# Searching for z>6 Quasars with Subaru / Hyper Suprime-Cam Survey

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

# SHELLQs

## Subaru High-z Exploration of Low-Luminosity Quasars

## Subaru Hyper Suprime-Cam SSP Project 47


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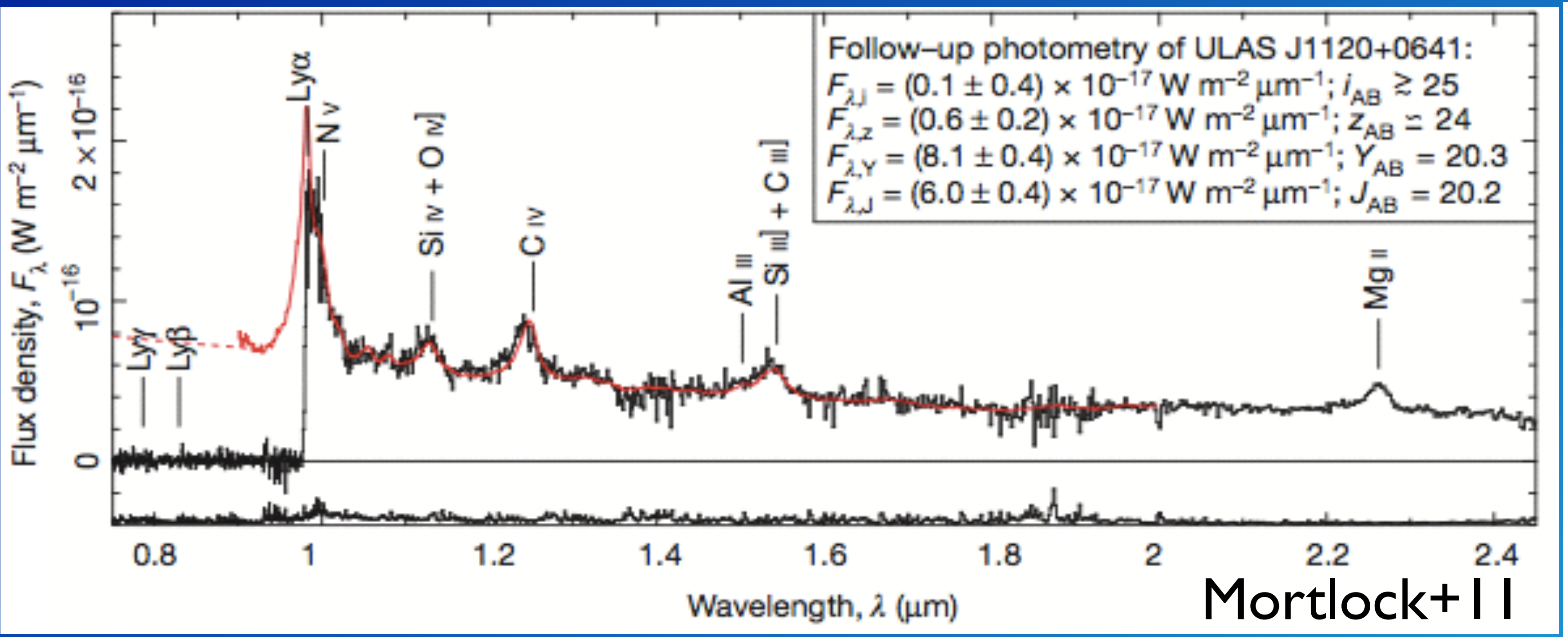
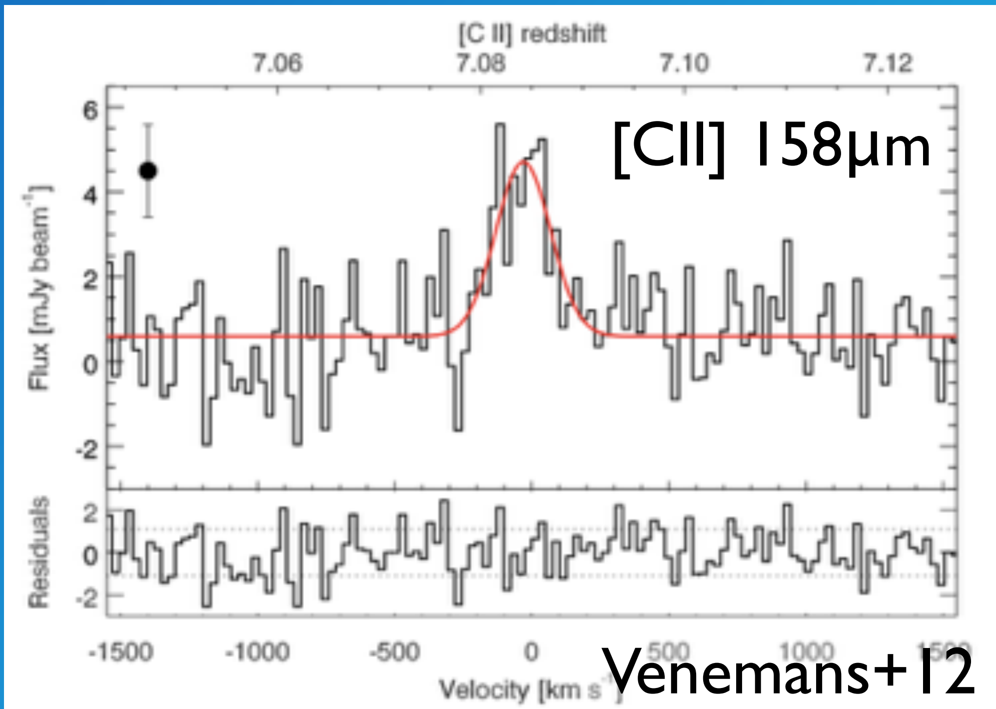
# Why we care high-z (z>6) quasar ?

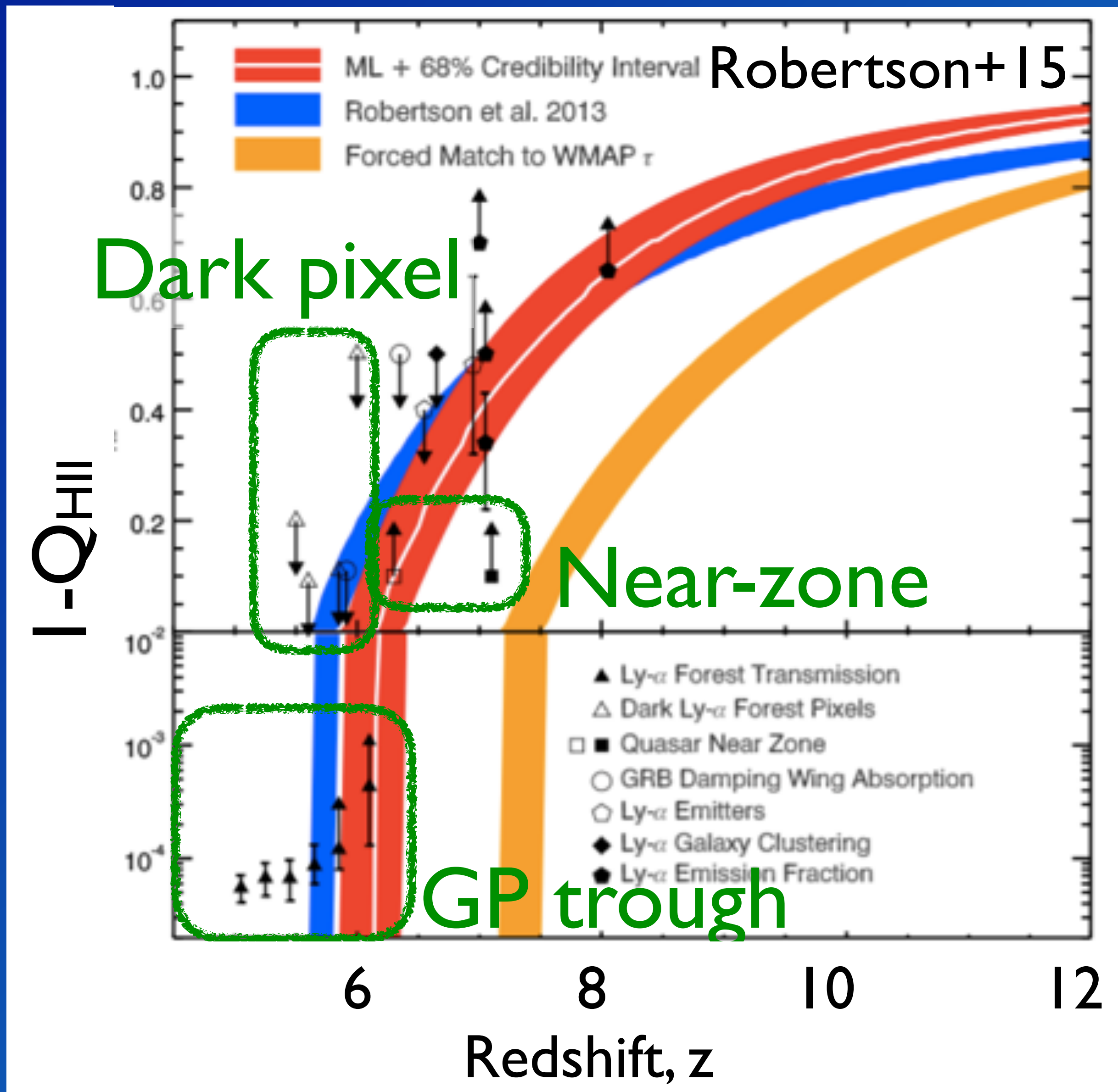


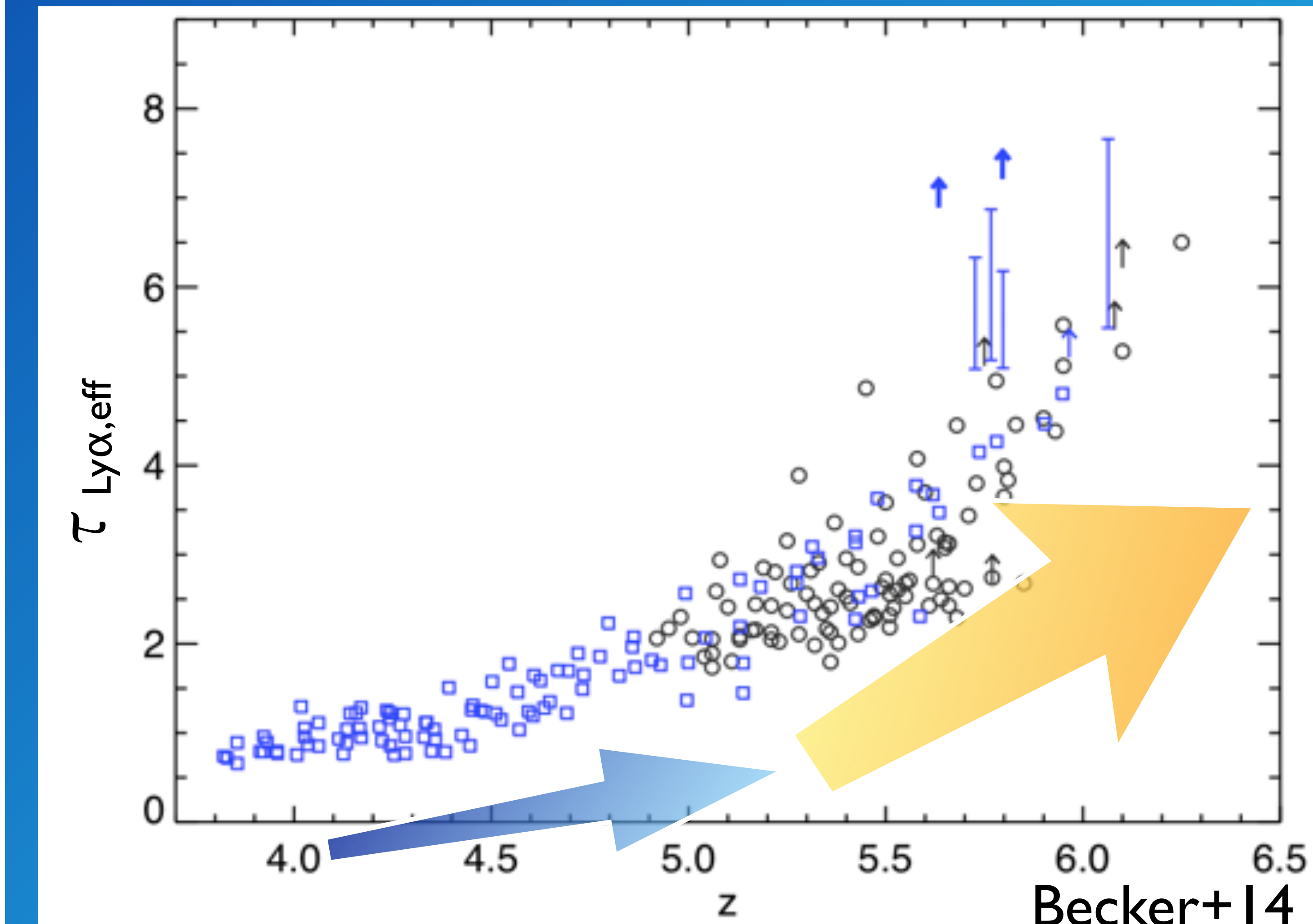




- ✦ SMBH evolution/formation scenario
- ✦ IGM opacity during EoR
- ✦ Co-evolution with host galaxy
- ✦ Proto-cluster search

**Unique probe of the early Universe !!**

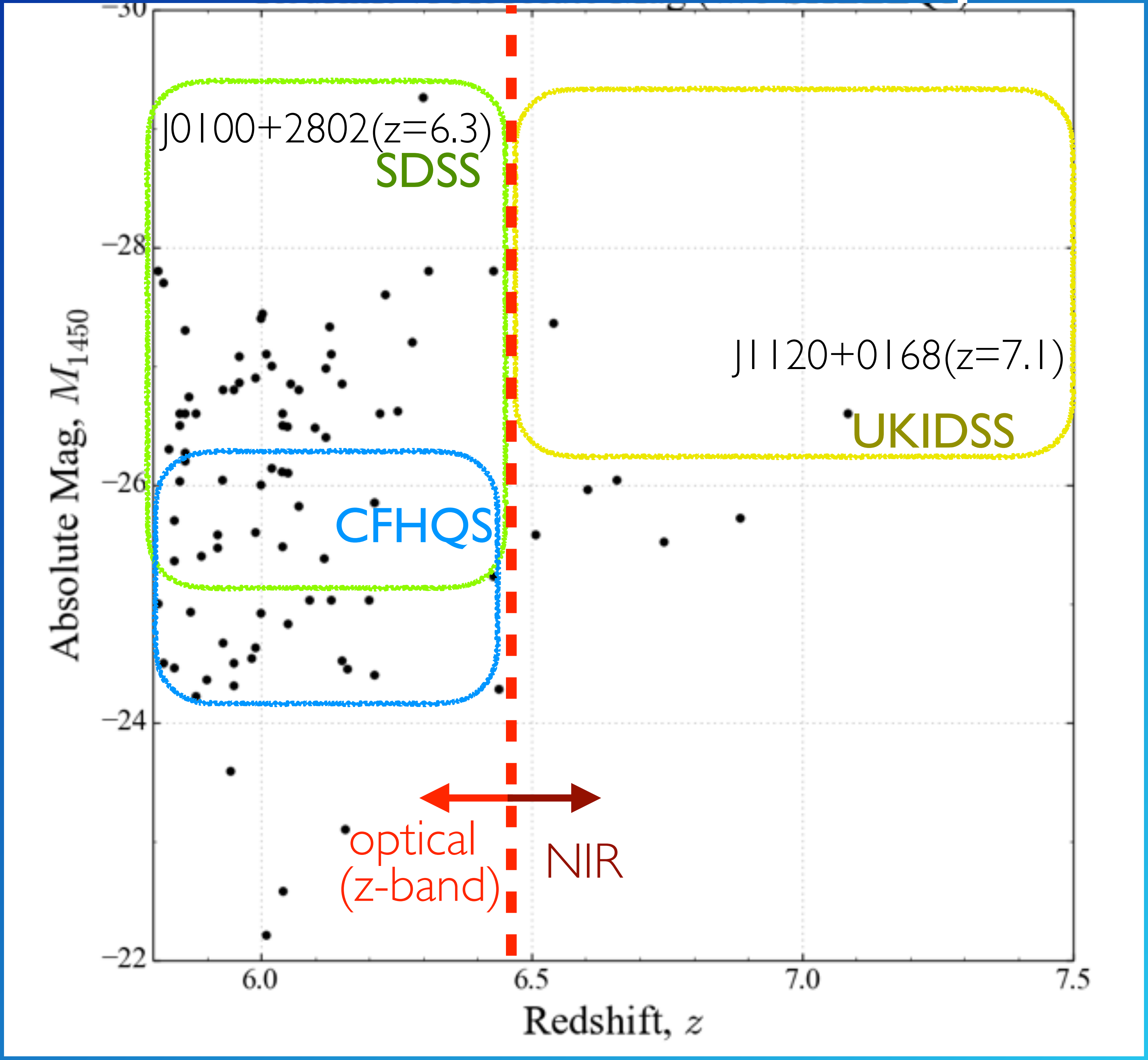
# IGM Opacity



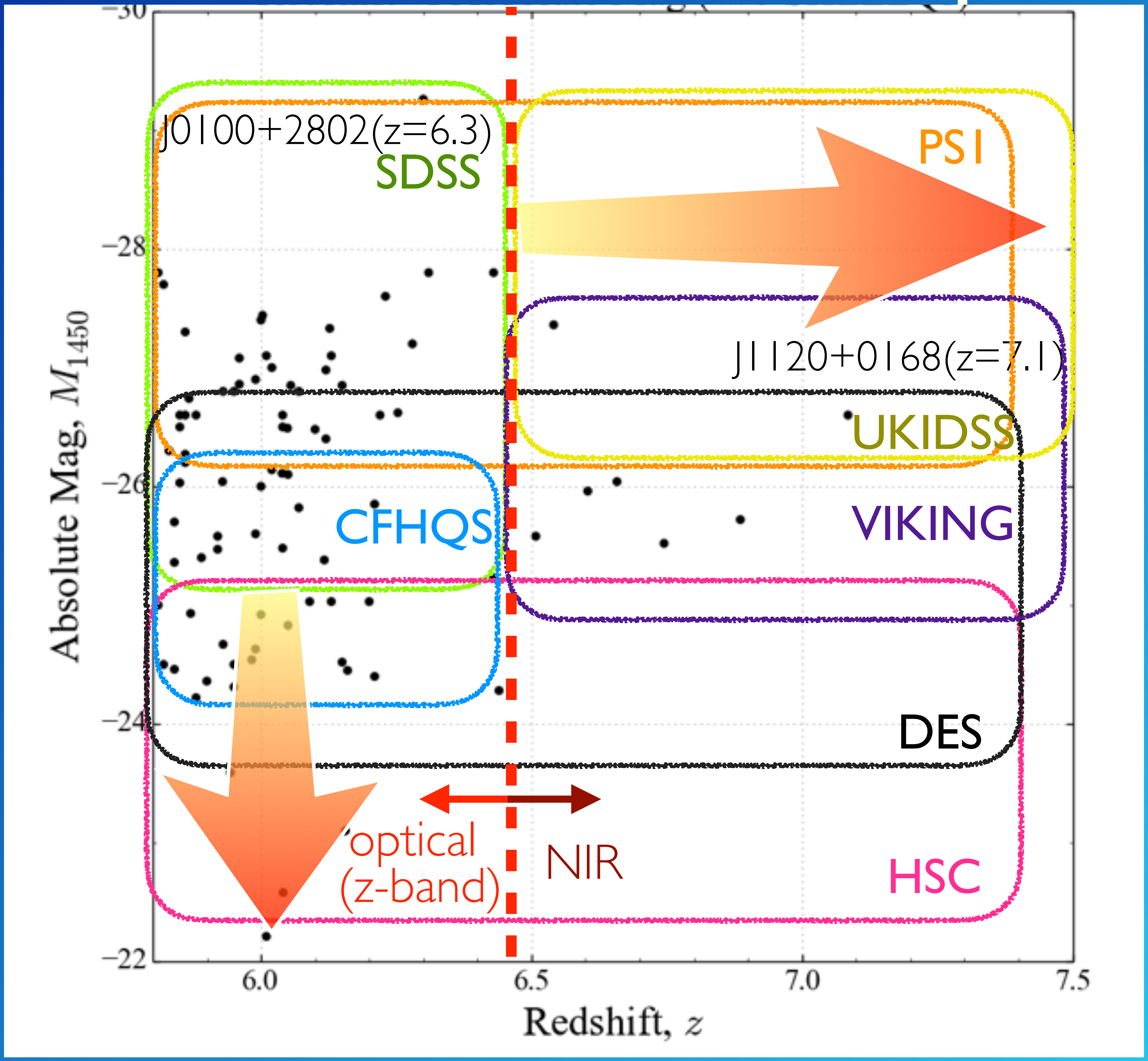

- ✦ Redshift evolution of IGM neutral fraction during EoR
- ✦ Spatially patchy reionization process suggested

# Published 100 z>6 qsos




Past High-z QSO Survey

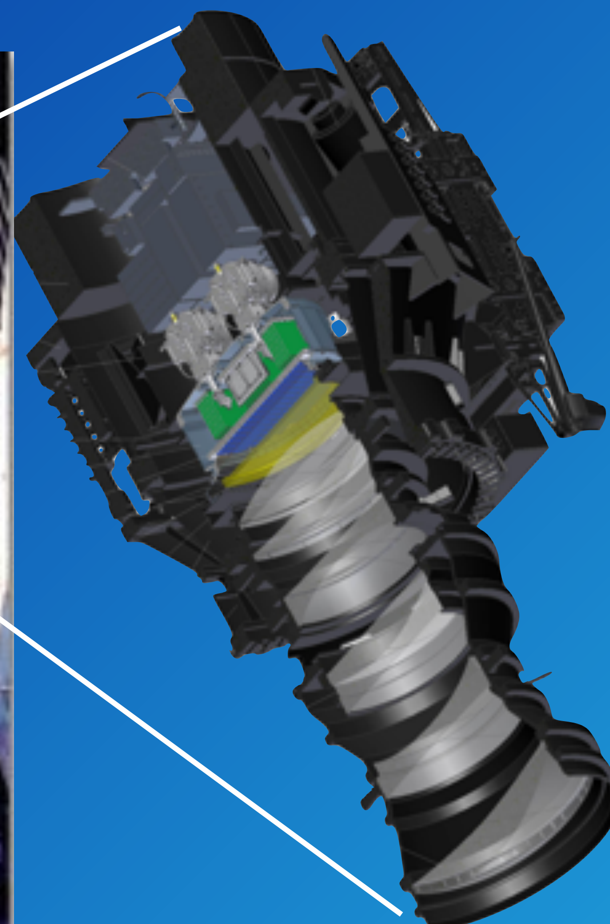
# Published 100 z>6 qsos

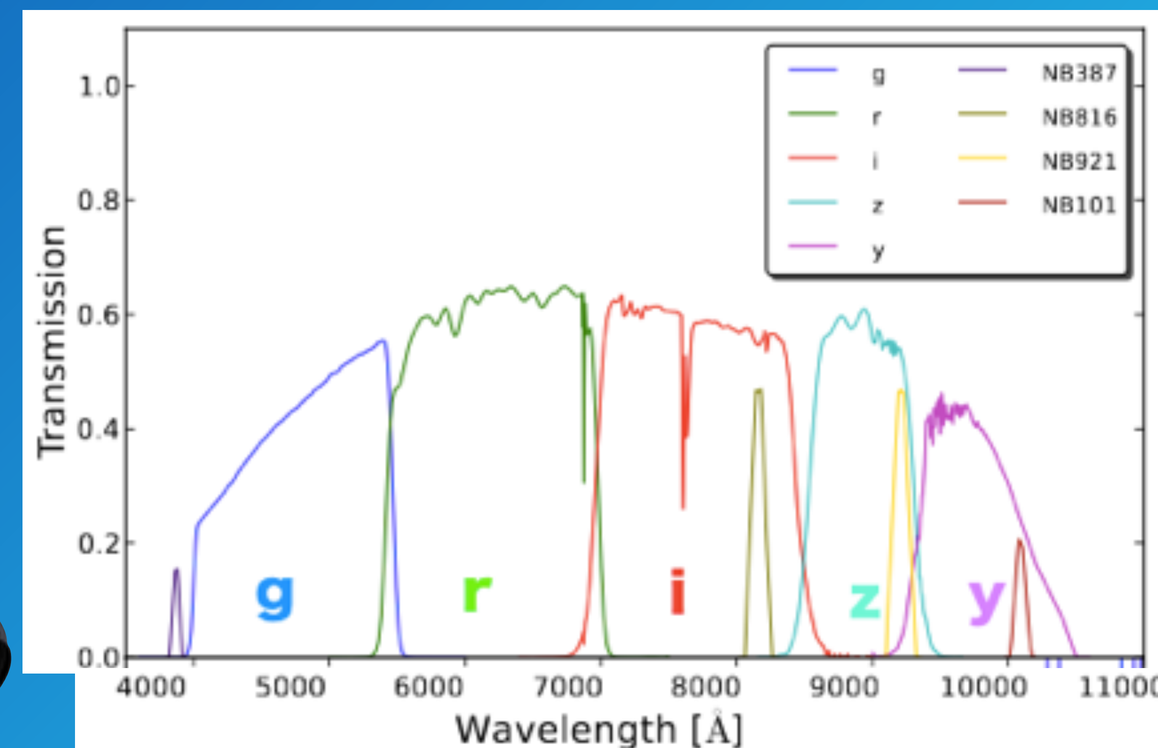



**Now, we should go deeper & higher-z (z>7)**

# Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) Survey

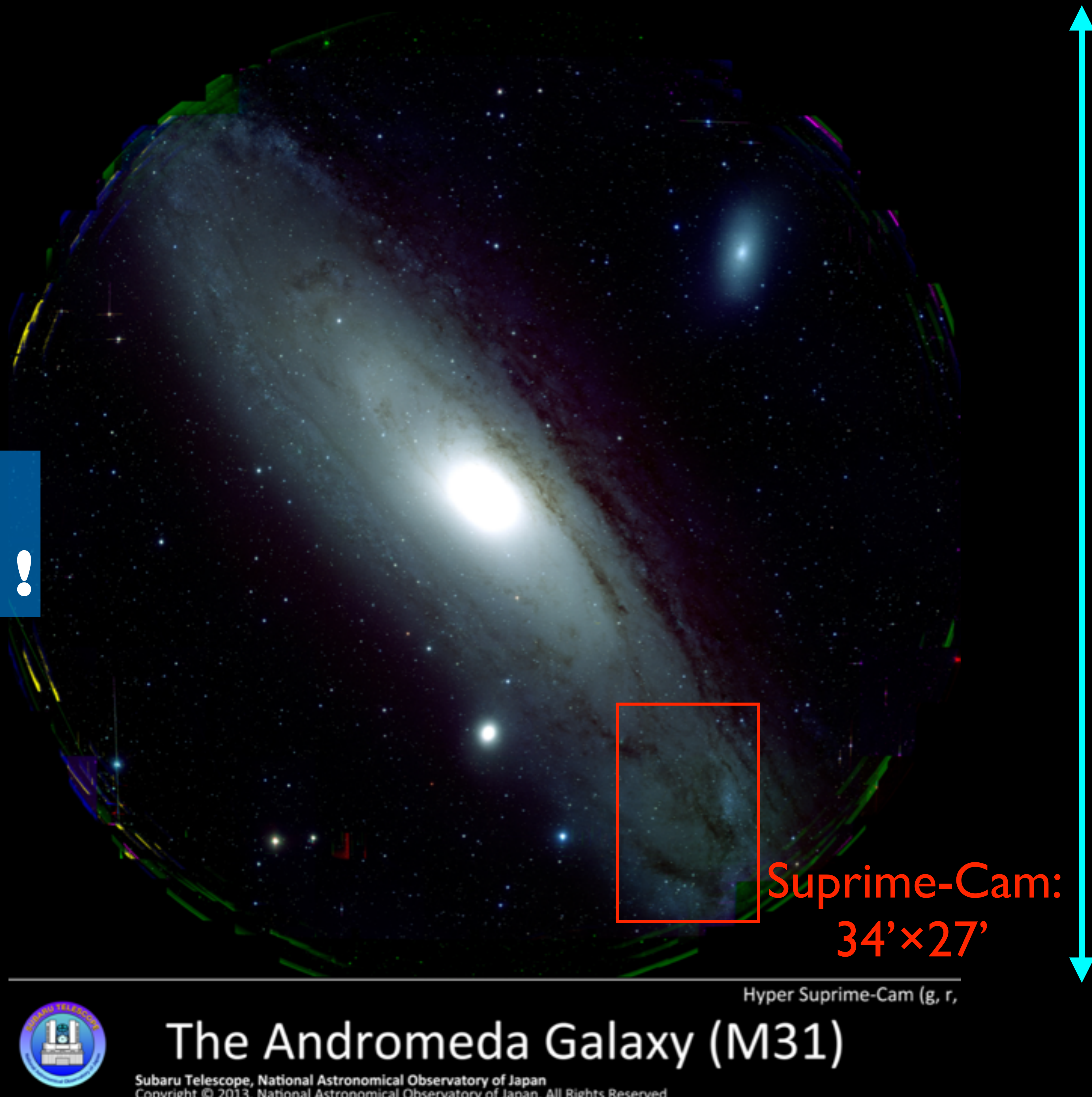
# Hyper Suprime-Cam (HSC)



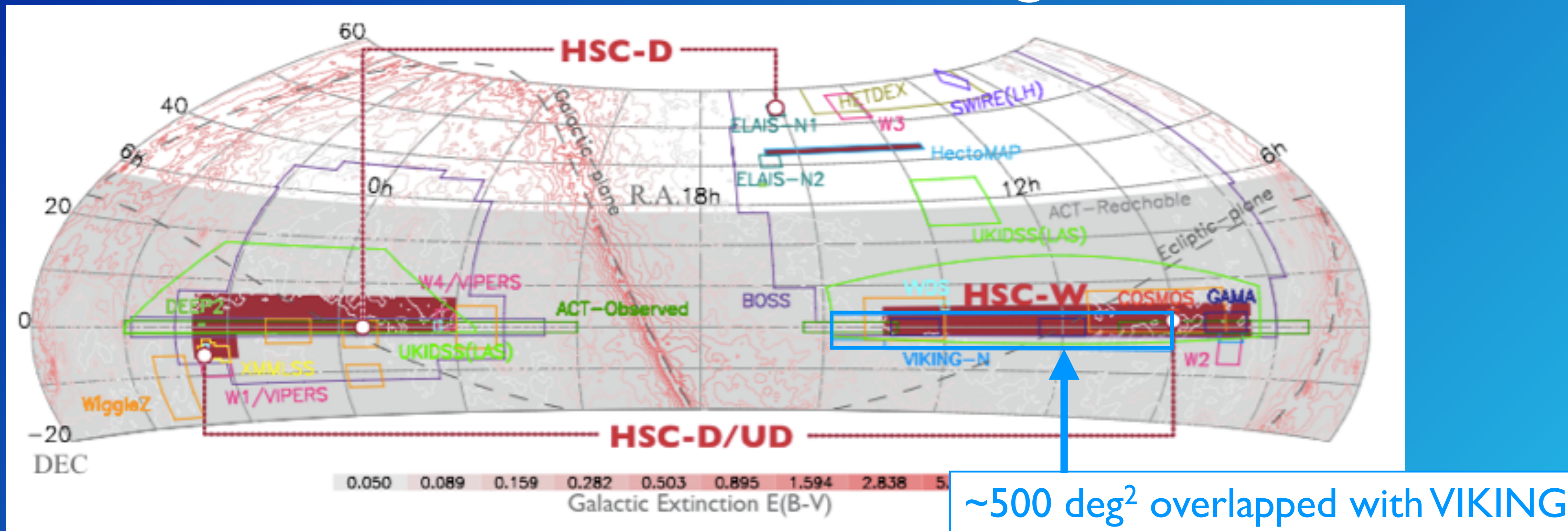


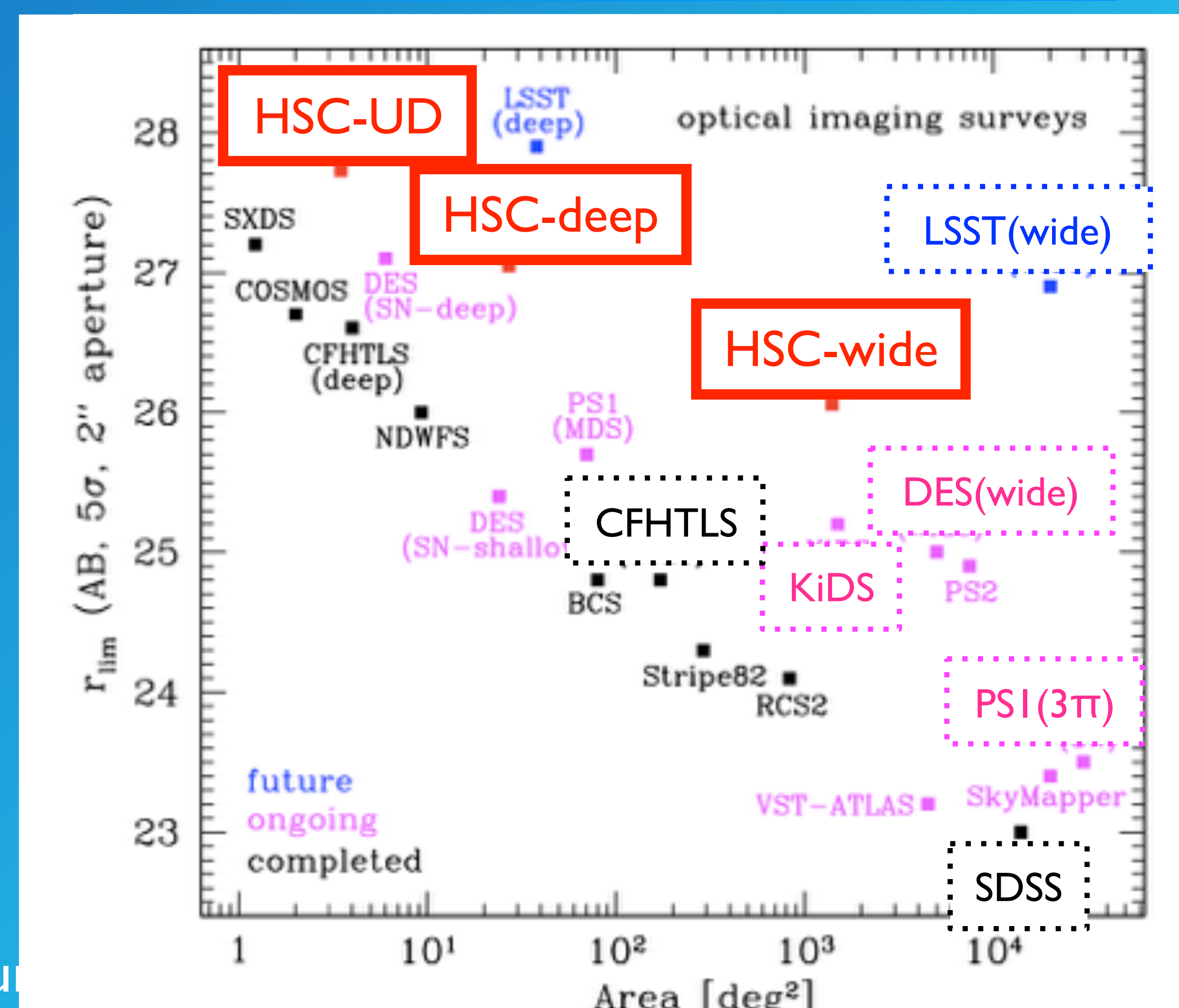

- Mounted on Subaru's prime focus
- Field of view: 1.5 deg diameter
  - ×7 Suprime-Cam !
- sensitive at 1μm (y-band)
  - ➡ essential for z>6 science

# M31 in one shot !



# HSC survey




- Optical multi-band survey with Subaru/HSC (5years, 300nights)
  - Wide: 1400 deg$^2$, $r_{lim,5\sigma}$~26
  - Deep: 27 deg$^2$, $r_{lim,5\sigma}$~27
  - UD: 3.5 deg$^2$, $r_{lim,5\sigma}$~28
- Most powerful optical survey before LSST

# HSC survey

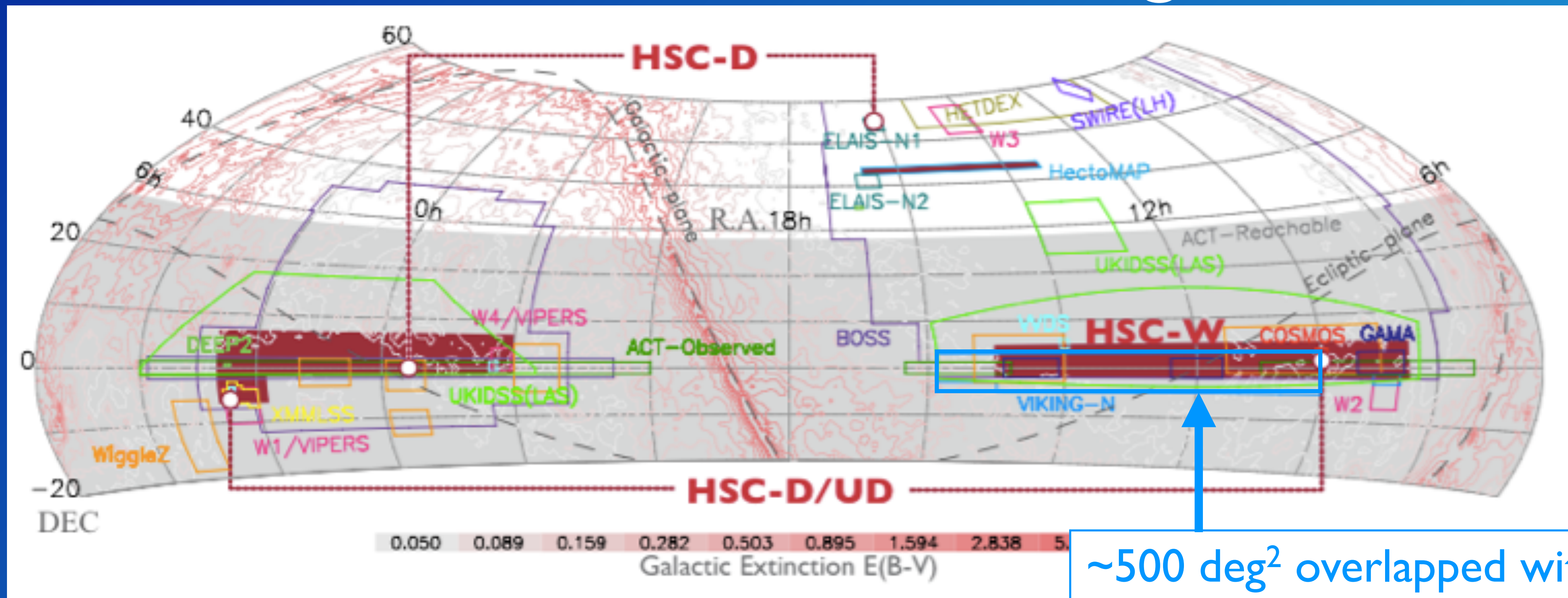



Table 7: Quasar Samples

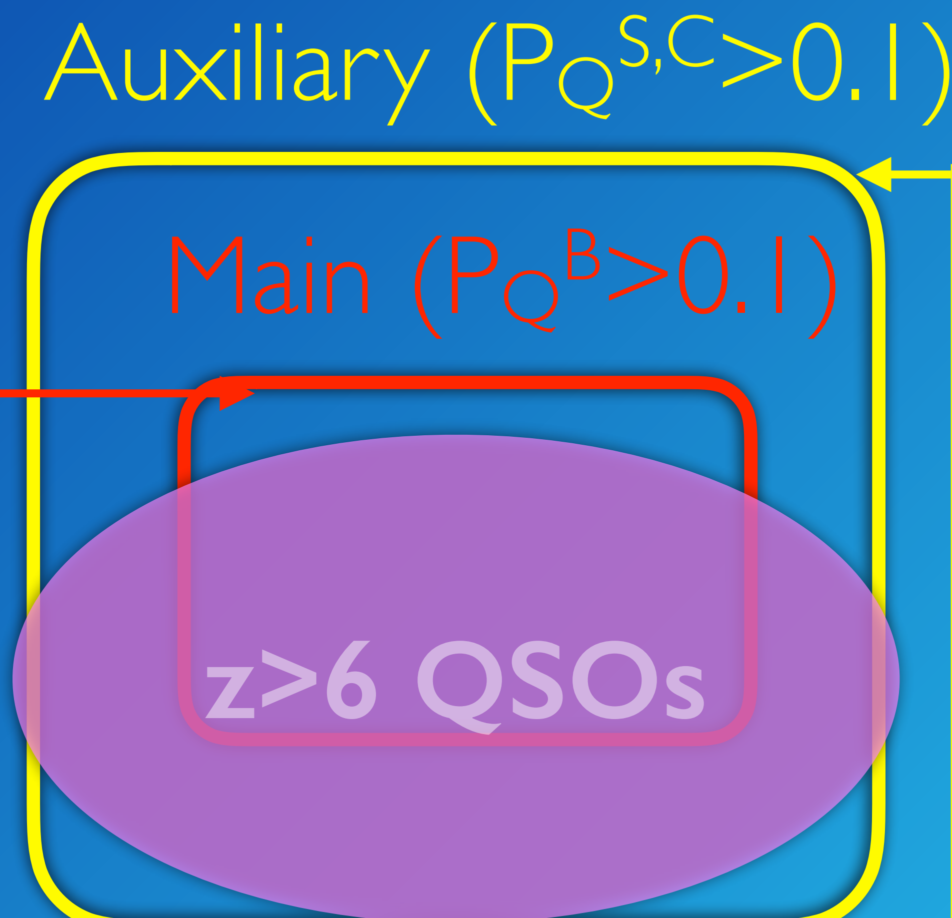
| | Wide (1400 deg$^2$) | | | | Deep (27 deg$^2$) | | | |
|---|---|---|---|---|---|---|---|---|
| redshift | 3.7–4.6 | 4.6–5.7 | 5.9–6.4 | 6.6–7.2 | $< 1$ | 3.7–4.6 | 4.6–5.7 | 6.6–7.2 |
| mag. range | $r < 23.0$ | $i < 24.0$ | $z < 24.0$ | $y < 23.4$ | $i < 25.0$ | $i < 25.0$ | $i < 25.0$ | $y < 25.3$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

- ✦ ~300@z~6 & ~50@z~7 QSOs are expected to be found
- ➡ We can address general SMBH evolutionary states at z>6

# Multi-color Candidate Selection

**1.Bayesian($P_Q^B$)**

- **efficient**
- but less complete
  - Based on Mortlock+12
  - Surface density of quasar/star included as a prior




**2.SED-fitting($P_Q^S$)**

- **complete**
- but less efficient
  - various SED templates
  - covering the bias in Bayesian selection

**3.Two-color($P_Q^C$)**

candidates

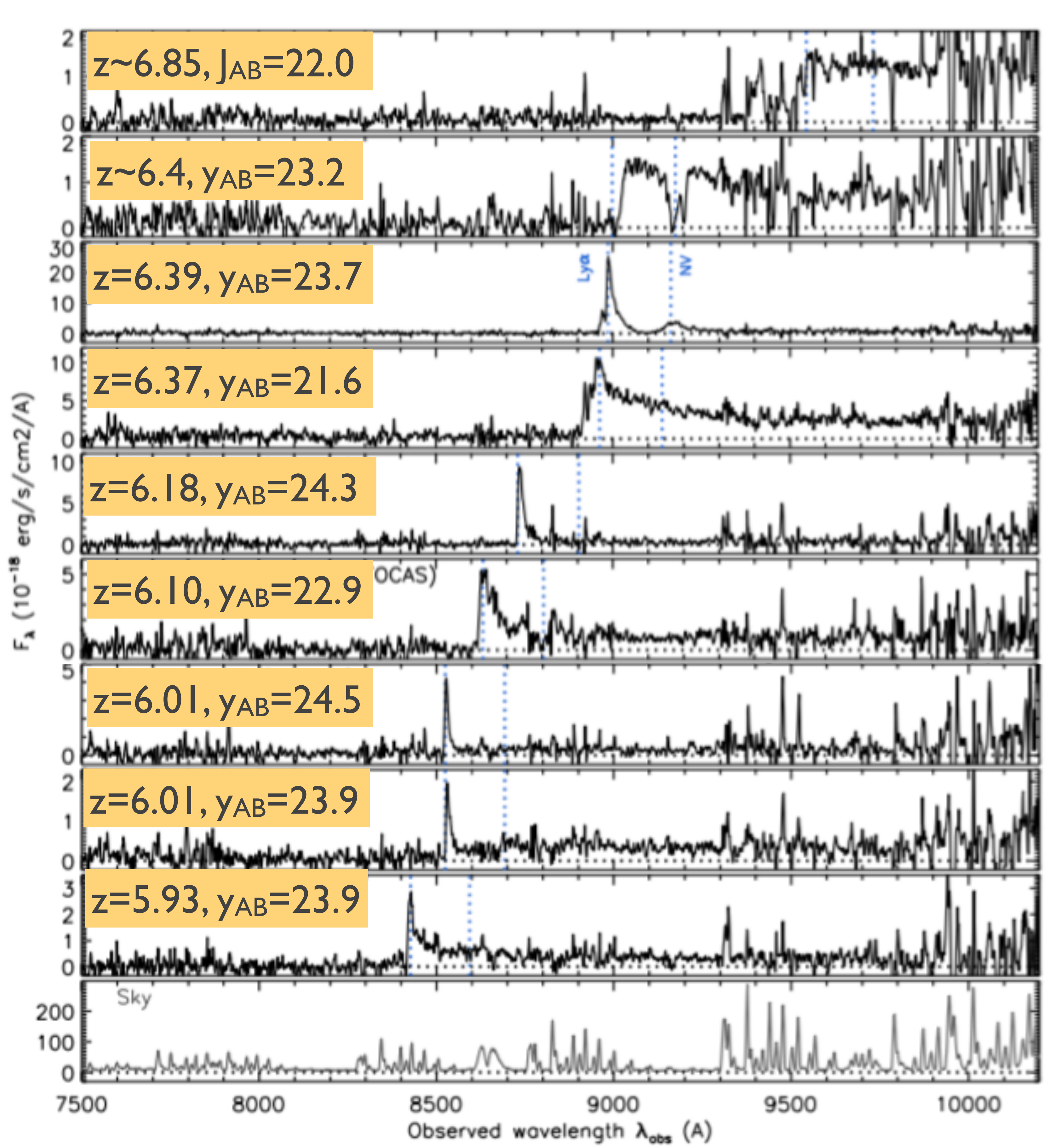
**We apply several probabilistic approaches for our z>6 quasar candidate selection**

# Current Status

- ✦ We have started our unprecedented high-z quasar search with the first internal data release (~80 $deg^2$, $z_{lim,5\sigma}$~25.5)
- ✦ Subaru & GTC have spectroscopically followed-up 19/38 Main candidates so far
  - The faint-end of z~6 QLF will be discussed when the first follow-up is completed (next paper)

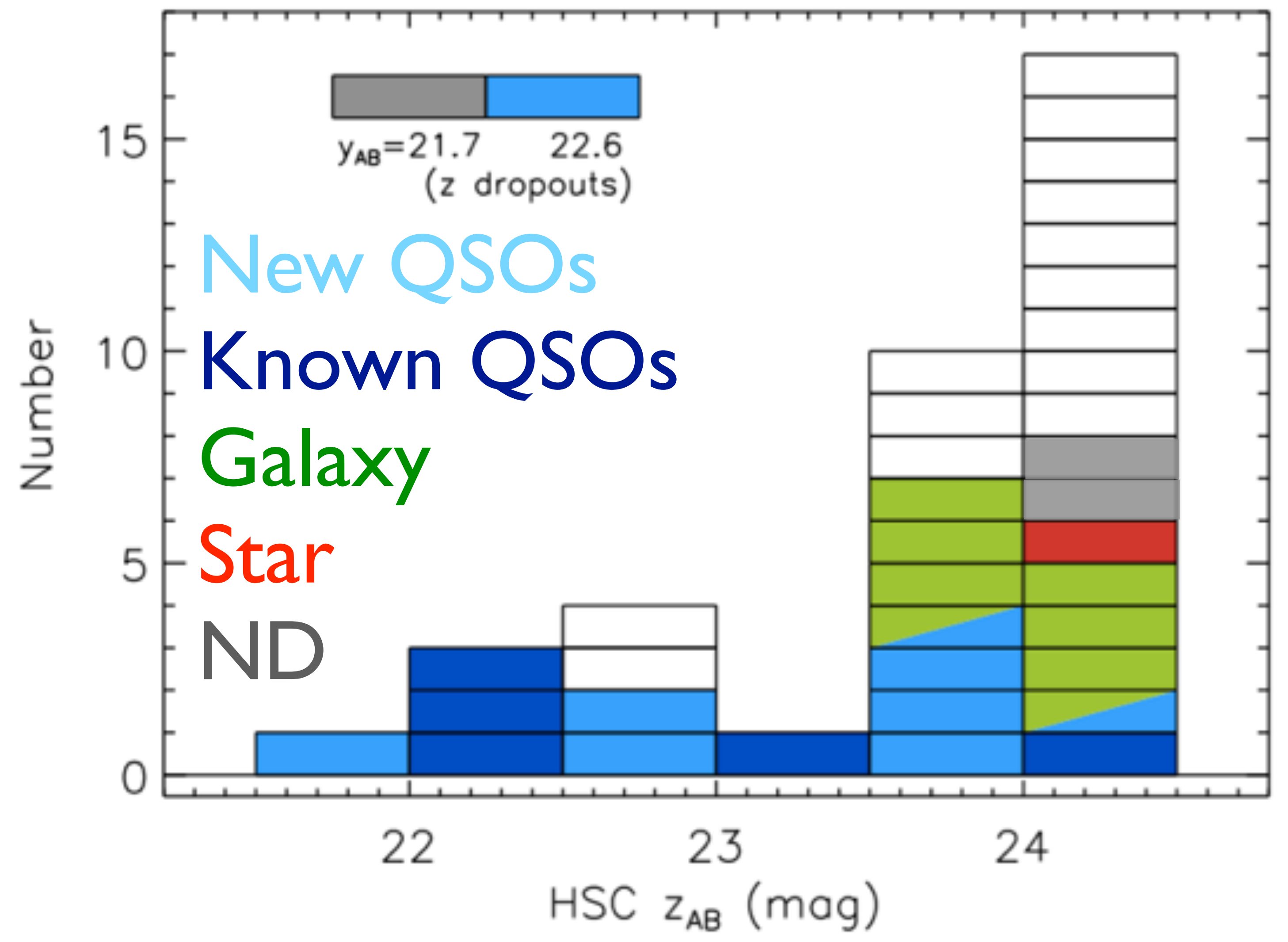
# Initial Result

- ✦ **9 QSOs Discovered**
  - 5.9<z<6.9
  - $M_{1450}$ down to -22
    - ~3 mag deeper than SDSS
  - Their multi-wavelength (opt/NIR/sub-mm) follow-up observation is ready to start
    - BH mass, accretion rate, BLR metallicity, IGM neutral fraction, host galaxy properties, etc…

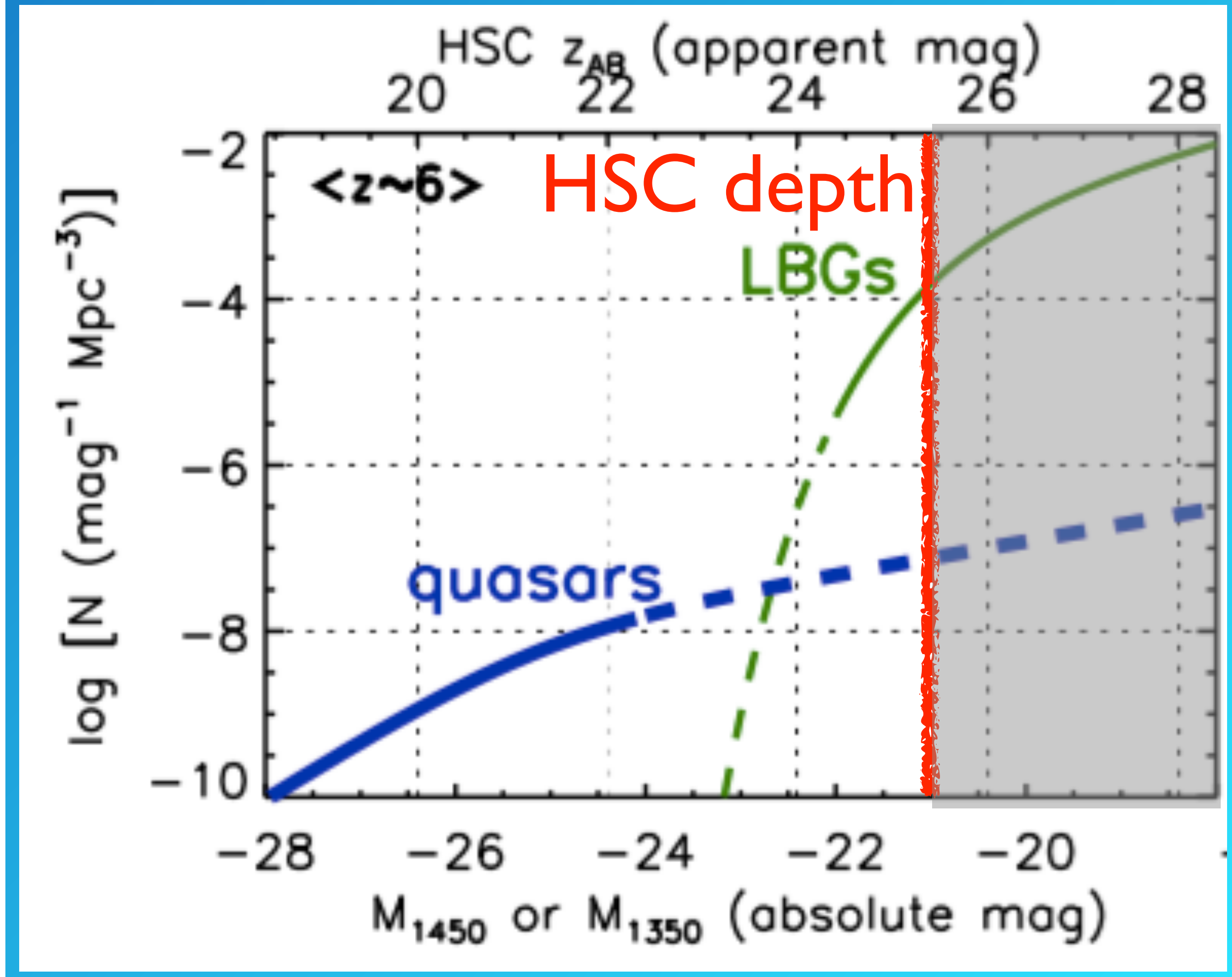


# Success Rate Quite High

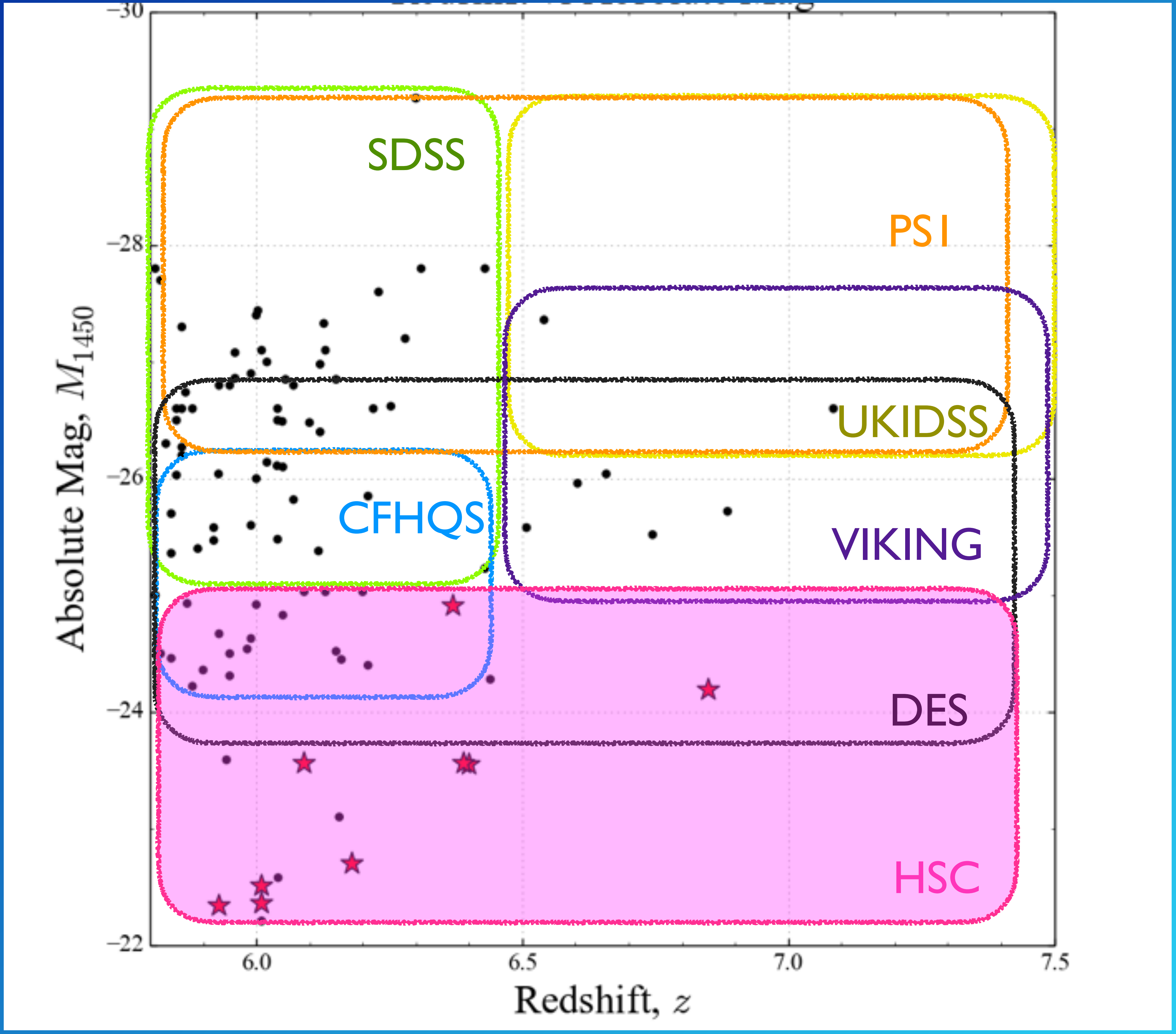
- We have identified **15 (/19)** extra-galactic objects in Main candidates
  - ~100% success rate at $z_{AB}<23.5$
  - All known z~6 QSOs are successfully recovered by our Main selection
  - **6 LBGs** found from faint candidates




z~6 QSO & LBG LF



# Beyond the Tip of the Iceberg

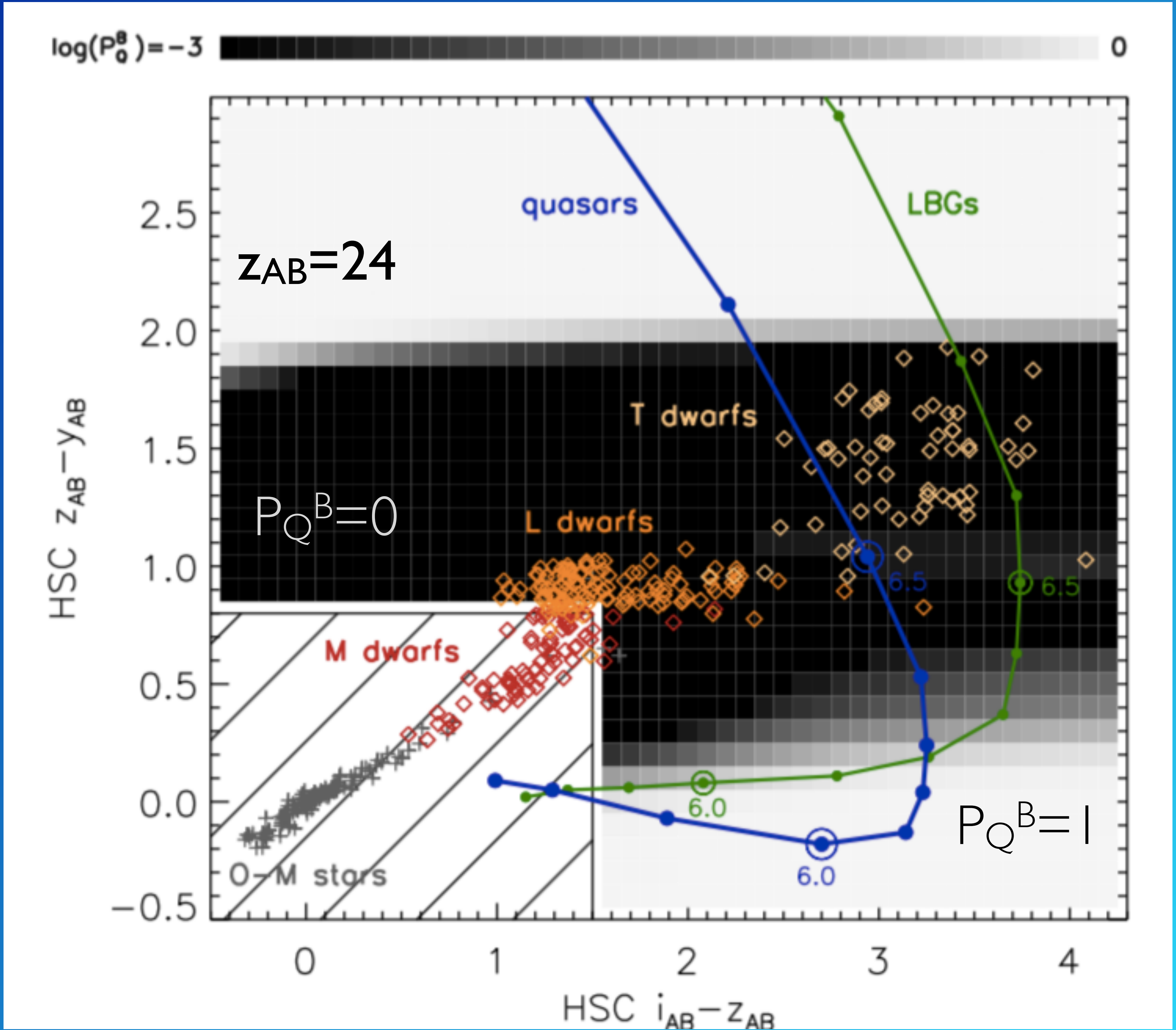


# Summary

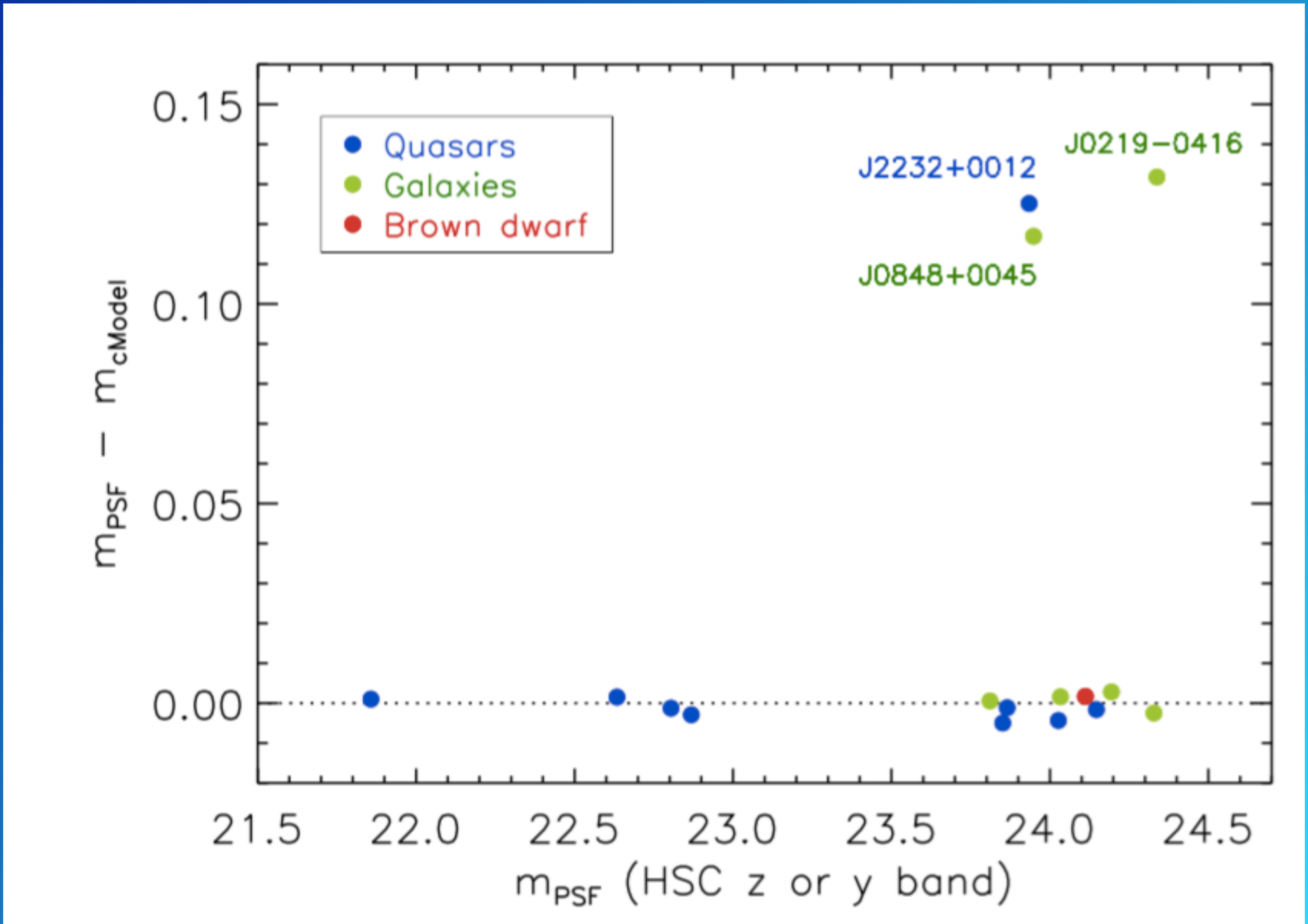
- Faint z>6 quasars contain valuable information on EoR
- HSC-SSP survey is able to reveal this unexplored realm by providing massive numbers of z>6 quasars, powered by more general SMBH population
- 9 z>6 quasars (+6 galaxies) have been discovered through the first follow-up observation. Our probabilistic candidate selection has worked quite successfully.
- Please check further details in Matsuoka et al. (2016)

# Back-up Slides

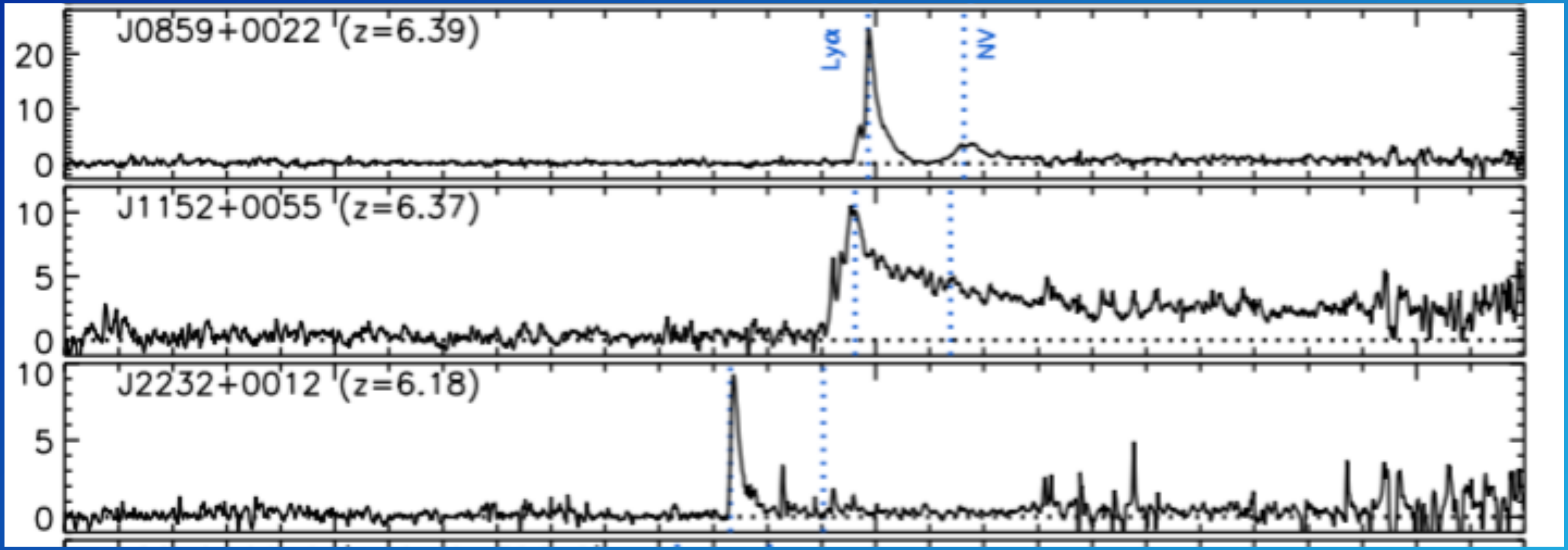
# Two-color diagram (i-z vs z-y)



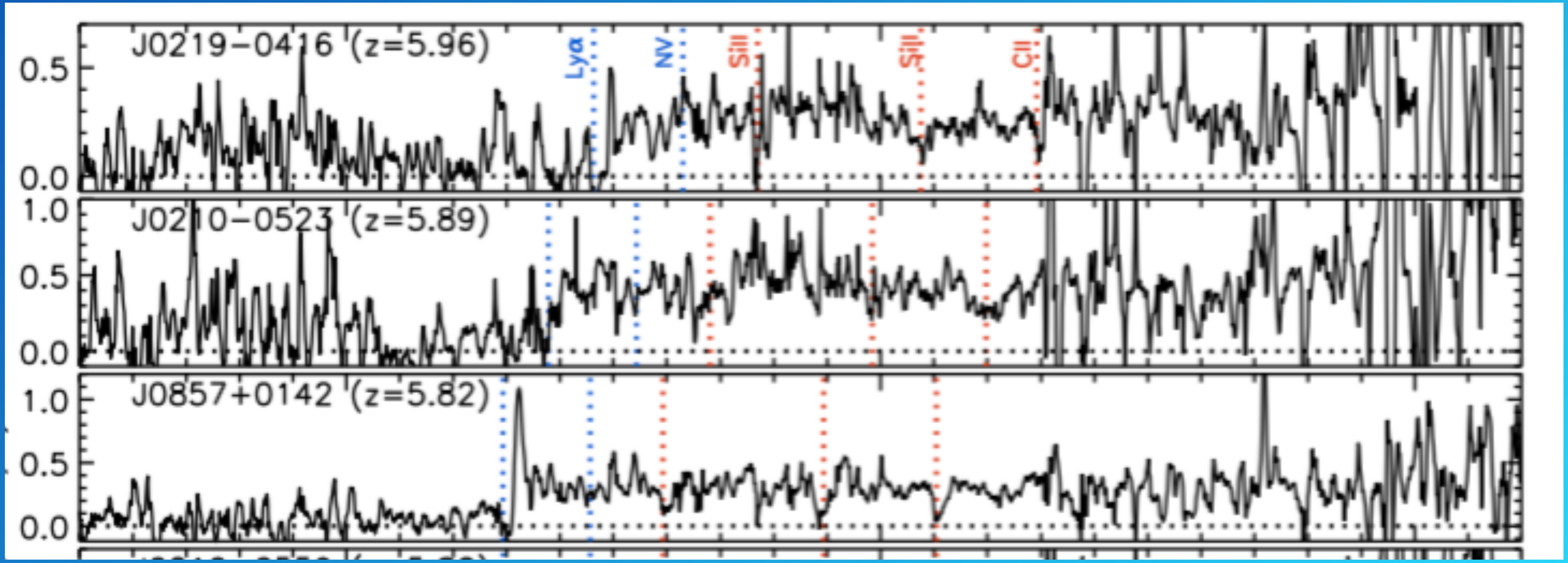
# Stellarity of new z>6 QSO/LBGs



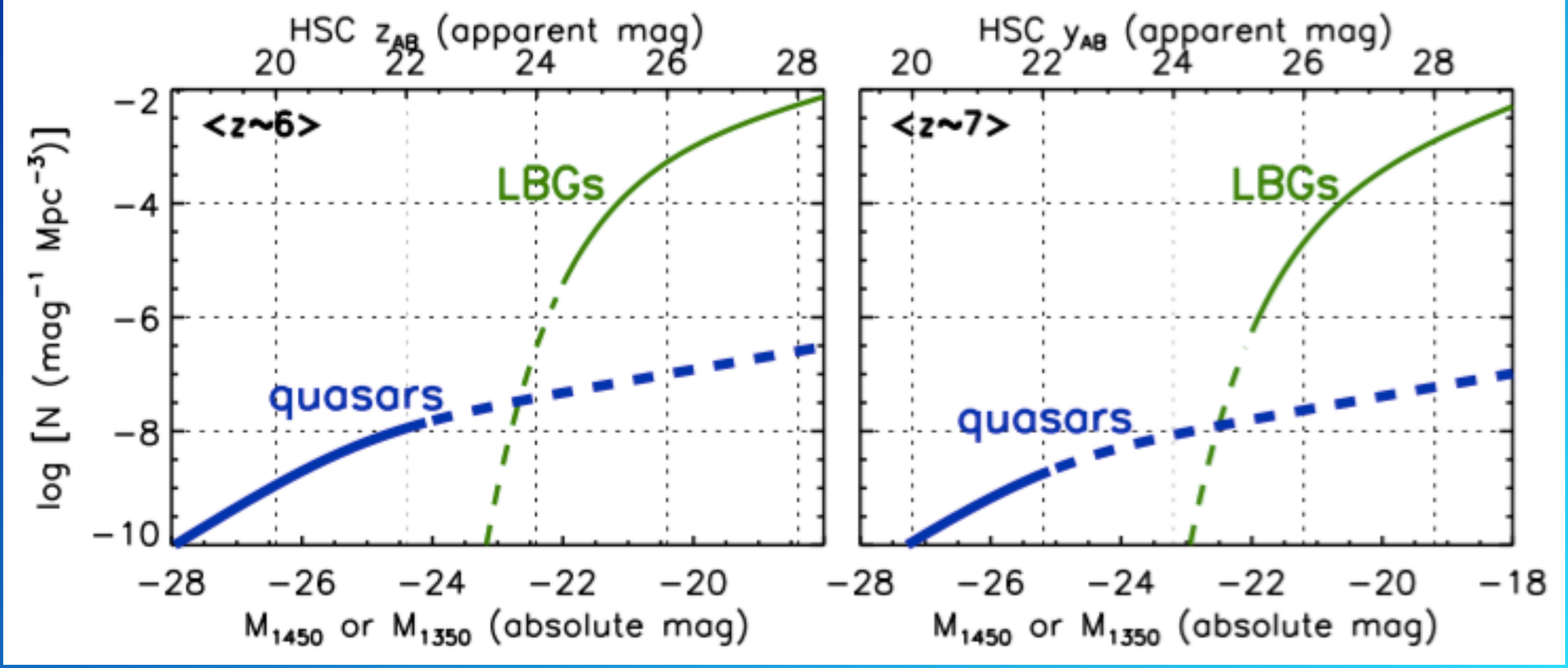
# QSOs




# Galaxies



# QLF vs LBG LF



HSC $z_{AB}$ (apparent mag)
20 22 24 26 28
HSC $y_{AB}$ (apparent mag)
20 22 24 26 28
<z~6>
<z~7>
LBGs
LBGs
quasars
quasars
log [N (mag$^{-1}$ Mpc$^{-3}$)]
−2 −4 −6 −8 −10
−28 −26 −24 −22 −20
−28 −26 −24 −22 −20 −18
$M_{1450}$ or $M_{1350}$ (absolute mag)
$M_{1450}$ or $M_{1350}$ (absolute mag)