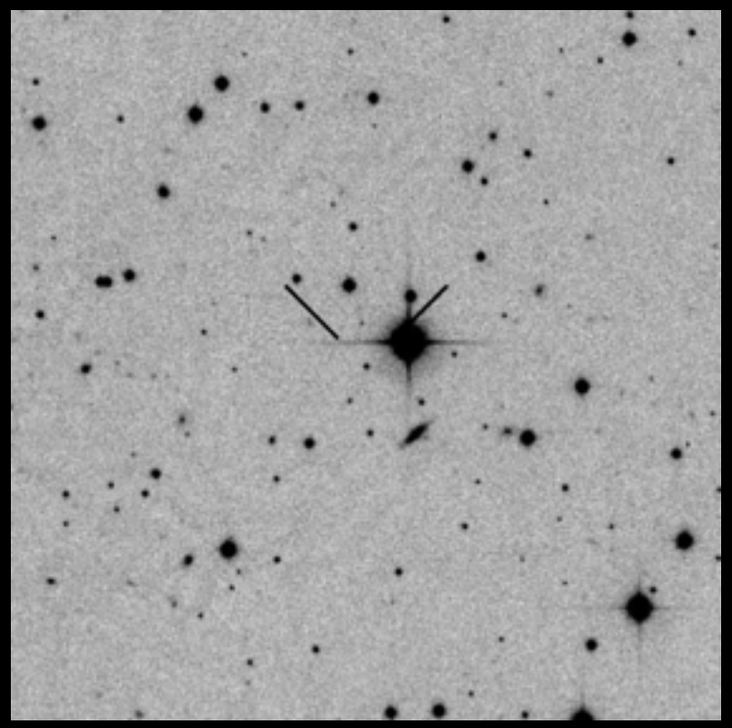


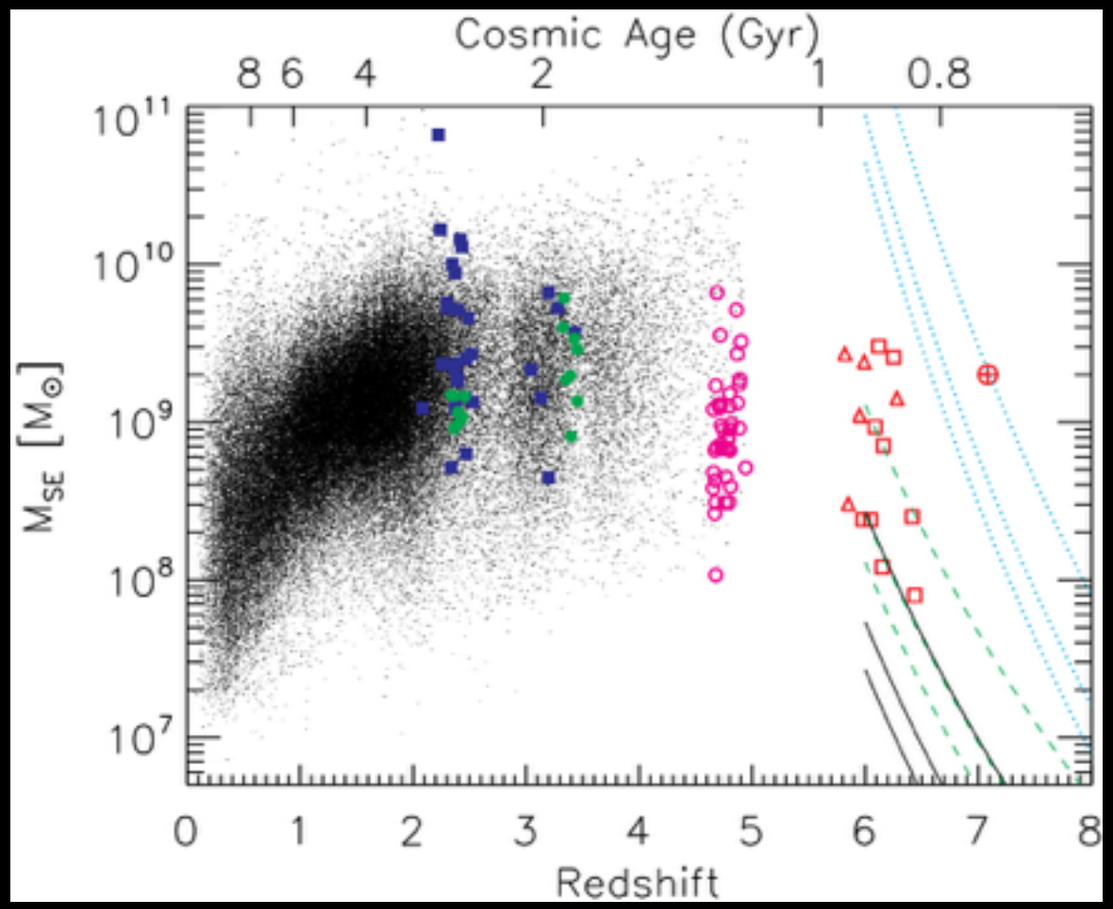
宇宙最遠クエーサーの探索

松岡 良樹（国立天文台）

Why do we care?

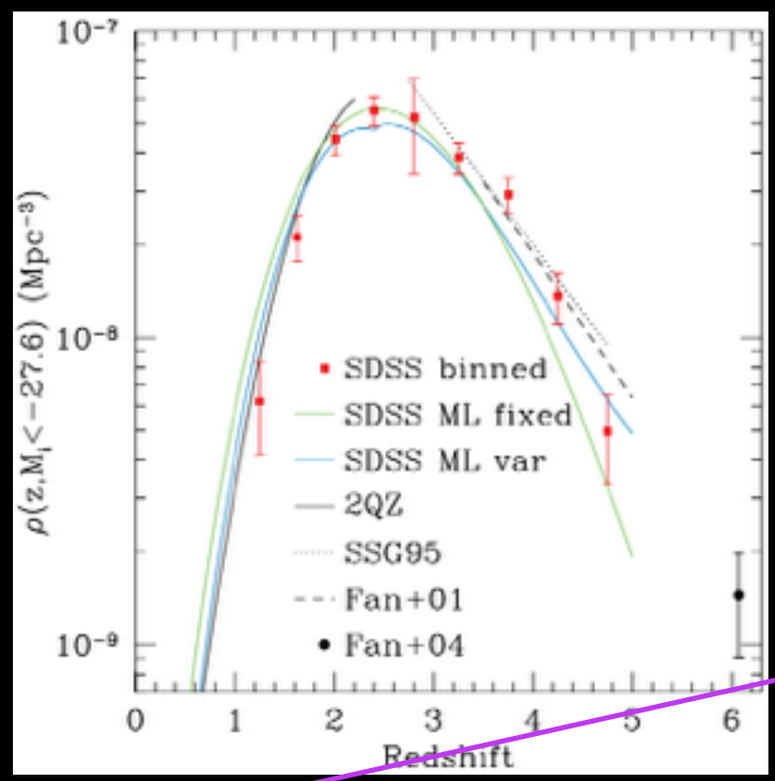
→ 1. Formation and evolution of SMBHs

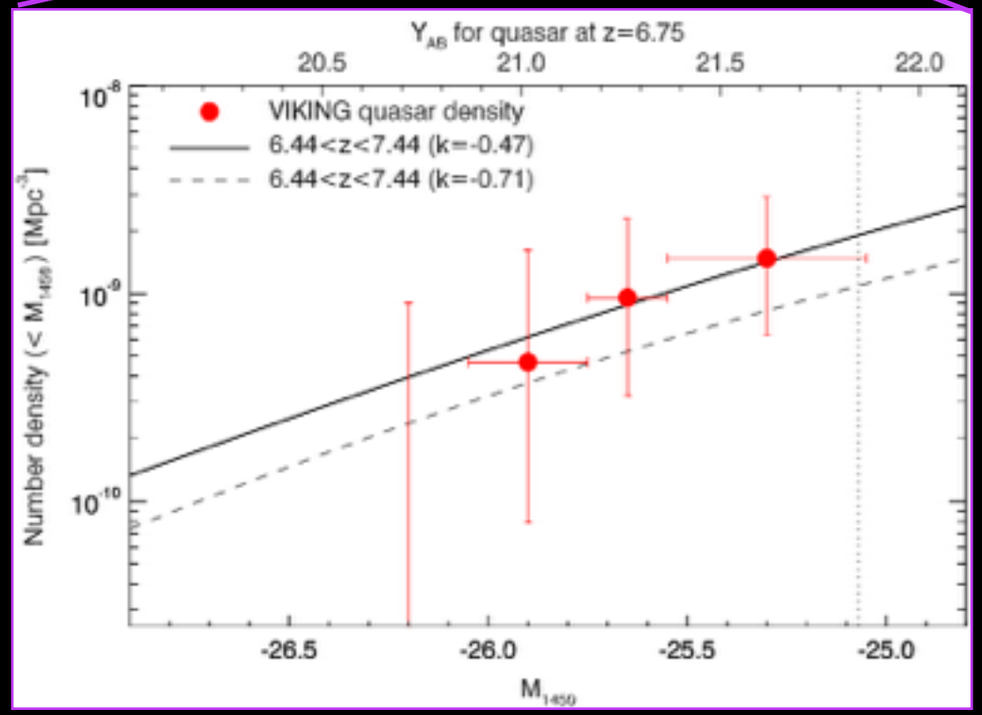
$M(t) = M_0\, e^{[\lambda(1-\varepsilon)/\varepsilon](t/0.45\ \mathrm{Gyr})}$



Shen11

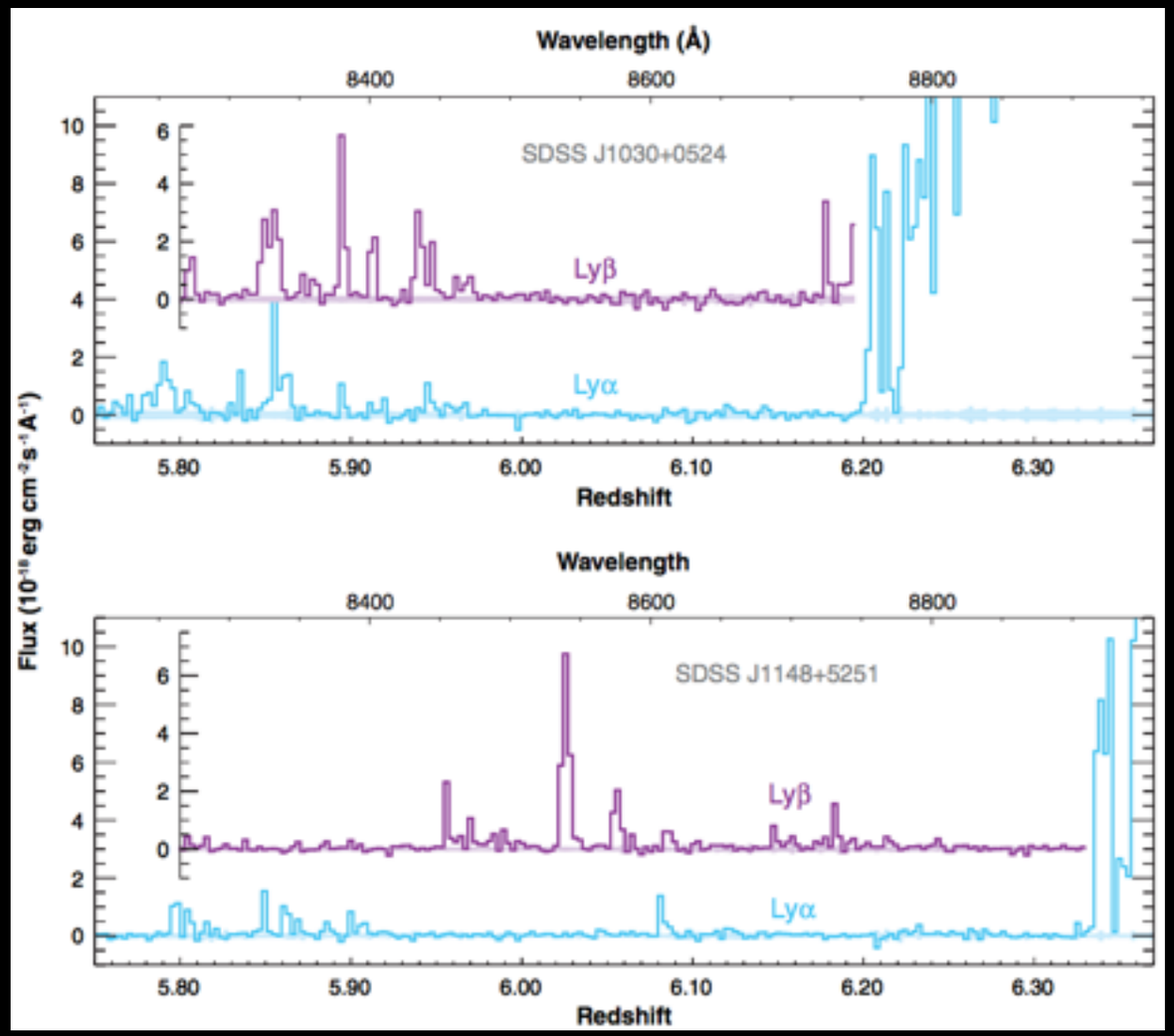
Richards+06



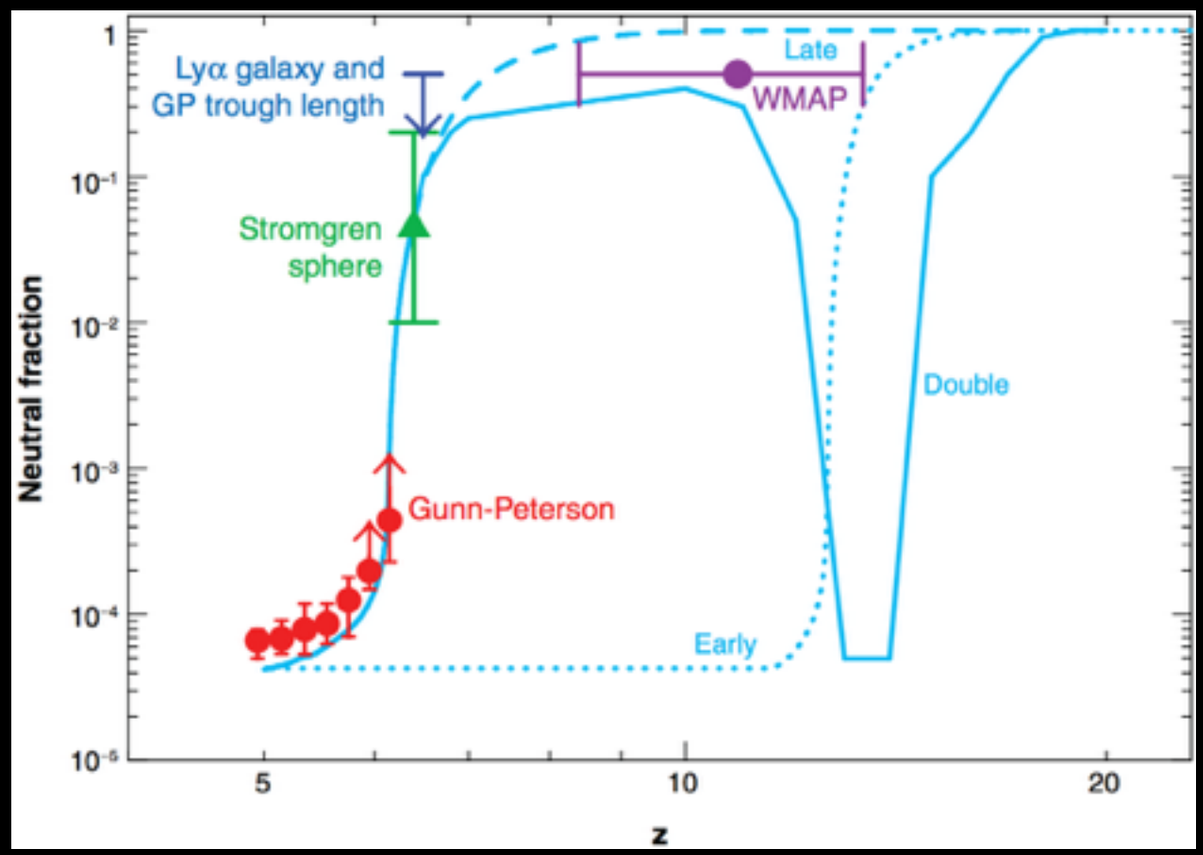


Venemans+13

Why do we care?
→ 2. Evolution of IGM; Re-ionization

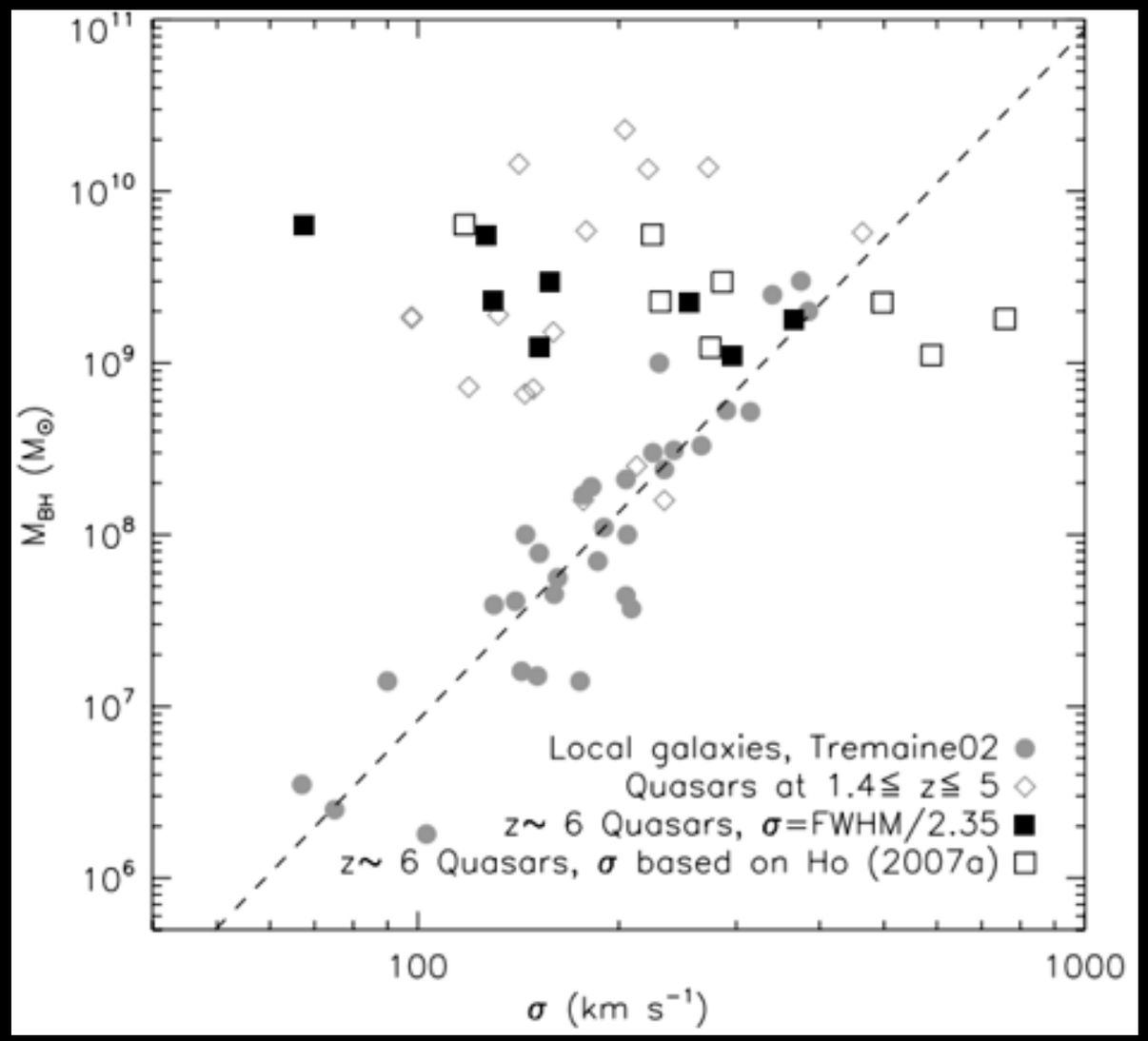


Fan+06



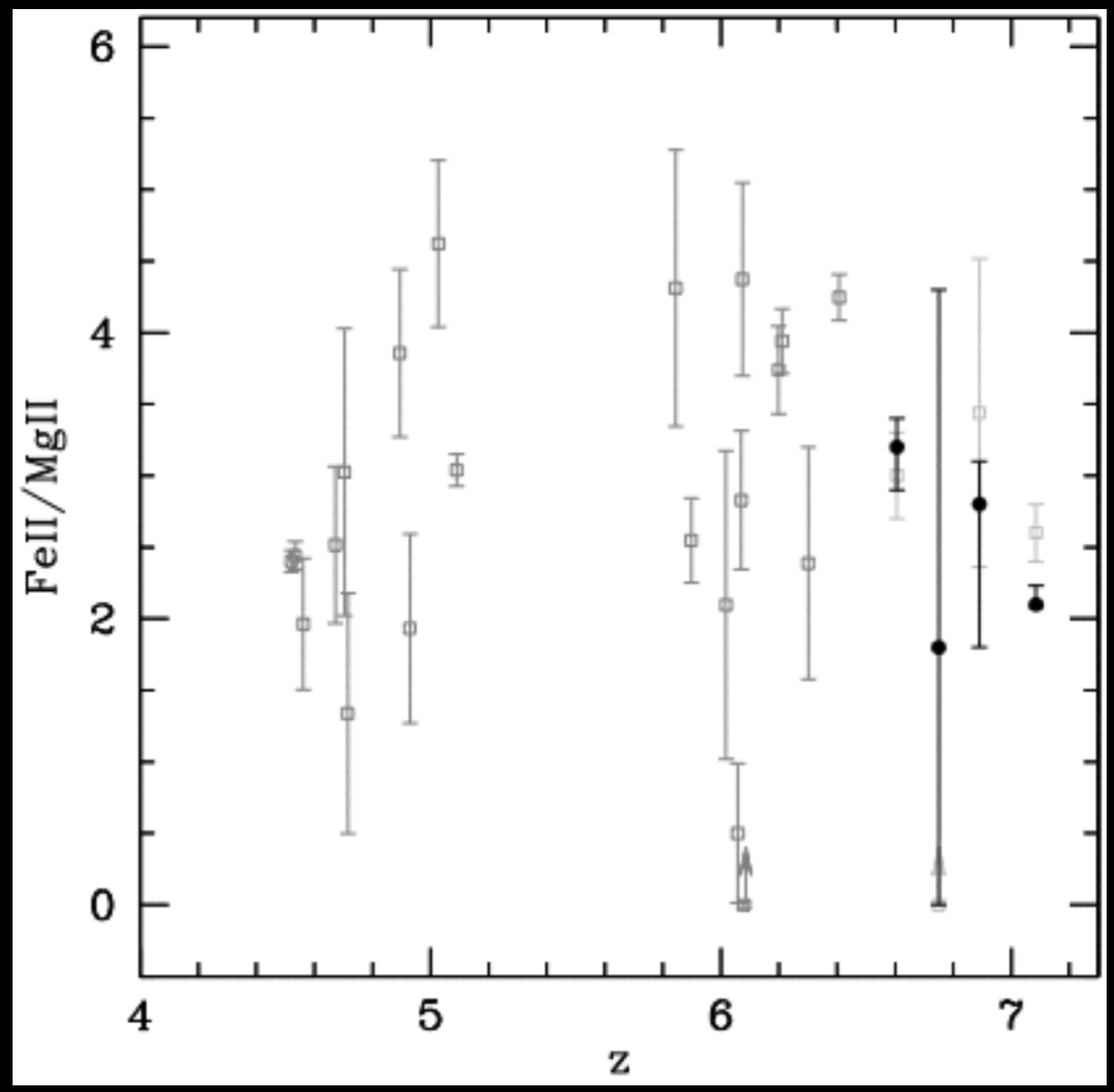
Why do we care?
→ 3. Evolution of host galaxies

SMBH - bulge relation



Wang+10

Chemical evolution

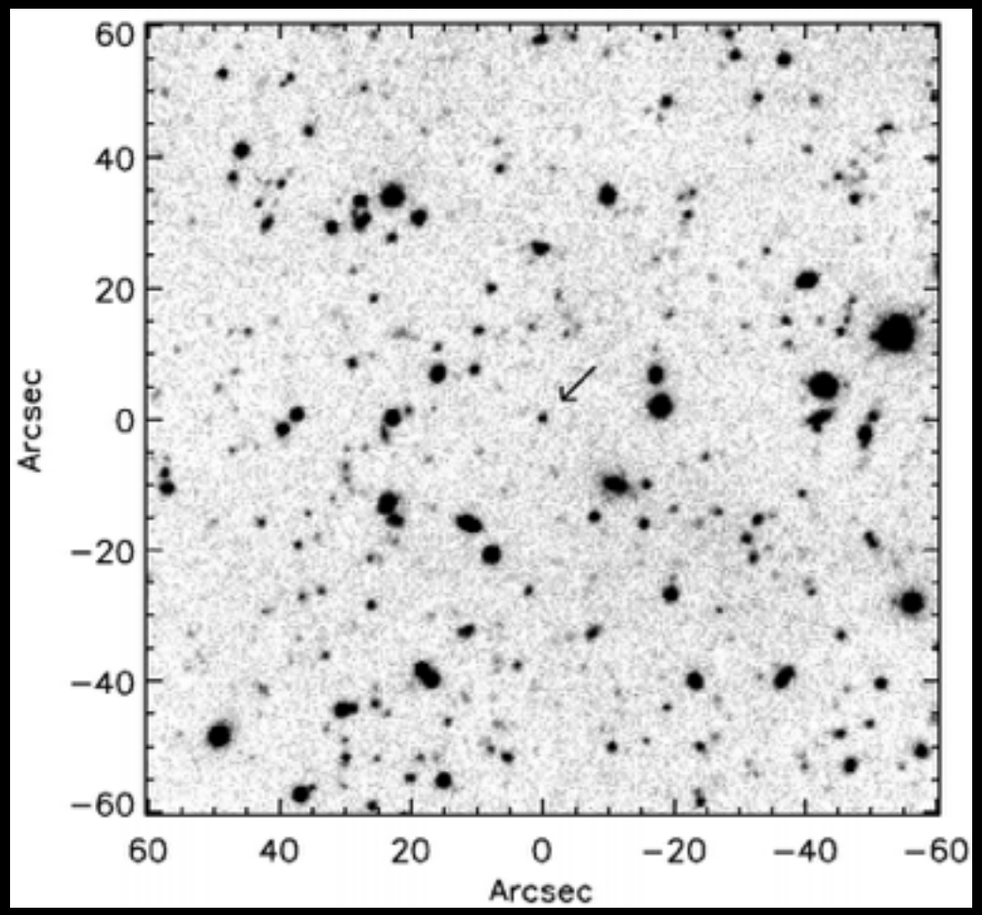


De Rosa+14

First identification of a high-z (z ≳ 6) quasar

RD J030117+1002025 (Stern et al. 2000)

z = 5.5, M_B = −22.7 mag

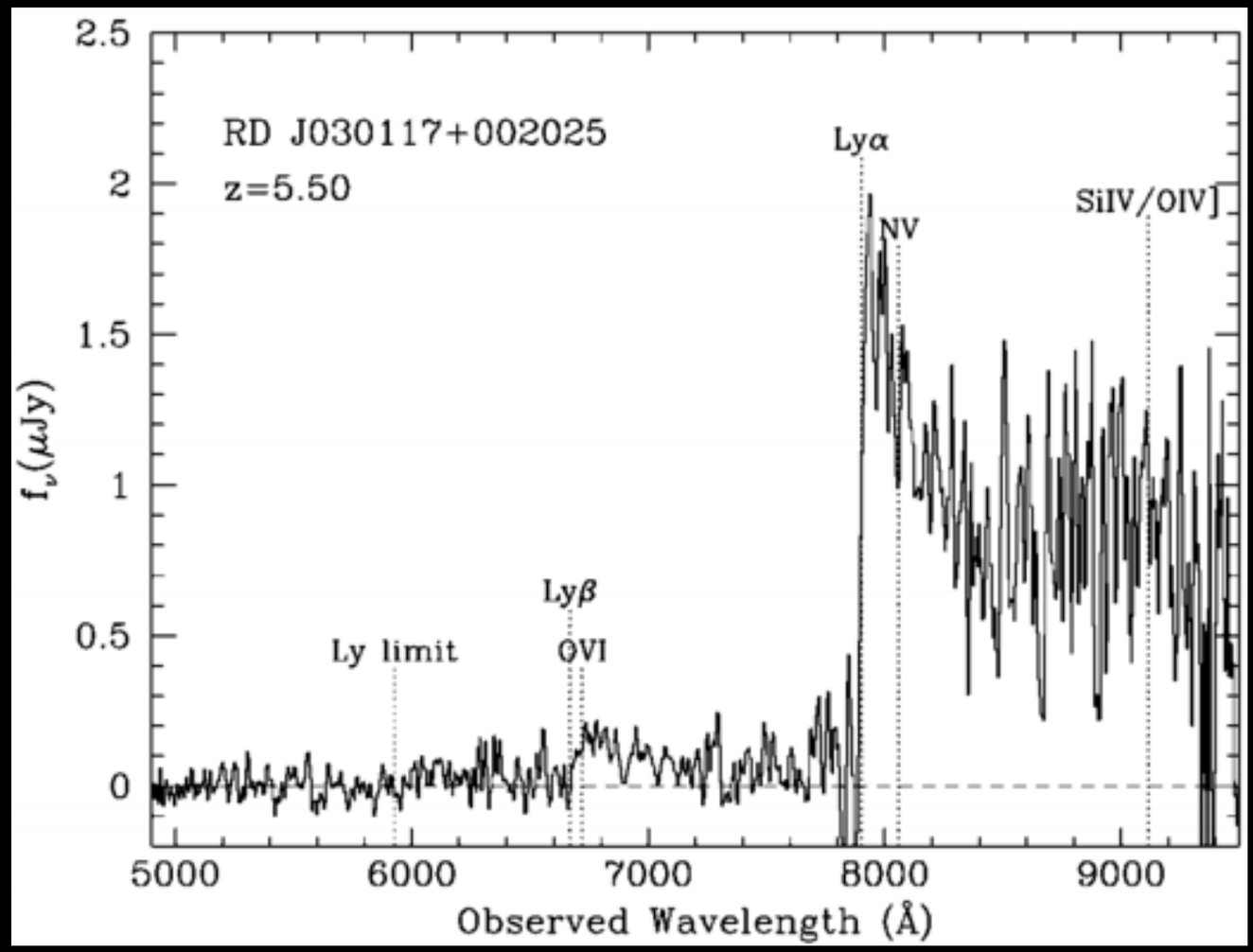


Candidate selection: red R - I and flat I - z colors.
"No morphological criteria were implemented since the primary goal of this program is to study normal, star-forming galaxies at high redshift."
→ six good candidates.

Survey area: 74 arcmin^2

Depth: R < 26.3 mag (Hale 5m, 4.4 hrs)
I < 25.7 mag (KPNO 4m, 2 hrs)
z < 24.8 mag (KPNO 4m, 3.3 hrs)

Spectroscopy: LRIS/Keck, 4.5 hrs



Era of systematic searches

Sloan Digital Sky Survey

✶ 2.5 m telescope
✶ optical (u, g, r, i, z) bands
✶ z < 20.5 mag
✶ 8,000 deg^2

High-z quasars
✶ 30 objects
(Fan+00,01,03,04,06; Jiang+08,09)
✶ 5.7 < z < 6.4
✶ $-27.9 < M_{1450} < -24.4$
✶ Completed.

Canada-France High-z Quasar Survey

✶ CFHT 3.6 m
✶ optical (u, g, r, i, z) bands
✶ z ≲ 22 mag
✶ ~600 deg^2

High-z quasars
✶ 19 objects
(Willott+07,09,10)

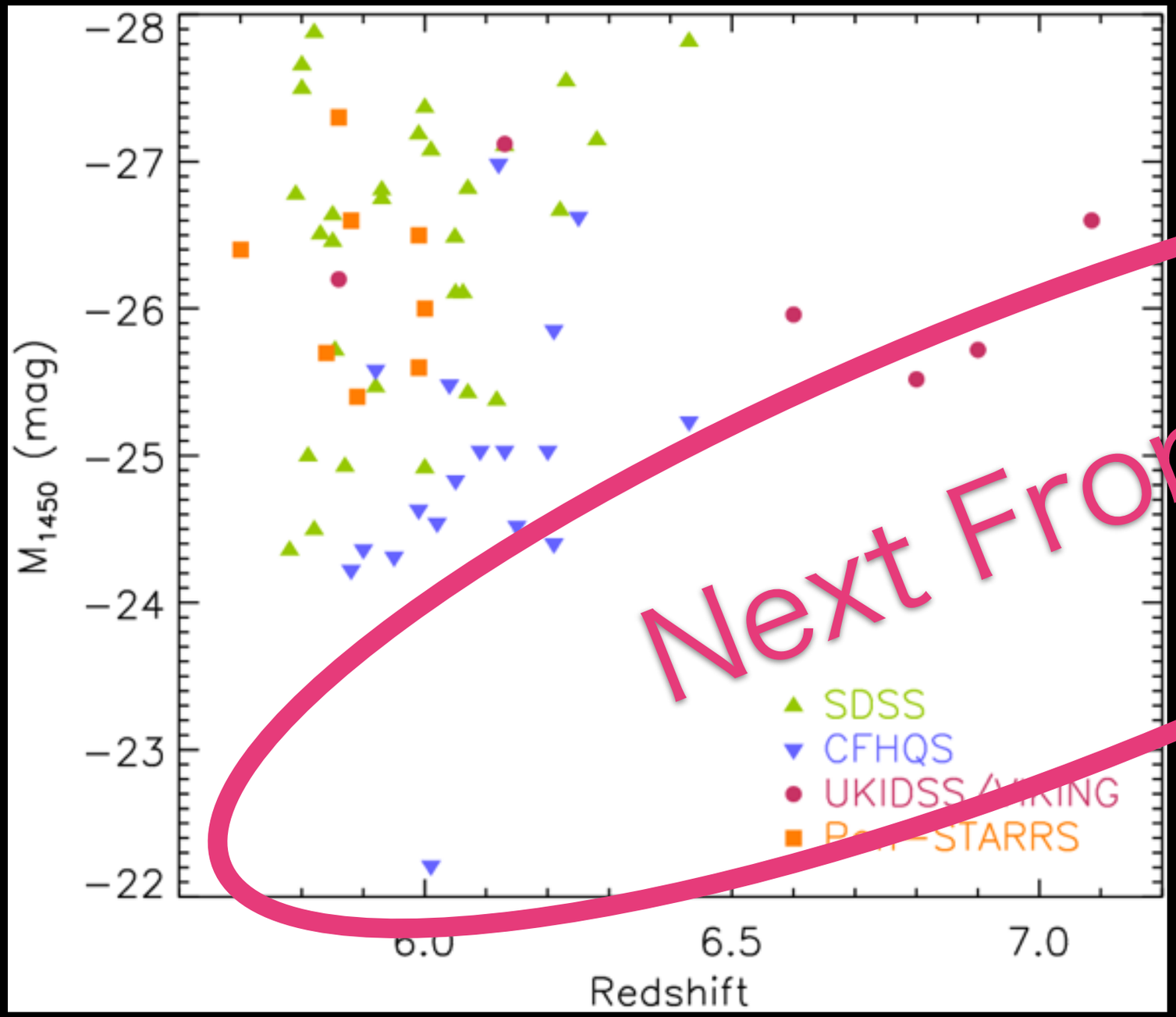
✶ 5.9 < z < 6.4
✶ $-27.0 < M_{1450} < -22.2$
✶ (nearly) Completed.

UKIDSS/VIKING surveys

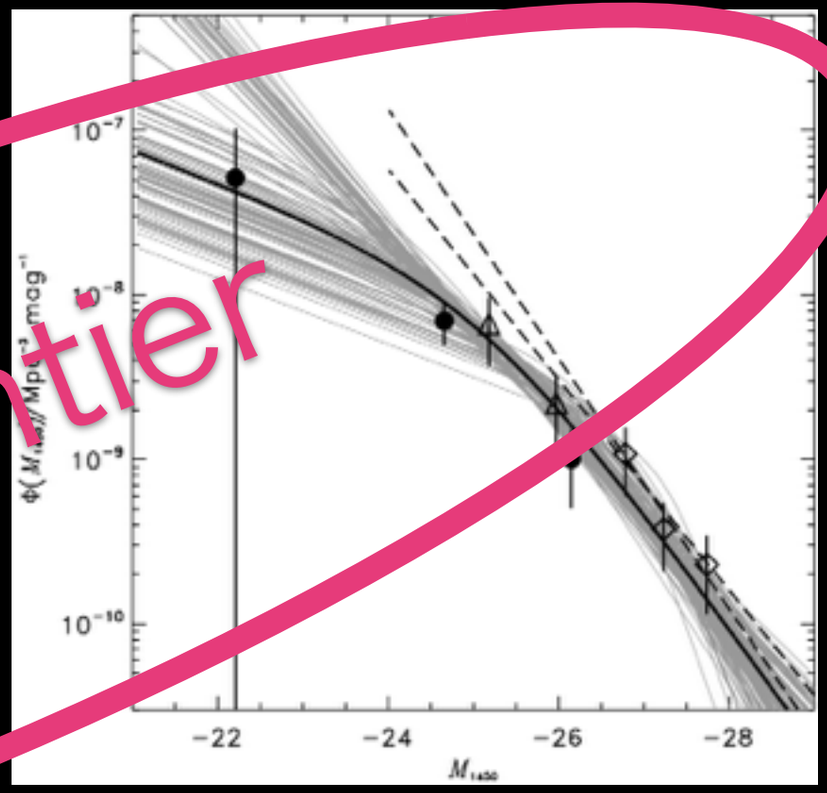
✶ 4-m telescopes
✶ NIR (Z, Y, J, H, K) bands
✶ Y < 22.3 mag
✶ 1,500 deg^2

High-z quasars
✶ 6 objects
(Venemans+07,13; Mortlock+09,11)
✶ 5.9 < z < 7.1
✶ $-27.1 < M_{1450} < -25.5$
✶ 10-20 more objects expected at z ~ 7.

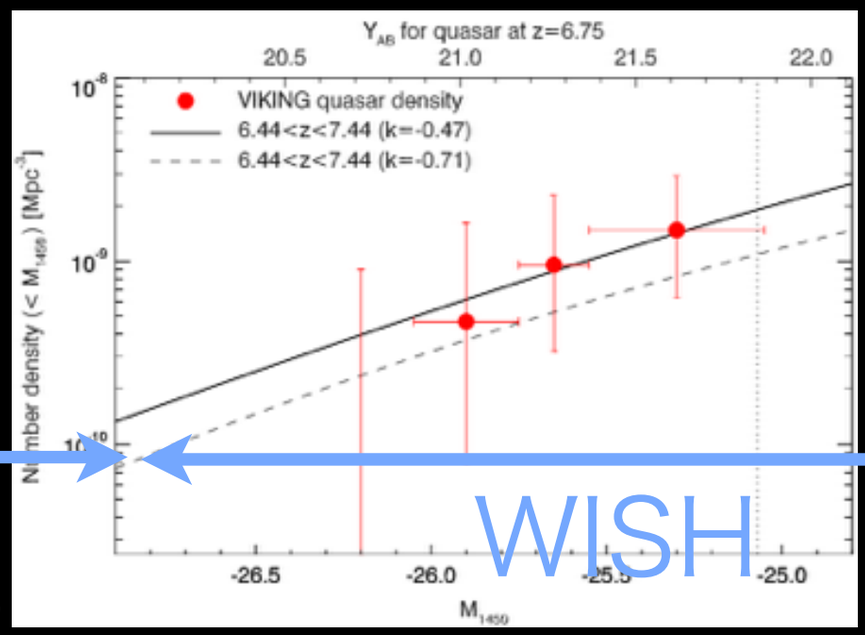
Era of systematic searches



Willott+10



Next Frontier



HSC

WISH

Venemans+13

HSC-SSP High-z Quasar Survey

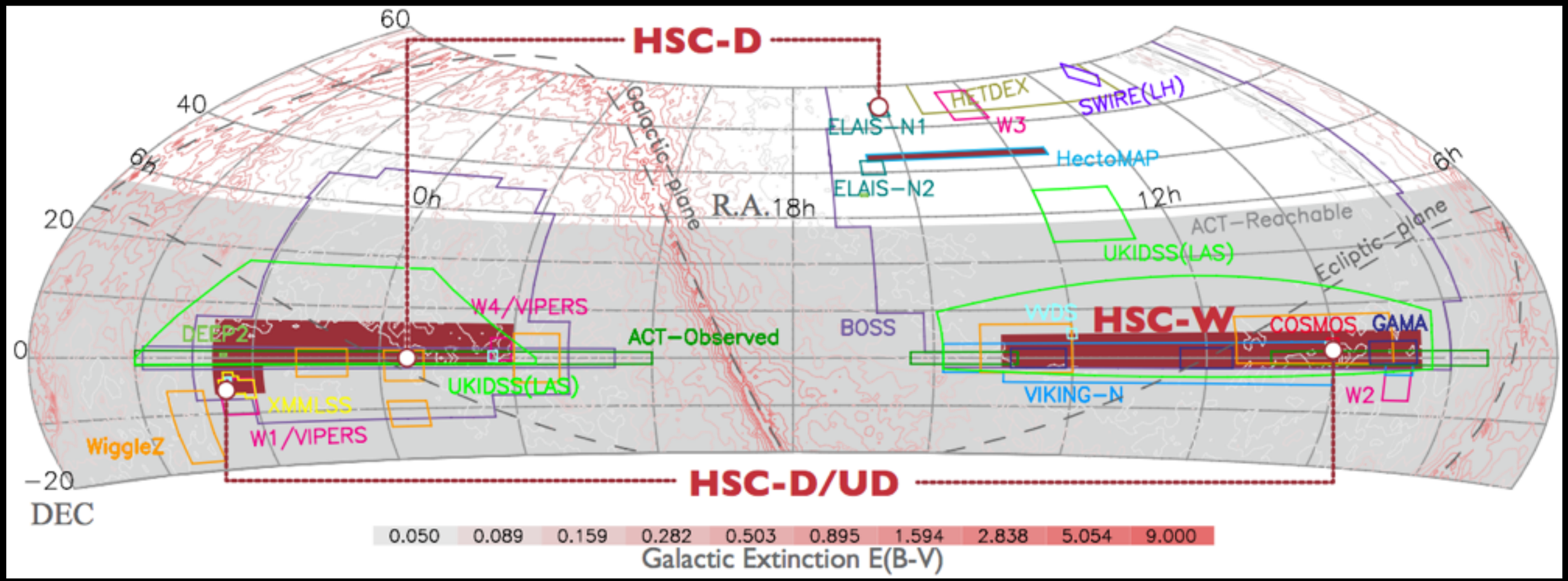
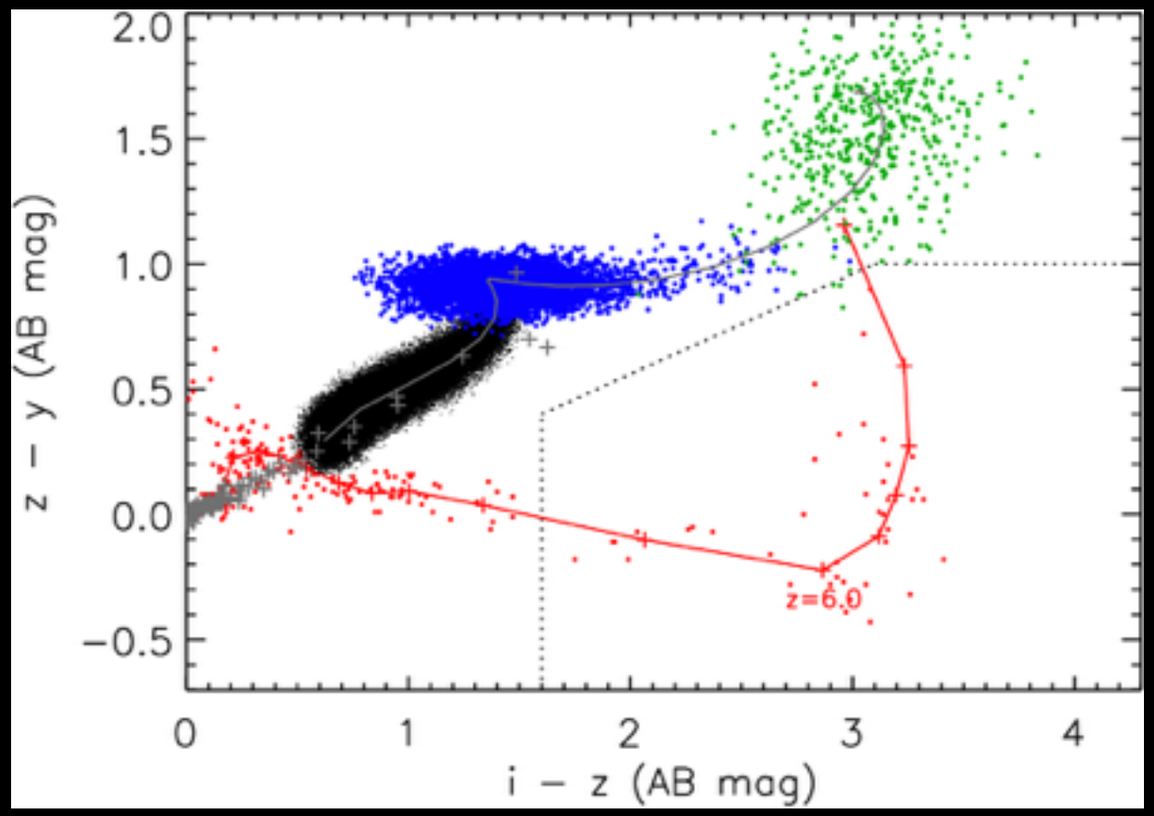


Table 7: Quasar Samples

	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

Uncovering $z \gtrsim 6$ quasars down to $M_{1450} \sim -22$ mag over 1,400 deg^2!

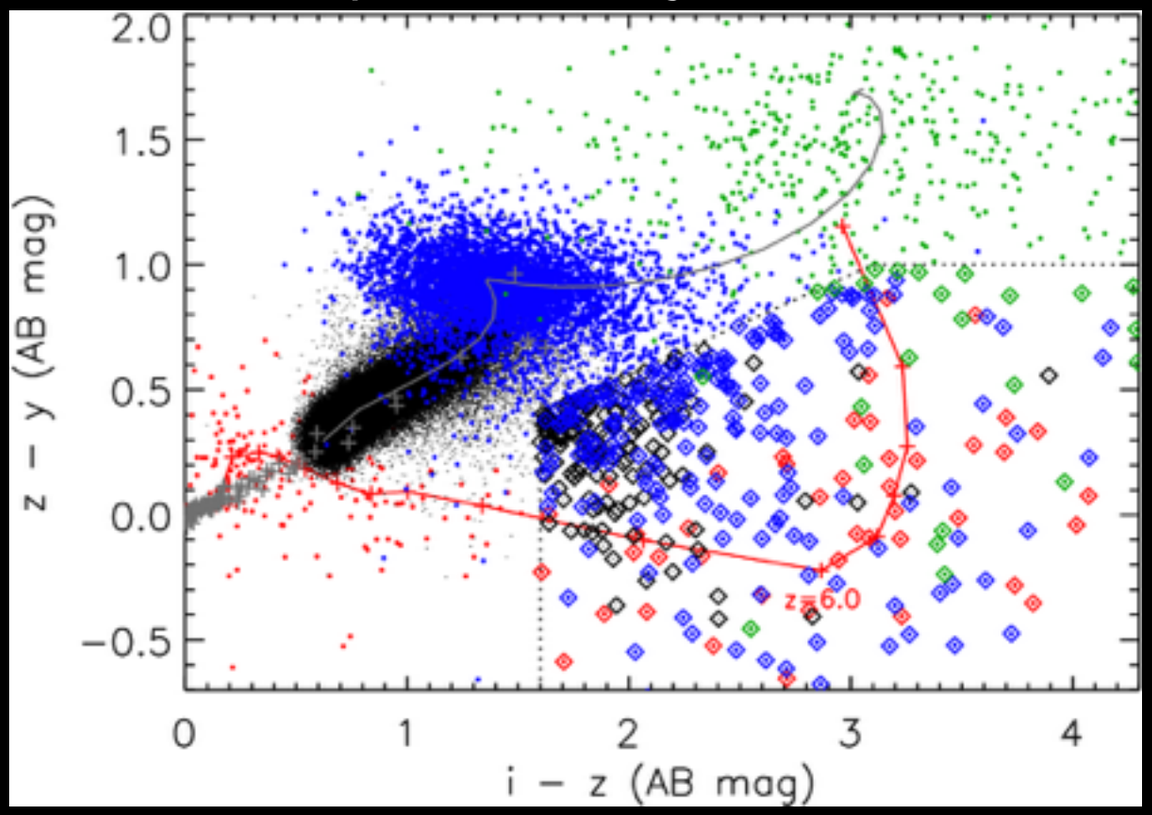
(Only a few object is currently known at $M_{1450} > -24$ mag)



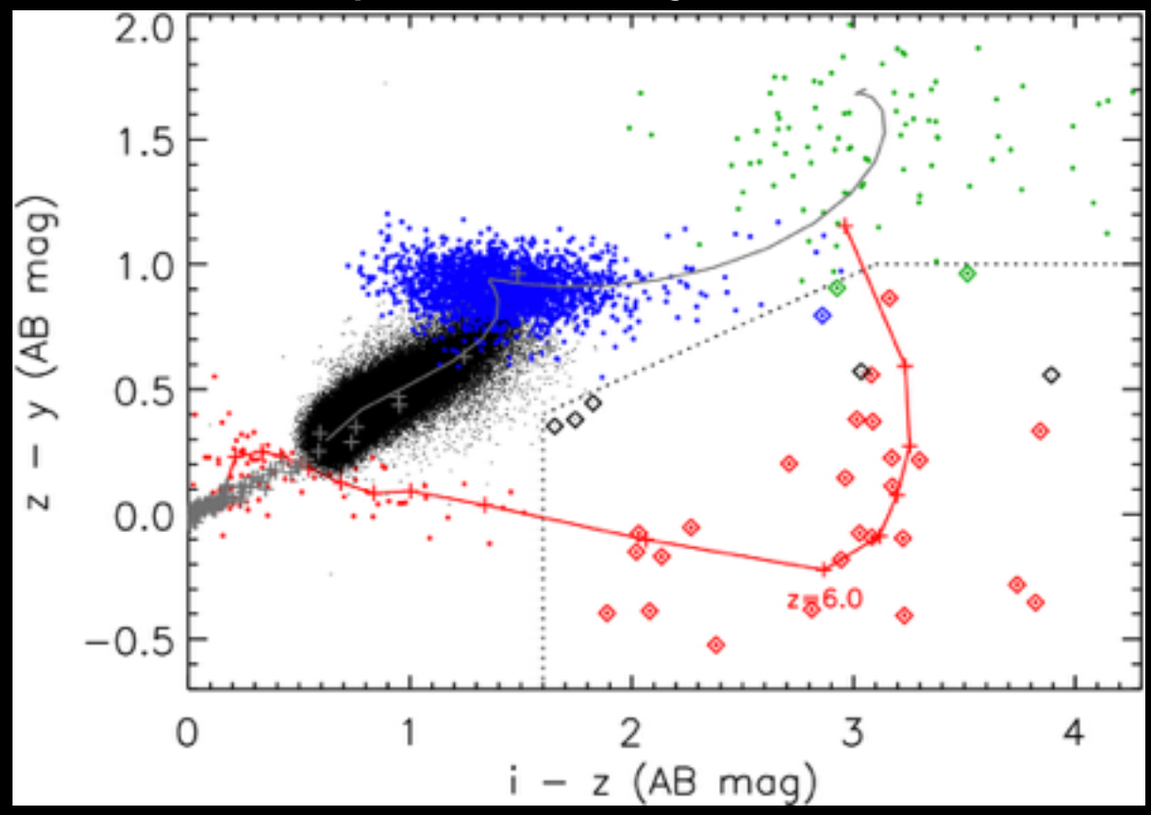
z_{AB} < 25 mag, 100 deg^2
w/o photometry errors

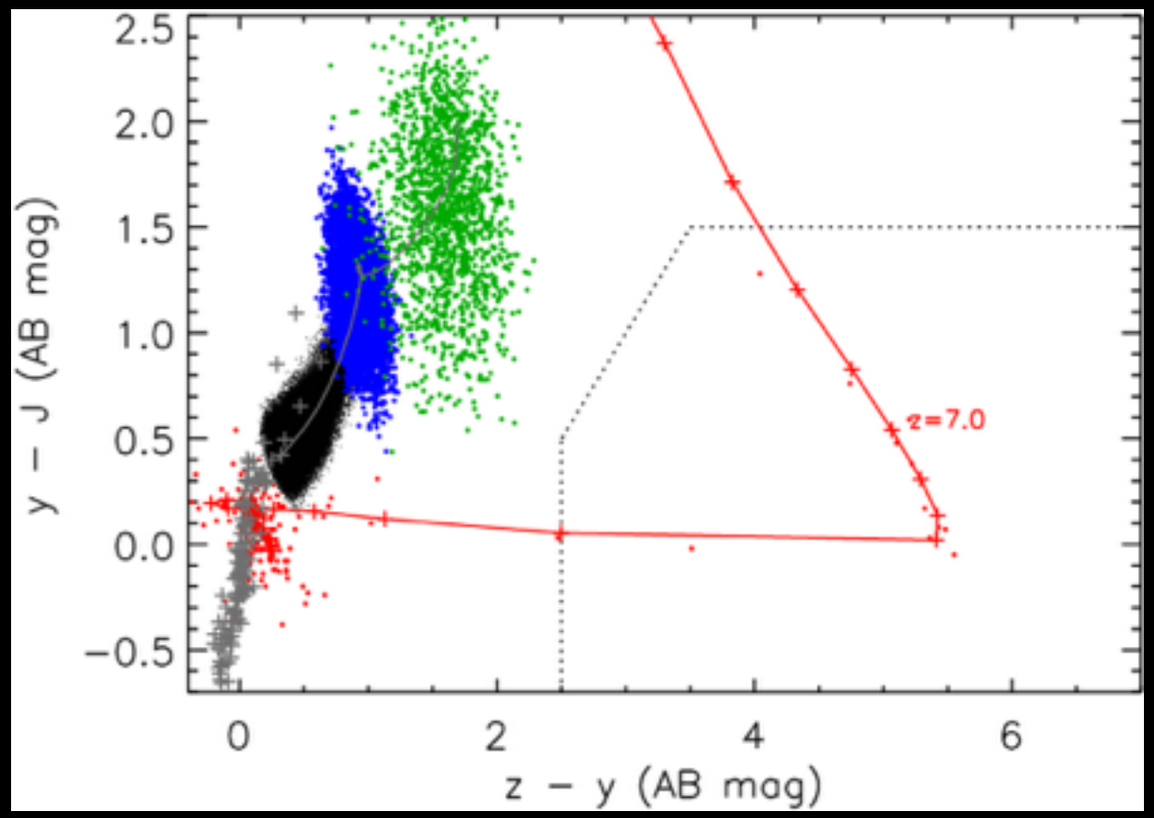
Legends:
- + O-M stars
- ・ Late-M dwarfs
- ● L dwarfs
- ● T dwarfs
- ● Quasars at z=5.0-6.5

z_{AB} < 25 mag, 100 deg^2
w/ photometry errors



z_{AB} < 24 mag, 100 deg^2
w/ photometry errors





y_{AB} < 24.5 mag, 100 deg^2

w/o photometry errors

Legends:

+ O-M stars

・ Late-M dwarfs

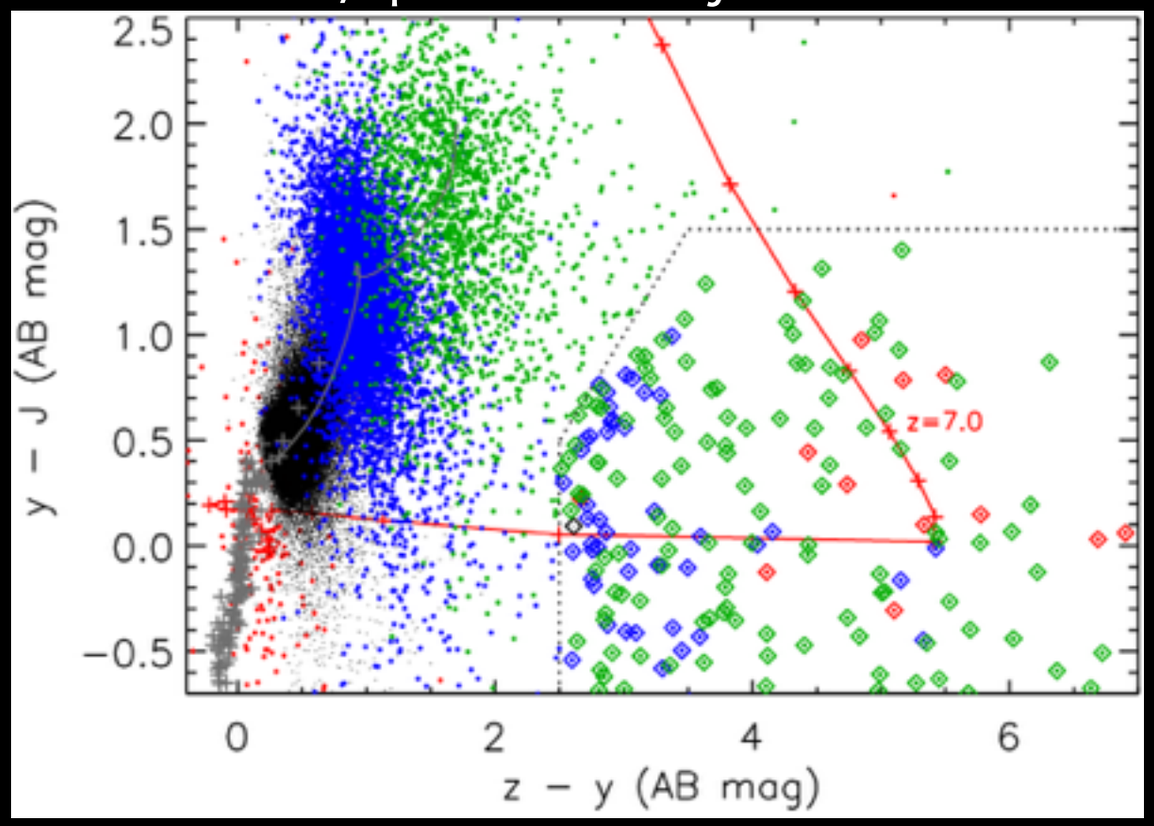
● L dwarfs

● T dwarfs

● Quasars at z=6.5-7.4

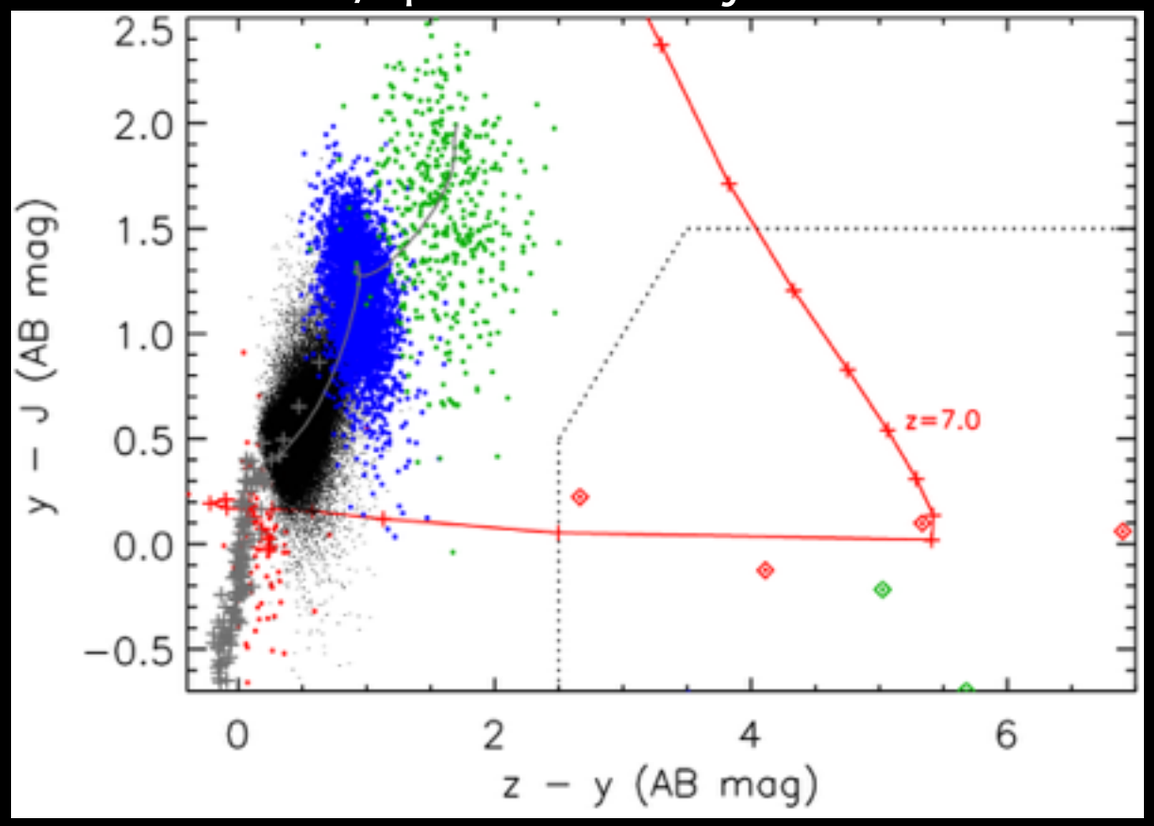
y_{AB} < 24.5 mag, 100 deg^2

w/ photometry errors

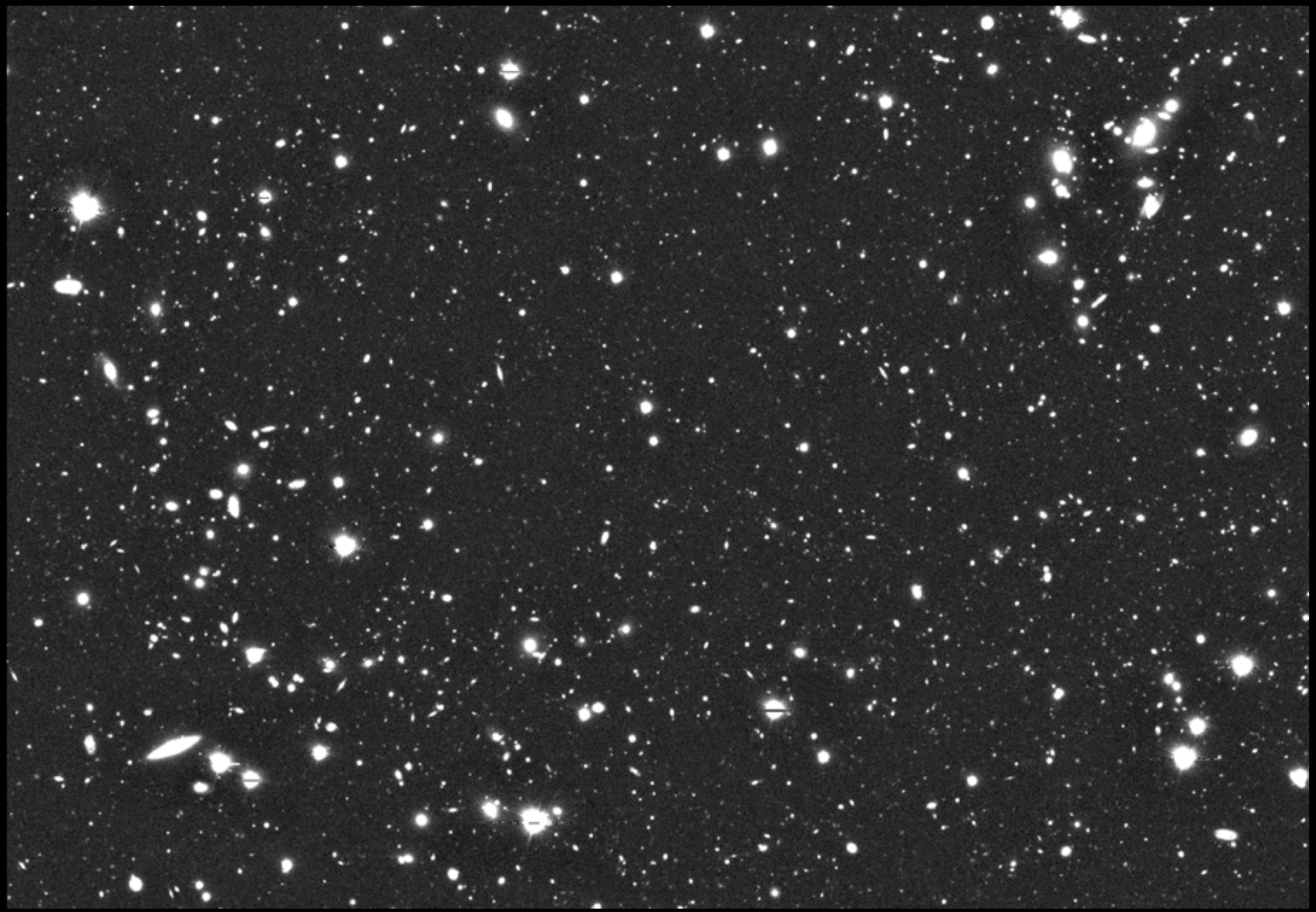


y_{AB} < 23.5 mag, 100 deg^2

w/ photometry errors

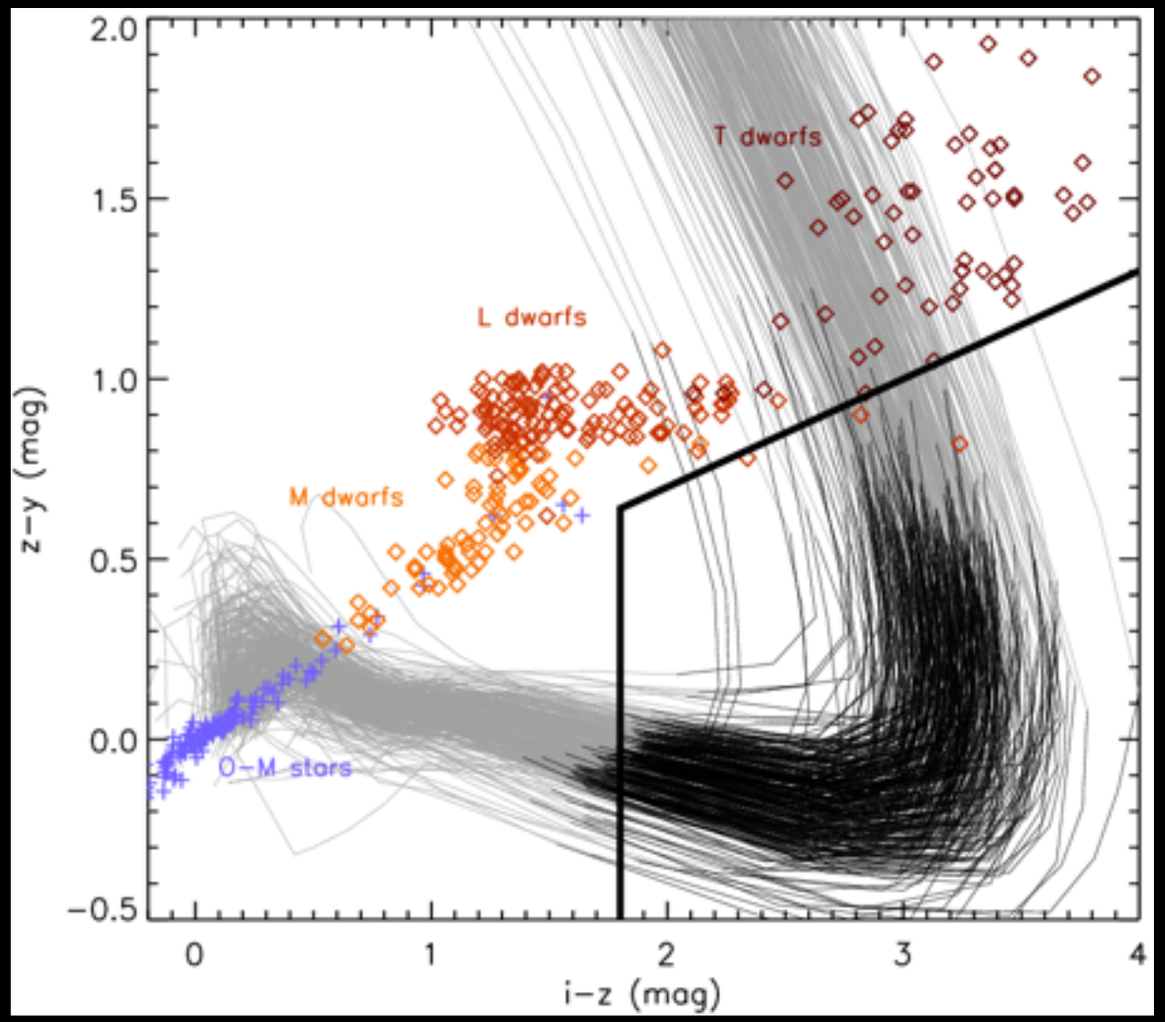


Experimental search with HSC-SSP S14A data

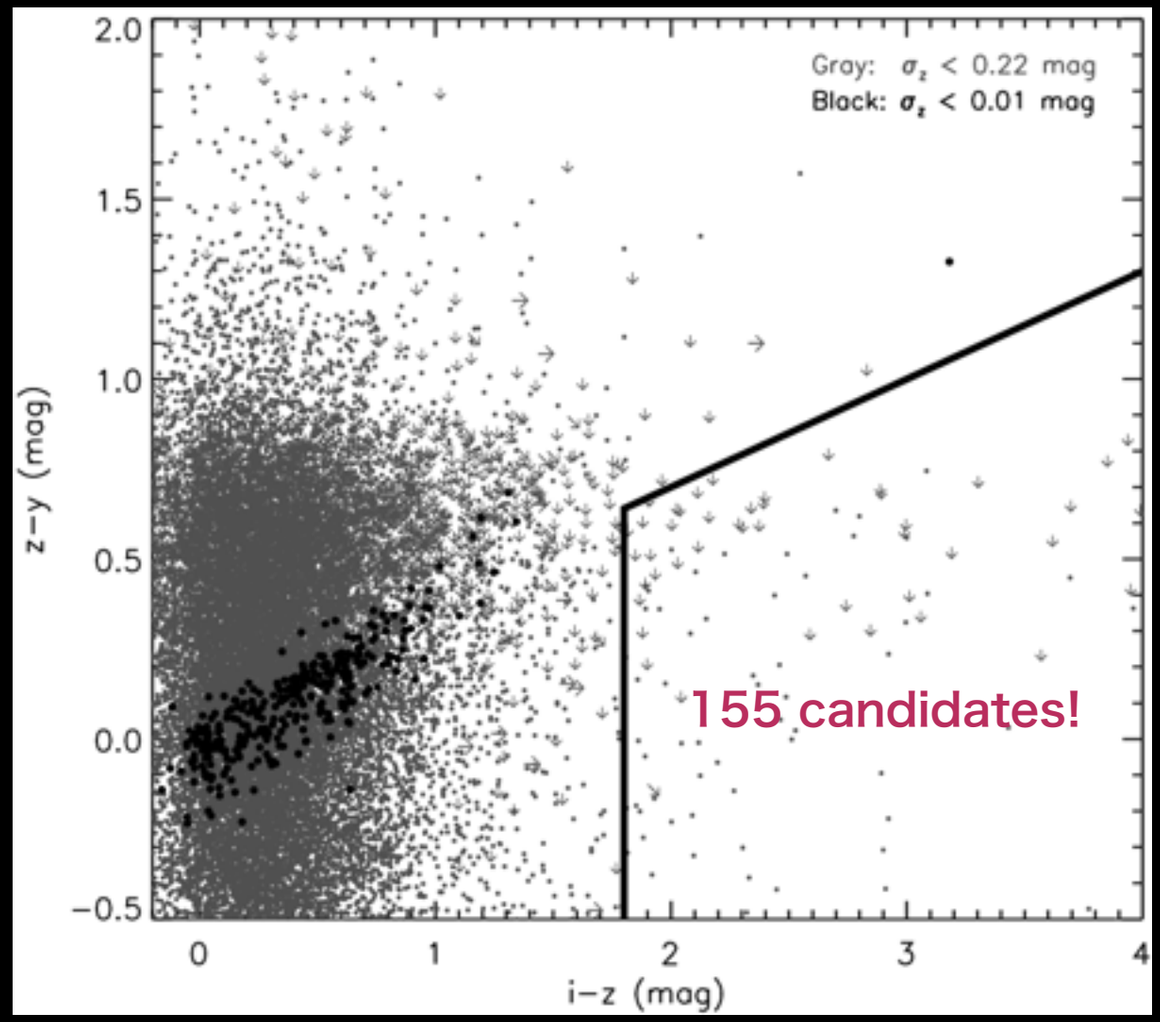


Experimental search with HSC-SSP S14A data

ideal



reality



We start with 25,385 z-band point sources with S/N > 5.
(z-band based forced photometry of m_{PSF} are used)

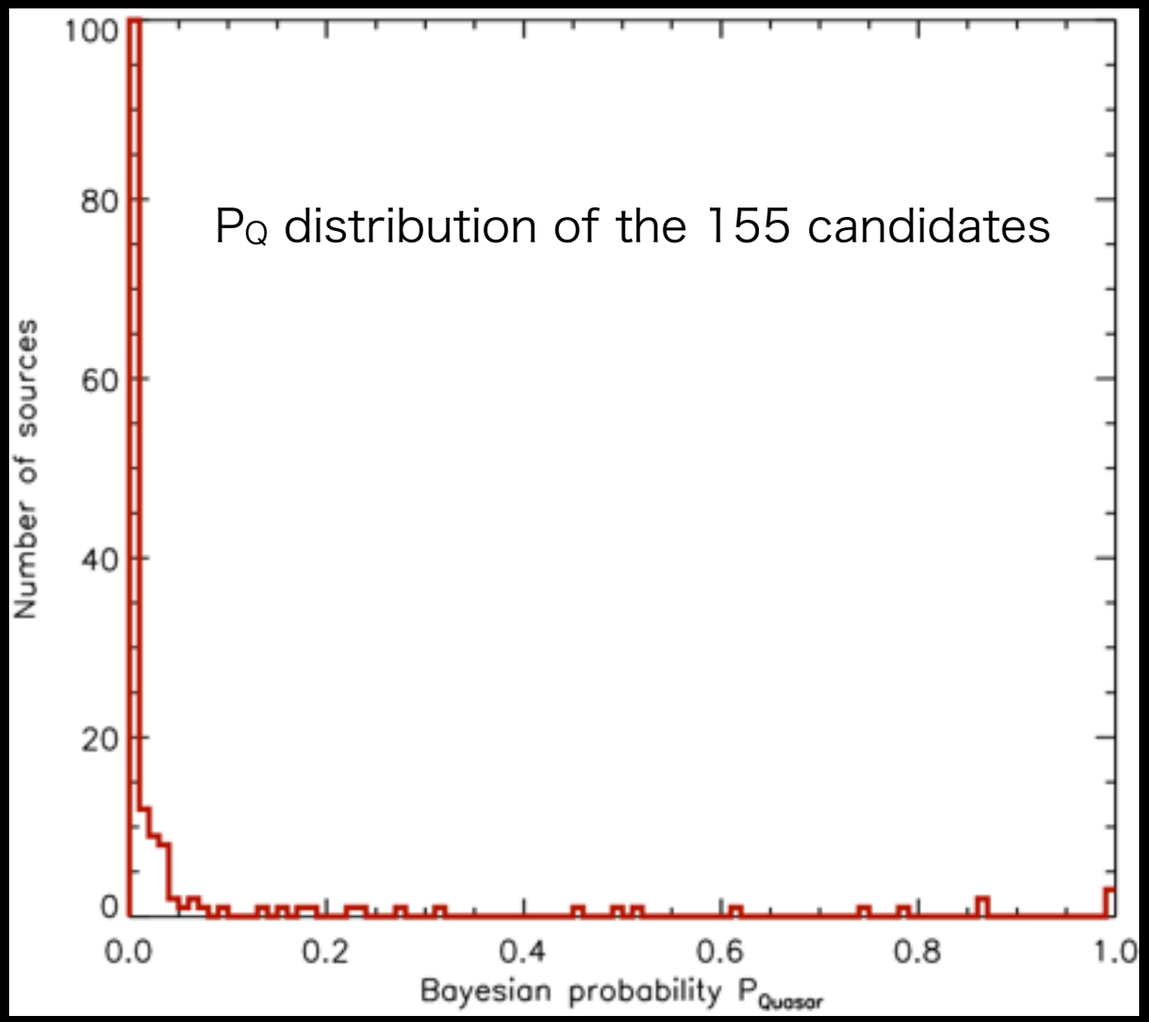
Experimental search with HSC-SSP S14A data

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

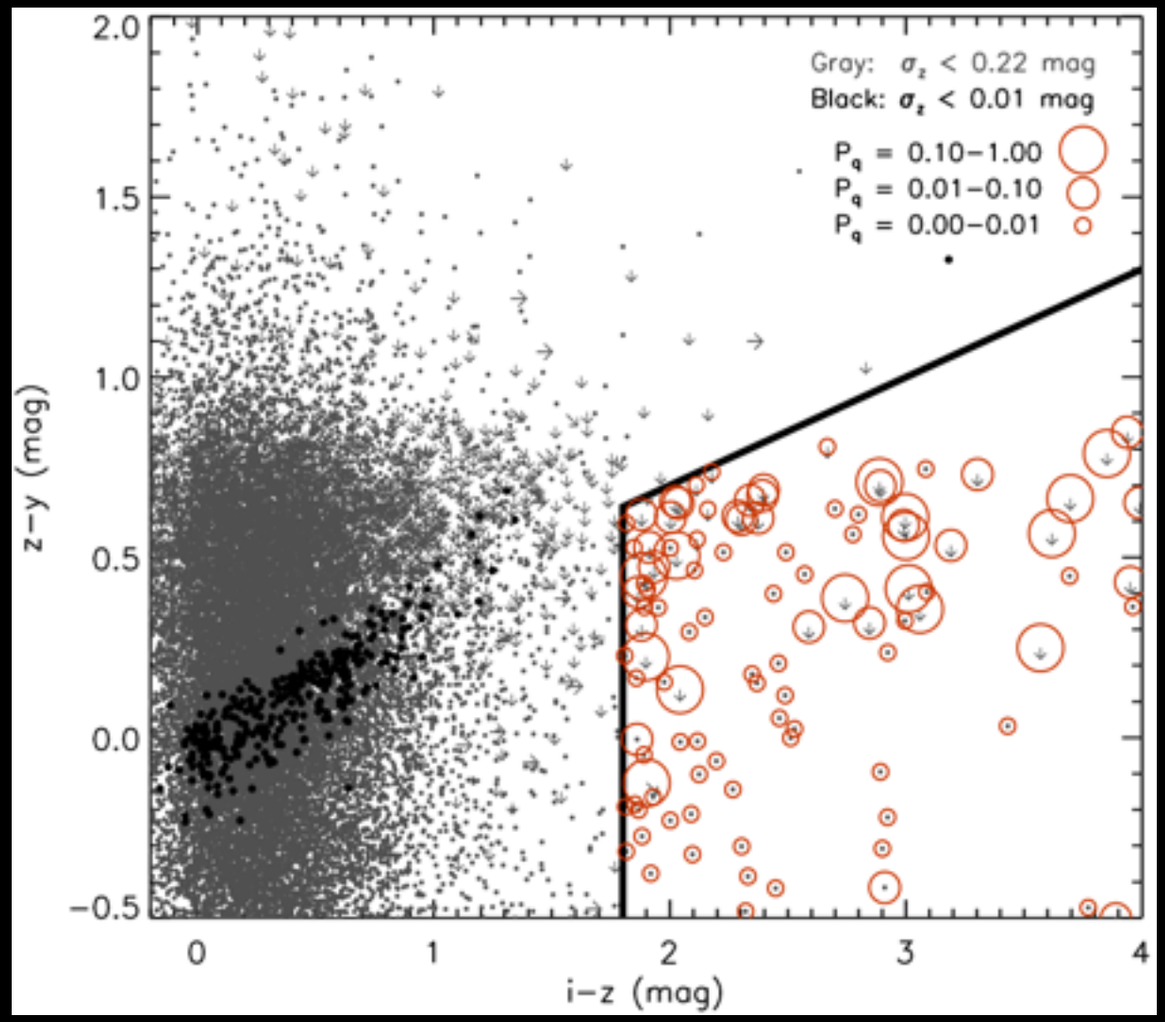
= $W_Q/(W_Q+W_D)$ where $W_{Q/D} = \int \rho(\mathbf{s})\, \Pr(\mathrm{det} \mid \mathbf{s})\, \Pr(\mathrm{d} \mid \mathbf{s})\, d\mathbf{s}$

P_Q distribution of the 155 candidates



→ Only 19 of them have $P_Q > 0.1$

P_Q distribution on the two-color diagram

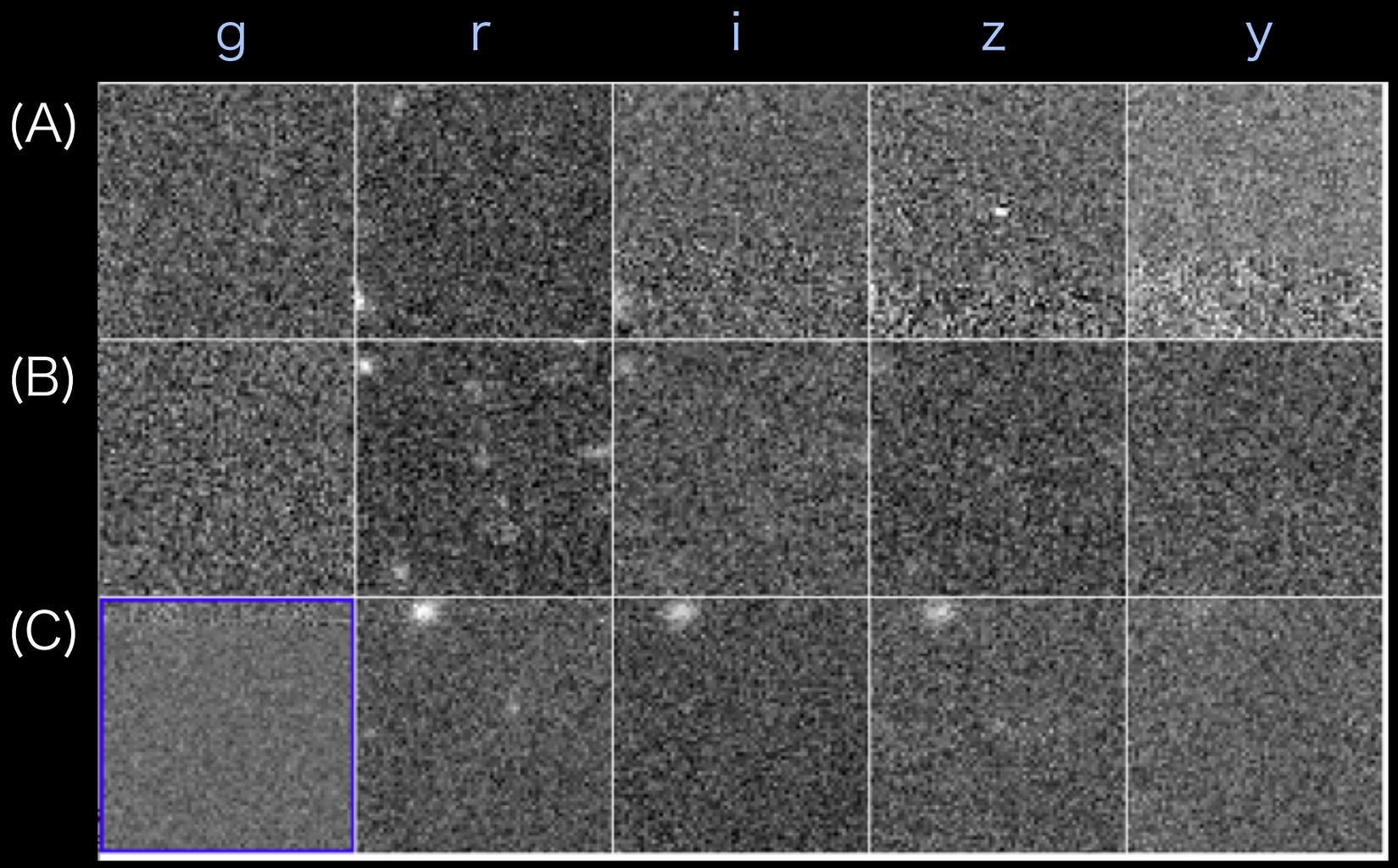


Experimental search with HSC-SSP S14A data

Visual inspection of the 19 candidates

✔ one cosmic ray hit (A)

✔ most of them are very faint and possibly spurious detections (B, C, ...)



Quality cut of $\sigma_z < 0.1$ mag

(this will be incorporated into the earlier stage in the real survey)

→ only 2 final candidates survive

Experimental search with HSC-SSP S14A data

The final candidates

HSC

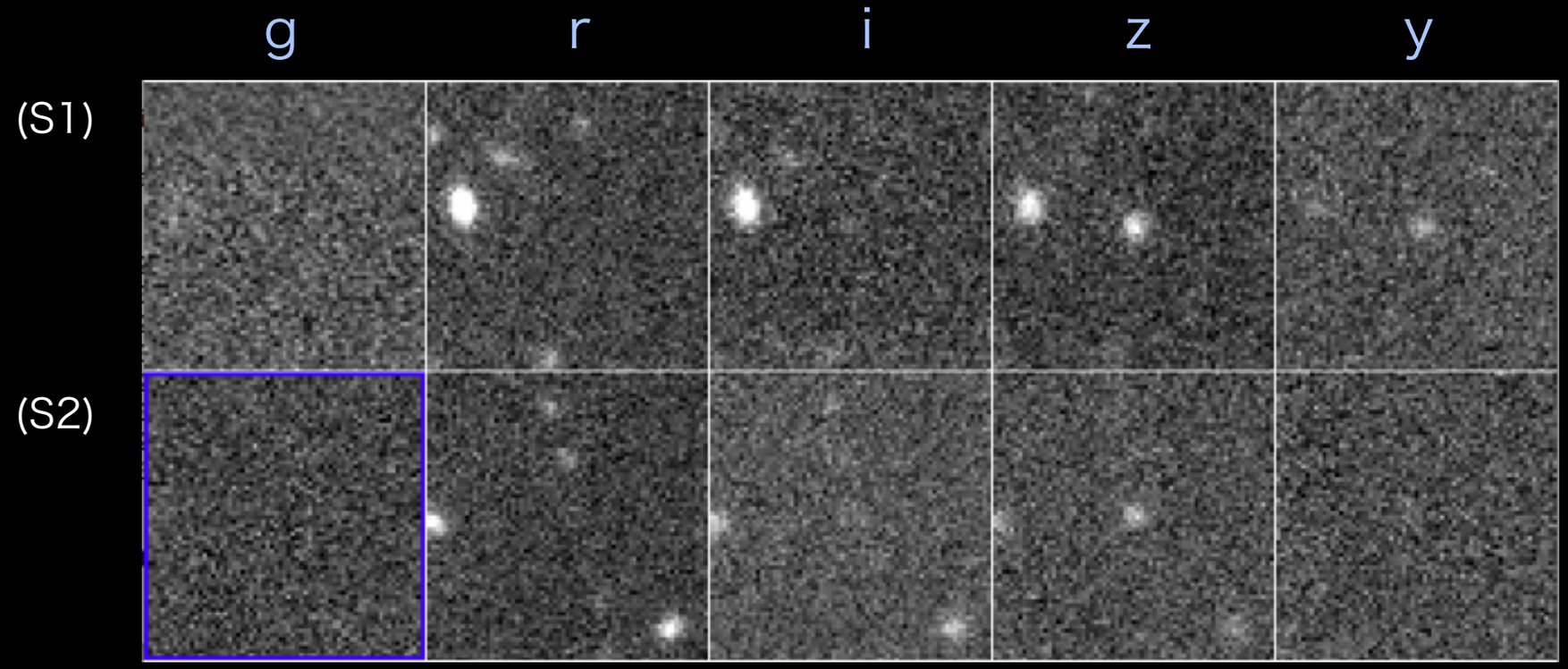
	HSC i (AB mag)	HSC z (AB mag)	HSC y (AB mag)	HSC P_0
S1	27.00 ± 0.35	24.00 ± 0.04	23.44 ± 0.08	0.9999
S2	26.39 ± 0.26	24.36 ± 0.07	25.37 ± 0.64	0.9985

COSMOS

	S-cam i (AB mag)	S-cam z (AB mag)	UKIRT J (AB mag)	CFHT K (AB mag)	KPNO K (AB mag)	HST F814 (AB mag)	HST class.star
S1	26.84 ± 0.38	24.08 ± 0.09	22.03 ± 0.02	20.96 ± 0.02	21.05 ± 0.15	25.57 ± 1.43	0.97
S2	26.18 ± 0.23	24.36 ± 0.10	24.03 ± 0.22	23.40 ± 0.15	n/a	n/a	n/a

ultraVISTA

	uVISTA Y (AB mag)	uVISTA J (AB mag)	uVISTA H (AB mag)	uVISTA K (AB mag)
S1	22.85 ± 0.02	21.90 ± 0.01	21.26 ± 0.01	20.80 ± 0.01



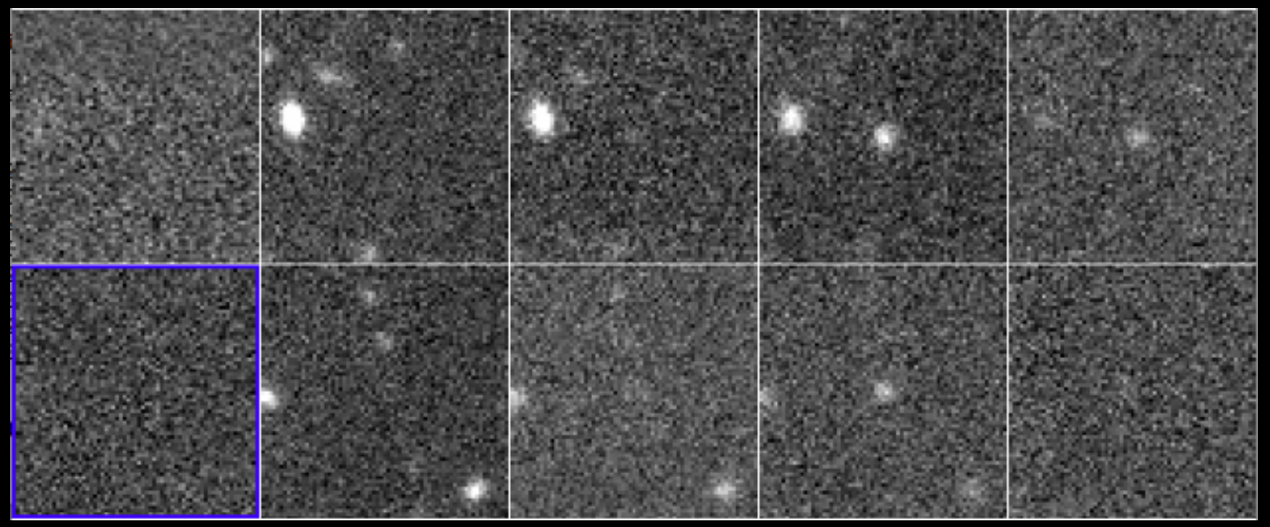
(S1) $z_{SCam} - J_{UKIRT} = 2.0$ suggests it is likely a contaminating Galactic T dwarf;
y_{HSC} might be much fainter than the true magnitude due to $>3\sigma$ photometry error.

(S2) $z_{SCam} - J_{UKIRT} = 0.3$ is consistent with being a z ~ 6 quasar.

Experimental search with HSC-SSP S14A data

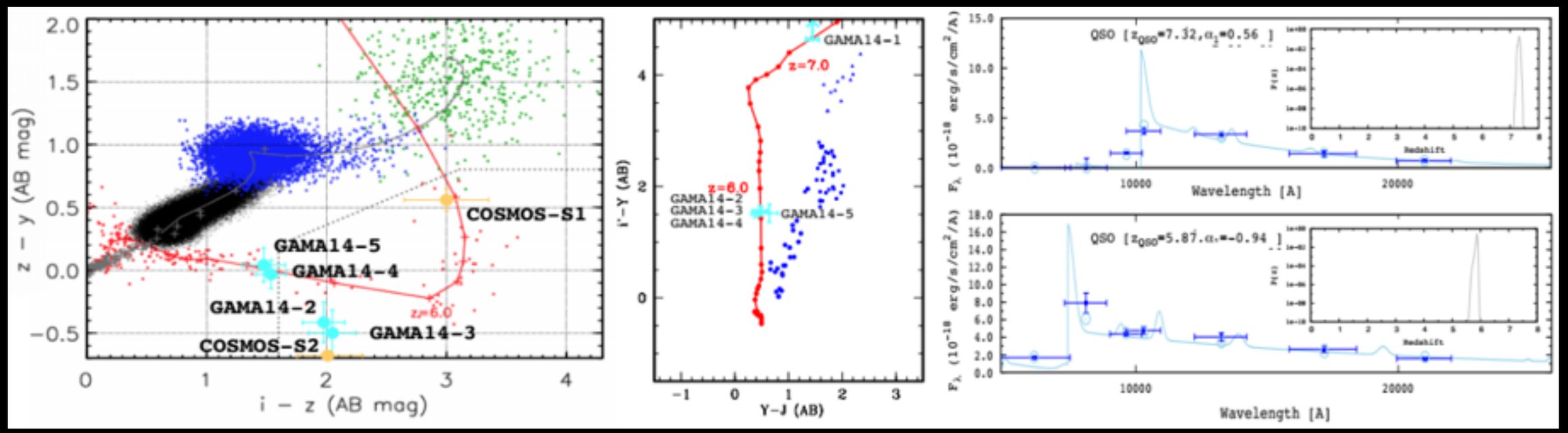
Spectroscopic follow-ups

✶ Subaru S15A: “First spectroscopic identification of HSC-SSP high-z quasar candidates”



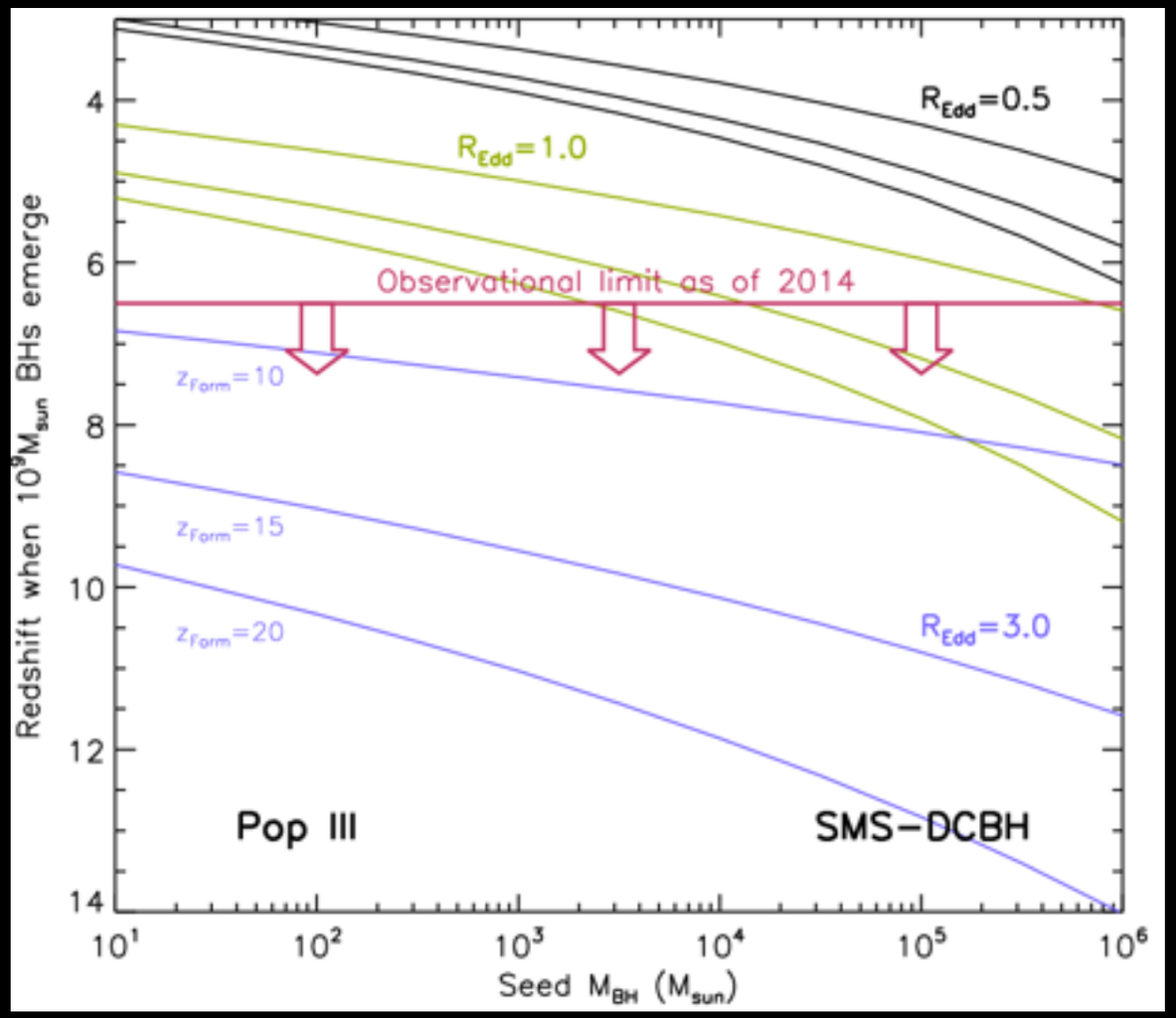
✶ Subaru S15A-service “Spectroscopic Identification of New z~6 HSC-SSP Quasars”

✶ VLT period 95 “Spectroscopic Identification and Mass Measurements of New z~6,7 Quasars”



Future prospects

When did first 10^9-M_{sun} SMBHs emerge?



Sensitivity of future instruments