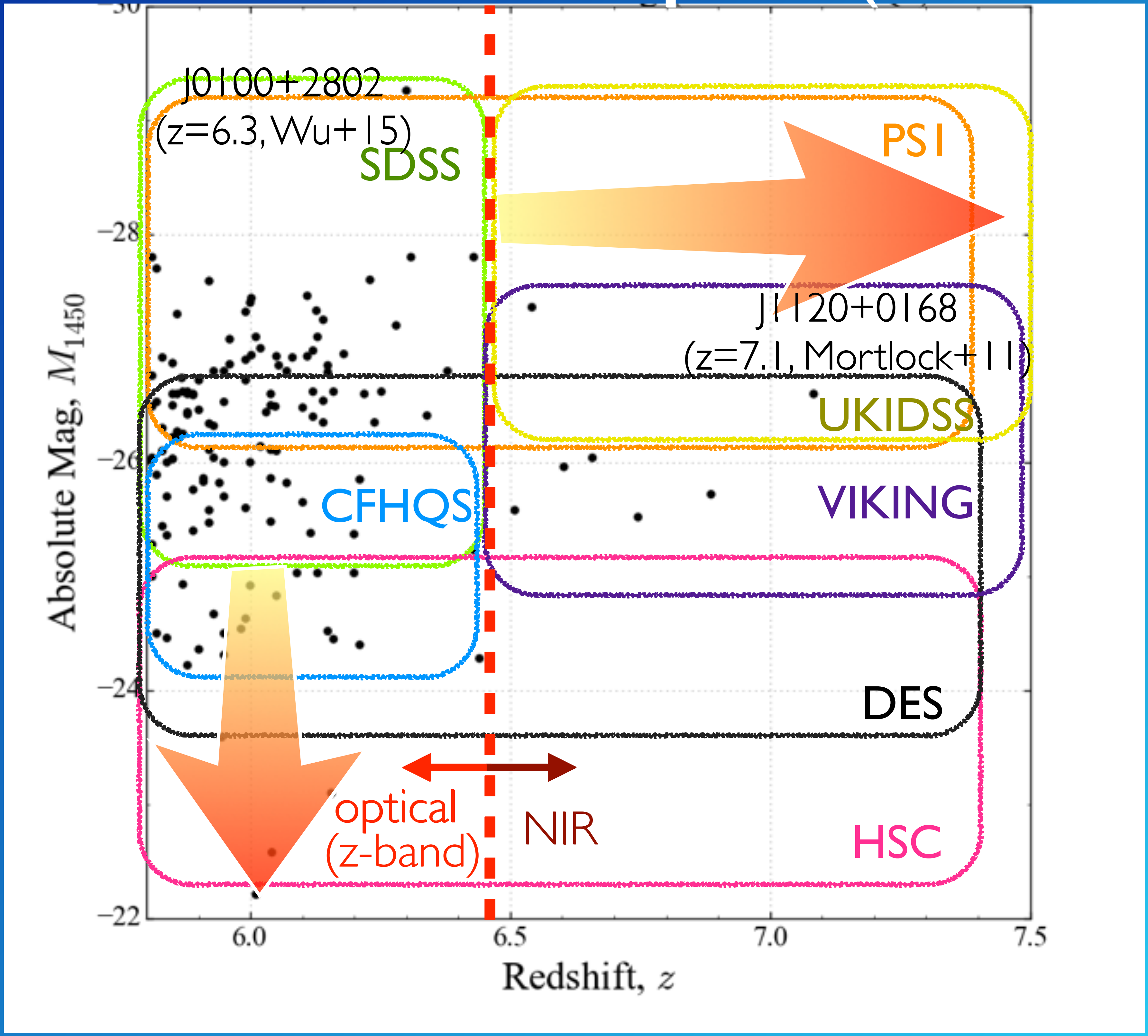
No photometric follow-up!

Published 100 z>6 qsos (Oct. 2016)



without HSC

Published 100 z>6 qsos (Oct. 2016)



Now, we should go deeper & higher-z (z>7)

(1) CORE selection by the Bayesian method

Prioritization of the candidates with the probabilistic approach:

P_Q = the Bayesian probability of being a high-z quasar rather than a Galactic brown dwarf = $W_Q/(W_Q+W_D)$ where $W_{Q/D}$ is the weighted evidence of being a quasar/dwarf.

observed magnitudes

the fact of detection

intrinsic magnitude and redshift

$$W_Q\,(m, det) = \int\int \underline{\rho_Q(m_{int}, z)}\ \underline{Pr(det \mid m_{int}, z)}\ \underline{Pr(m \mid m_{int}, z)}\ dm_{int}\, dz$$

(1) Quasar LF and its evolution (Willott+10)

0 if $m_{int} > m_{limit}$

1 if $m_{int} < m_{limit}$

(2) Mean quasar colors from ~340 SDSS quasars at z~3 with the Songaila (2004) IGM opacity

(3) multi-D Gaussian function with $\sigma = m_{err}$

$$W_D\,(m, det) = \int\int \underline{\rho_D(m_{int}, t_{sp})}\ Pr(det \mid m_{int}, t_{sp})\ \underline{Pr(m \mid m_{int}, t_{sp})}\ dm_{int}\, dt_{sp}$$

(4) Galactic brown-dwarf distribution model (Caballero+08)

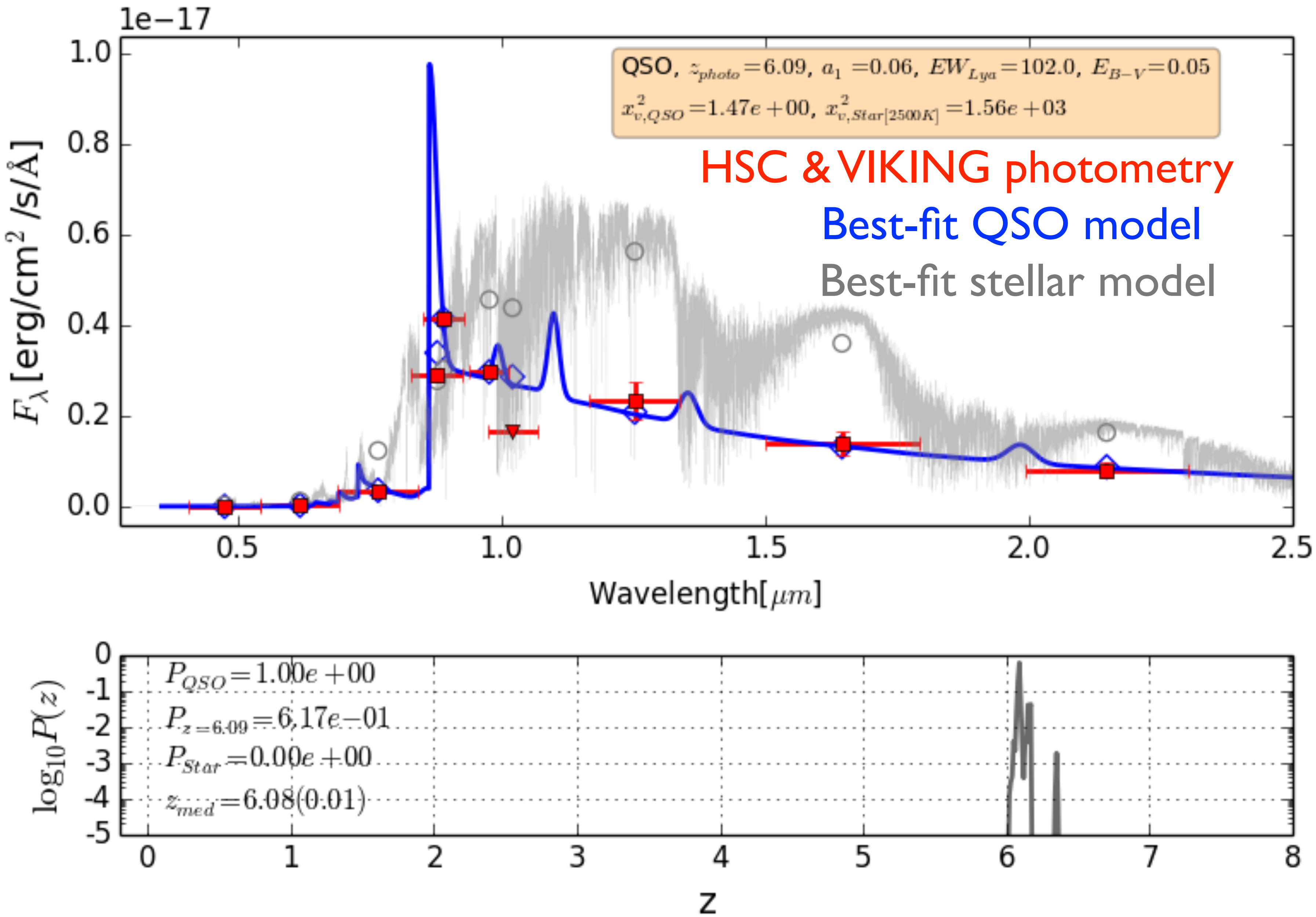
(5) SpeX and CGS4 spectral library

(2) BONUS selection by the SED-fitting method

In the overlapping fields with VISTA/VIKING, we perform a classical SED fitting with the g, r, i, z, y (HSC) + Y, J, H, K (VIKING) magnitudes.

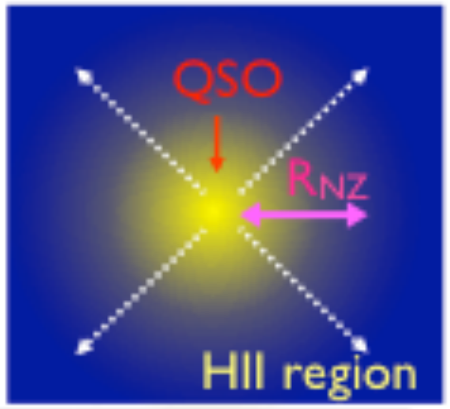
Quasar templates: power-law continuum + emission lines, with a large range of power-law slope, line strengths, and dust extinction based on the statistics measured at z > 3.

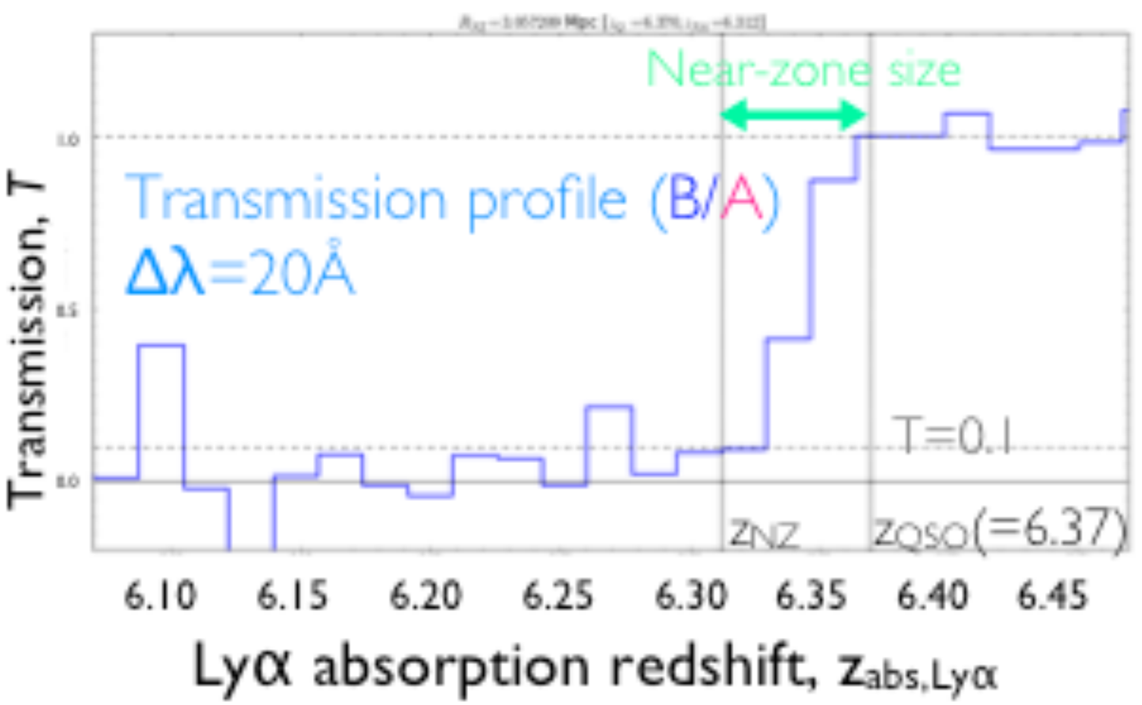
Stellar templates: Kurucz (1993) stars and Alllard (2012) brown dwarfs.

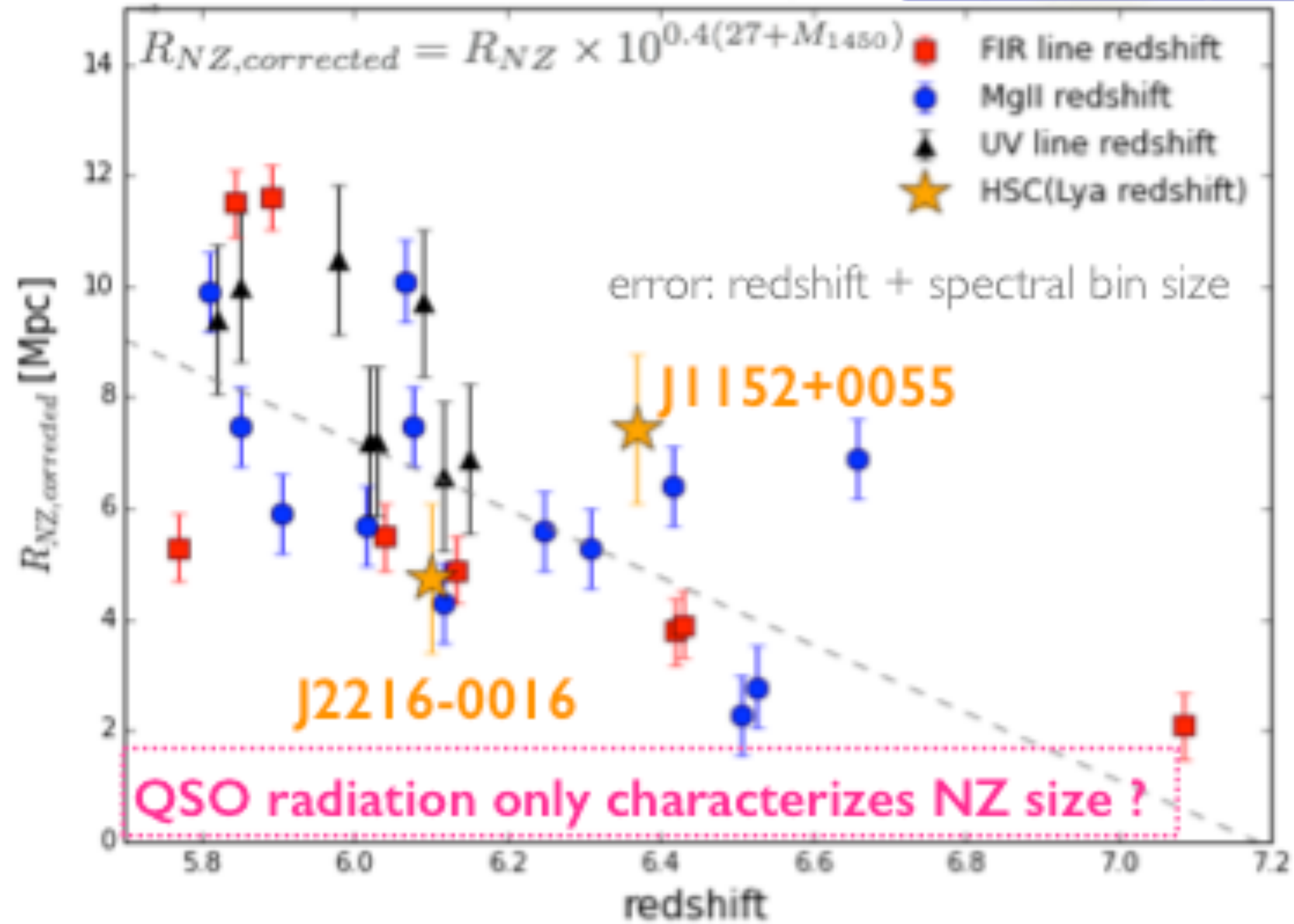


Project 93 [Kashikawa, Onoue+]
Reionization probed by high-z quasars

- Near-zone size (R_{NZ}): the size from central quasars to where transmission first drops to $T=0.1$ [Fan+06b, Carilli+10]
- R_{NZ} have been measured for two low-luminosity QSOs at z~6 from the SHELLQs project [Project 47]

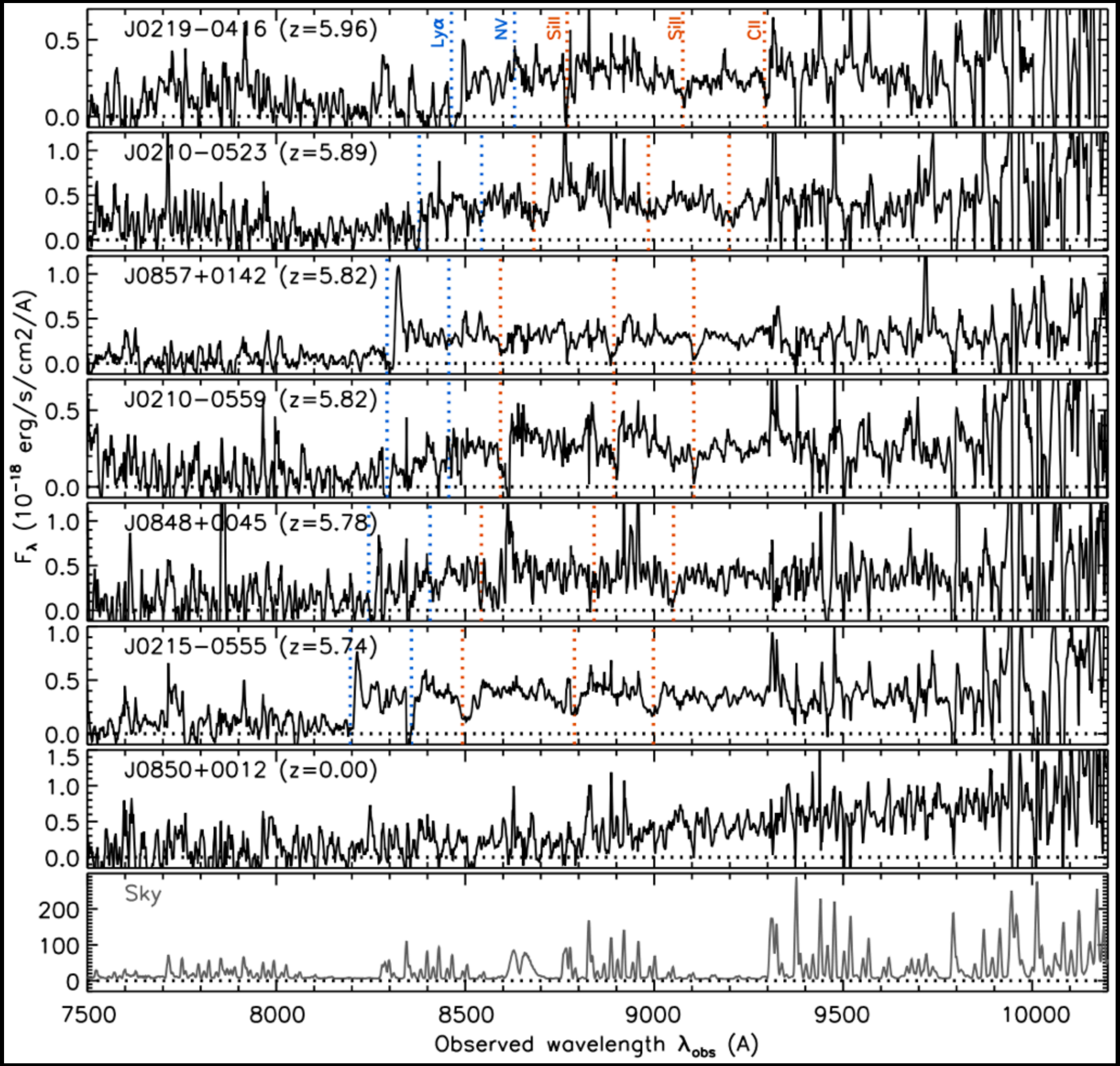






VLT/X-Shooter (25hrs) + Gemini/GNIRS (5.1hrs) programs have been allocated observing times!
-> more precise NZ size measurements for 4 z>6 QSOs with deeper optical spectra & MgII redshift

Surprisingly...



Our score sheet

- Spectroscopic identification as of 2016 Sep 2

Candidates ($z_{AB} < 24.5$, $y_{AB} < 24.0$)	80
Known z ≥ 6 quasars	5
Spectroscopy done	55
Quasars at z ≥ 6	31
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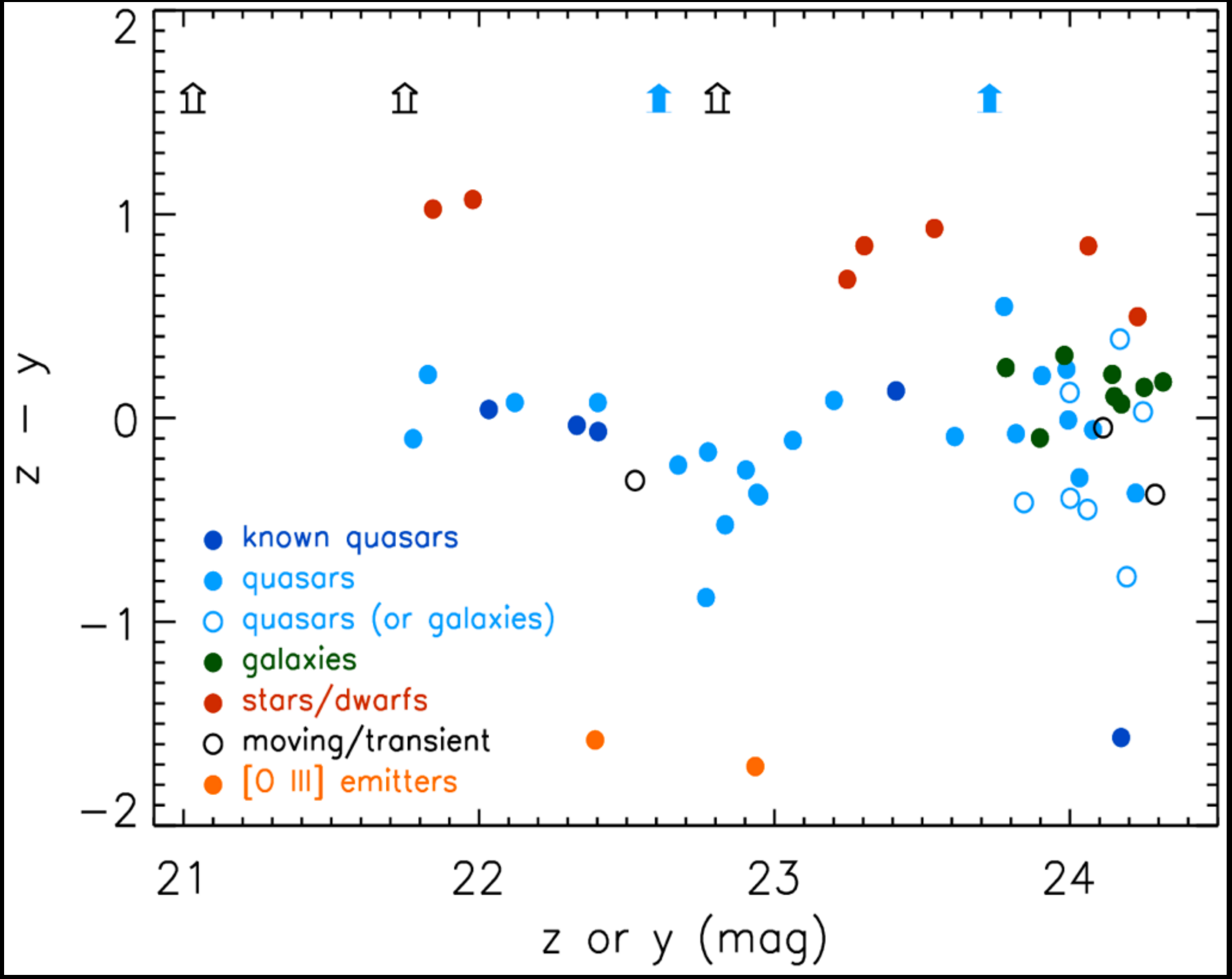

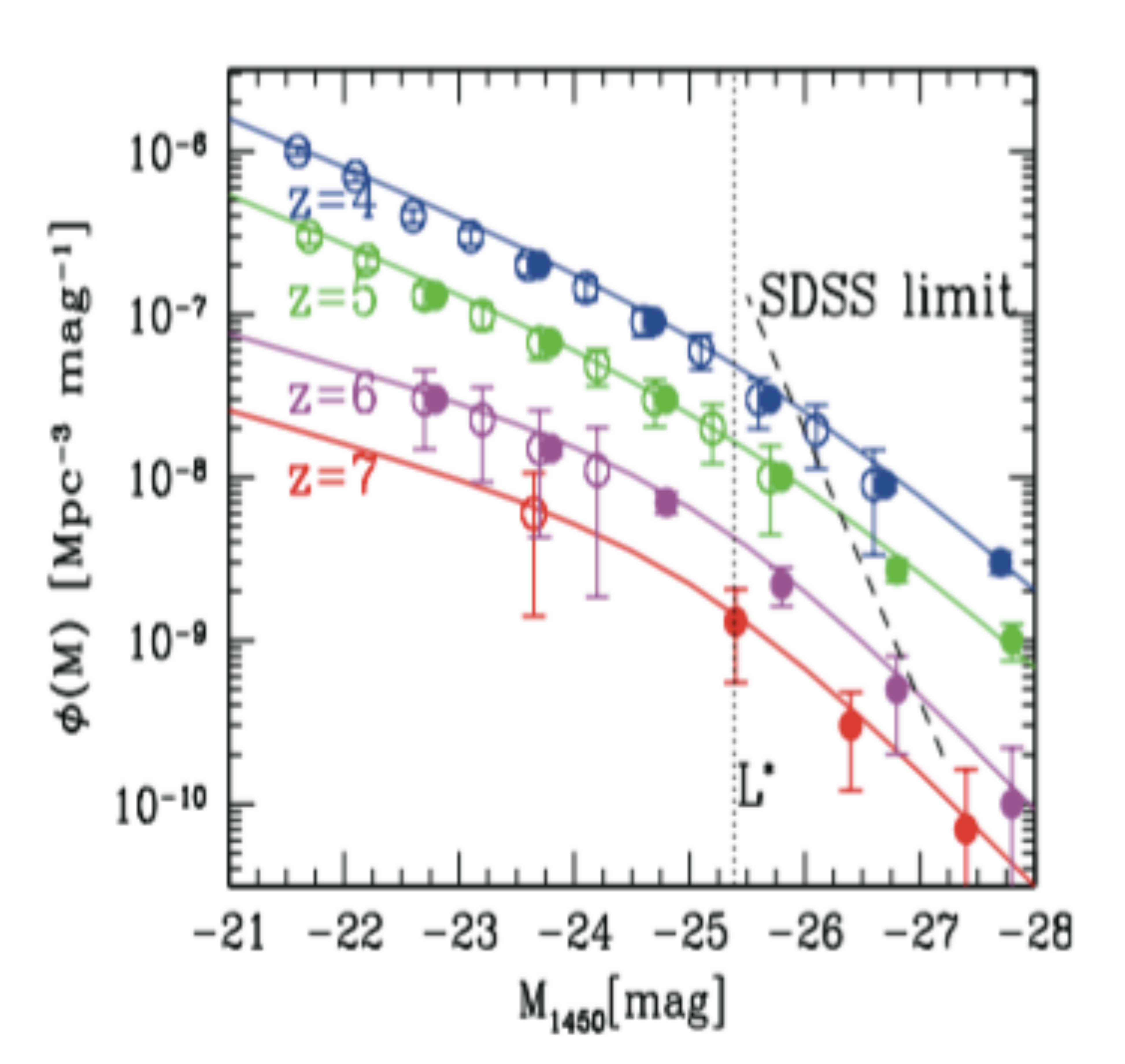

10^-6
10^-7
10^-8
10^-9
10^-10
z=4
z=5
z=6
z=7
SDSS limit
L*
−21
−22
−23
−24
−25
−26
−27
−28
M1450[mag]
φ(M) [Mpc^-3 mag^-1]