Search for High-z Quasars and Brown Dwarfs with HSC data: Survey Design

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on behalf of
the HSC High-z QSO/Brown Dwarf Survey team
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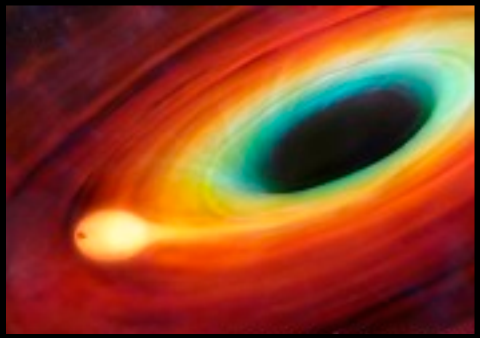
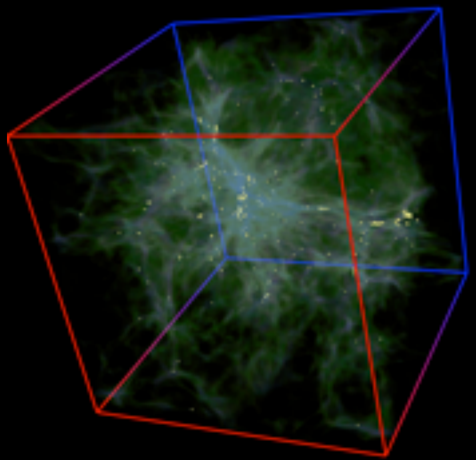
What motivate us to search for distant quasars



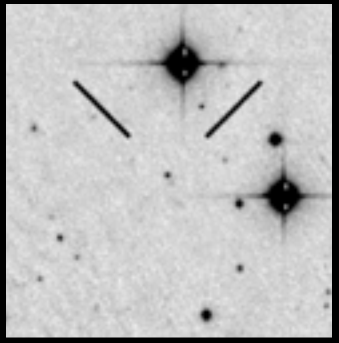


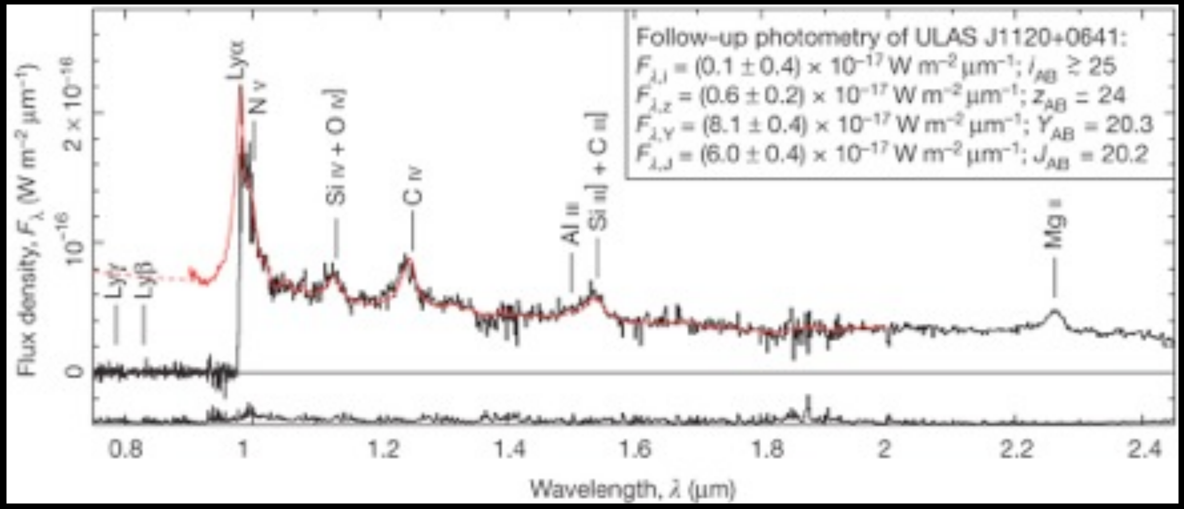
Formation of SMBHs
- Seed BH?
- How did they grow ?
- Co-evolution with host galaxies?

Cosmic Reionization
- When and where?
- How did it proceed?
- Ionizing sources?

Chemical Evolution of the Universe
- SF history right after the dark age?
- Frequency of SNe Ia/II?

⇨ Search for Most Distant Quasars!





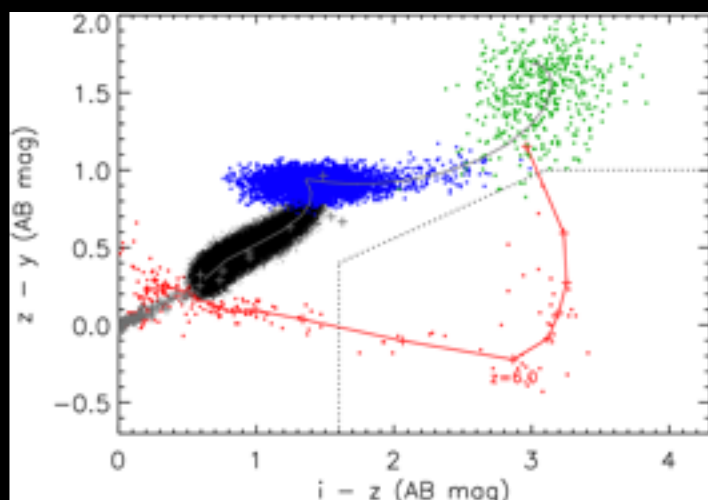
Only ~20 quasars at $z > 6$ expected with $z_{AB} < 24$ mag over 100 deg^2

➔ Wide and deep imaging survey with multiple bands around 1 μm.

Survey Flow

HSC imaging data
Photometry catalog

Color selection



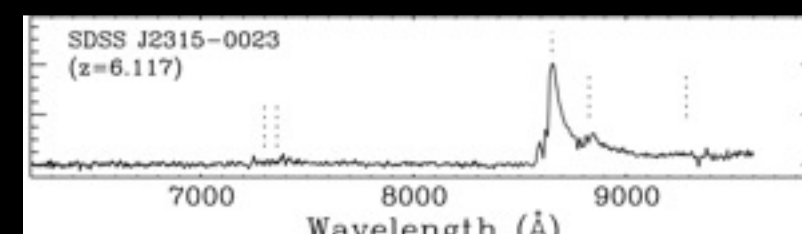
Initial candidate list

Follow-up photometry

Probabilistic selection

Final candidate list

Spectroscopy

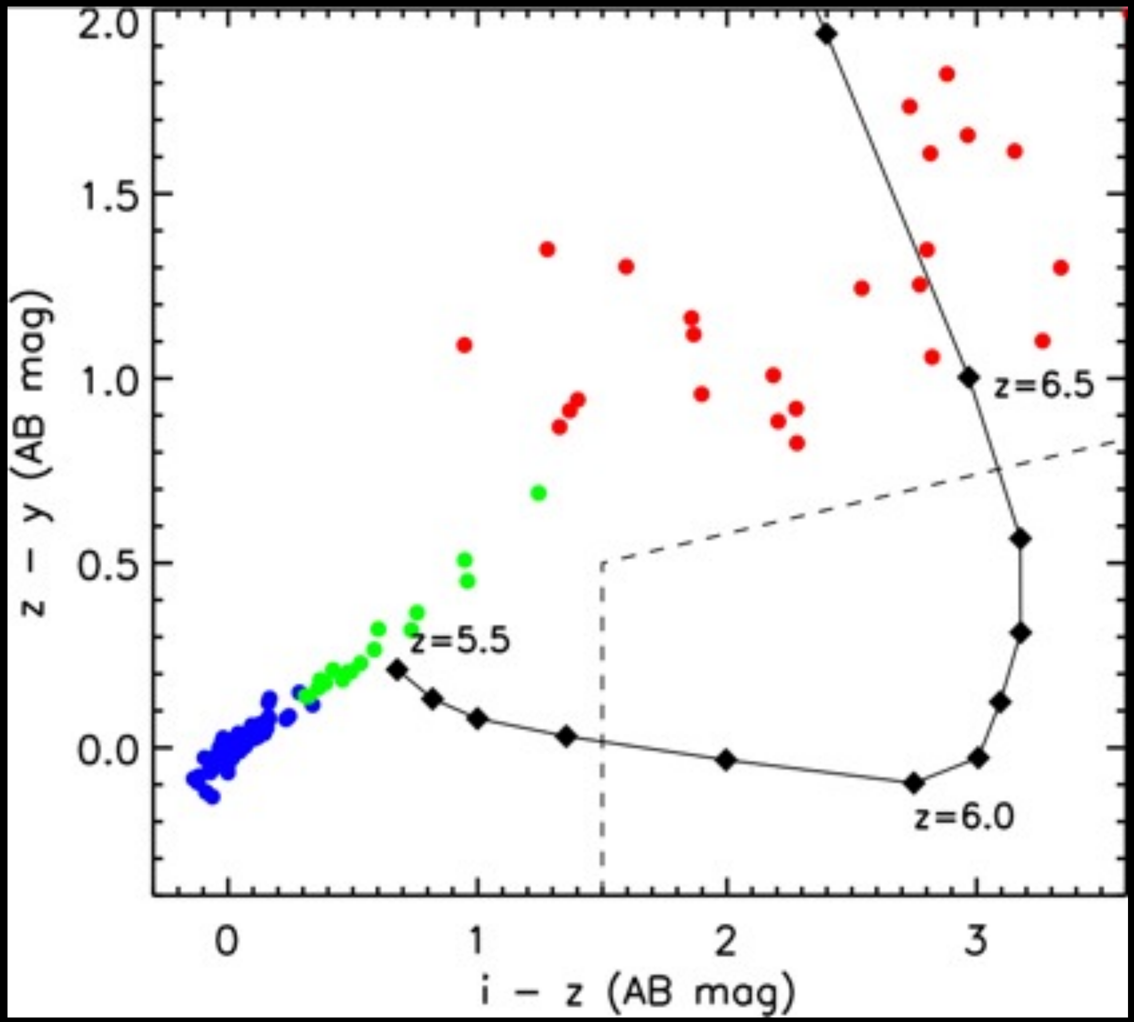


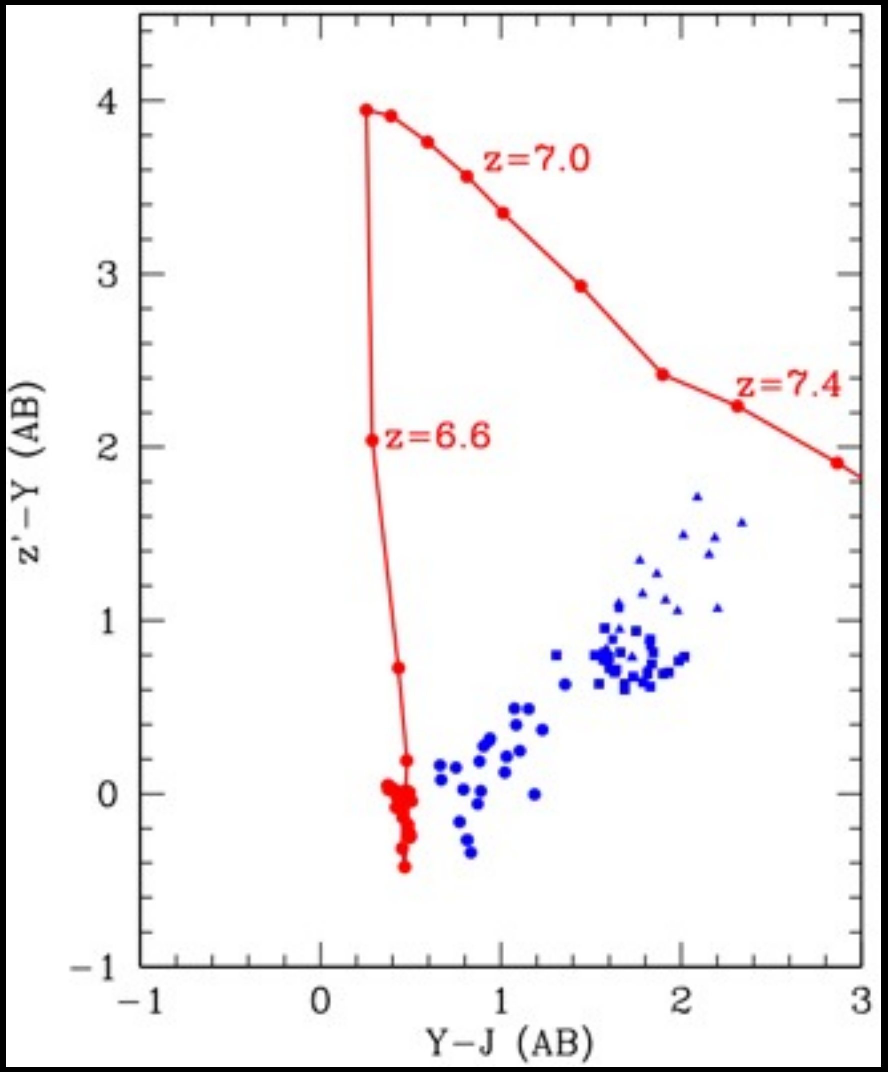
Brown dwarfs

High-z quasars

Individual science

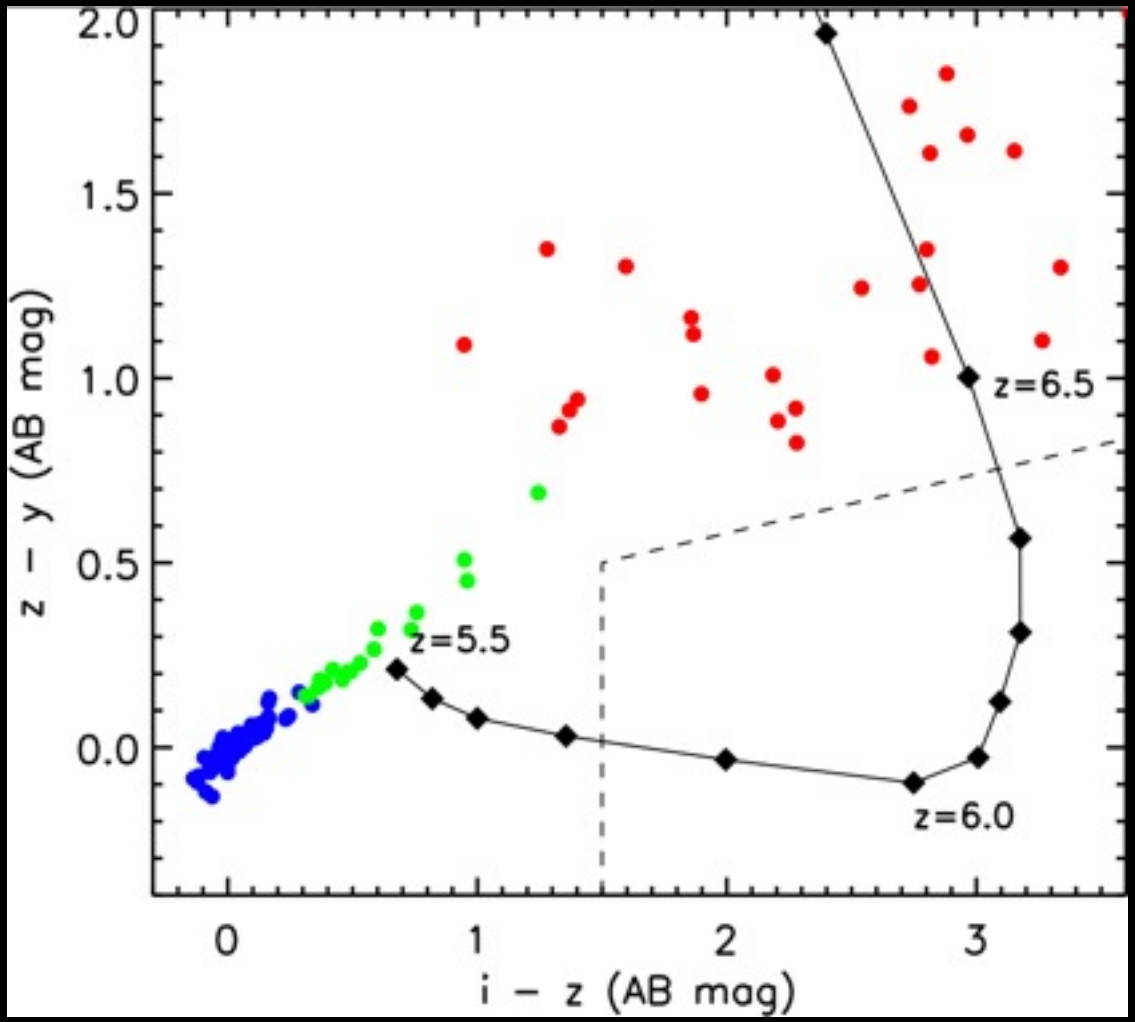
Initial Selection of Candidates





5.9 < z < 6.4	6.6 < z < 7.2
color selection through i, z, and y filters	color selection through z, y, and J filters
~ 200 objects at z_{AB} < 24 mag	~ 30 objects at y_{AB} < 23.5 mag
~ 400 objects at z_{AB} < 25 mag	~ 70 objects at y_{AB} < 24.5 mag
(/1,000 deg^2)	(/1,000 deg^2)

Initial Selection of Candidates



5.9 < z < 6.4

color selection through i, z, and y filters

~ 200 objects at z_{AB} < 24 mag

~ 400 objects at z_{AB} < 25 mag

(/1,000 deg^2)

Survey simulation with

- realistic surface density
- intrinsic scatter of colors

of quasars and brown dwarfs and

- photometry errors

assuming the HSC wide survey

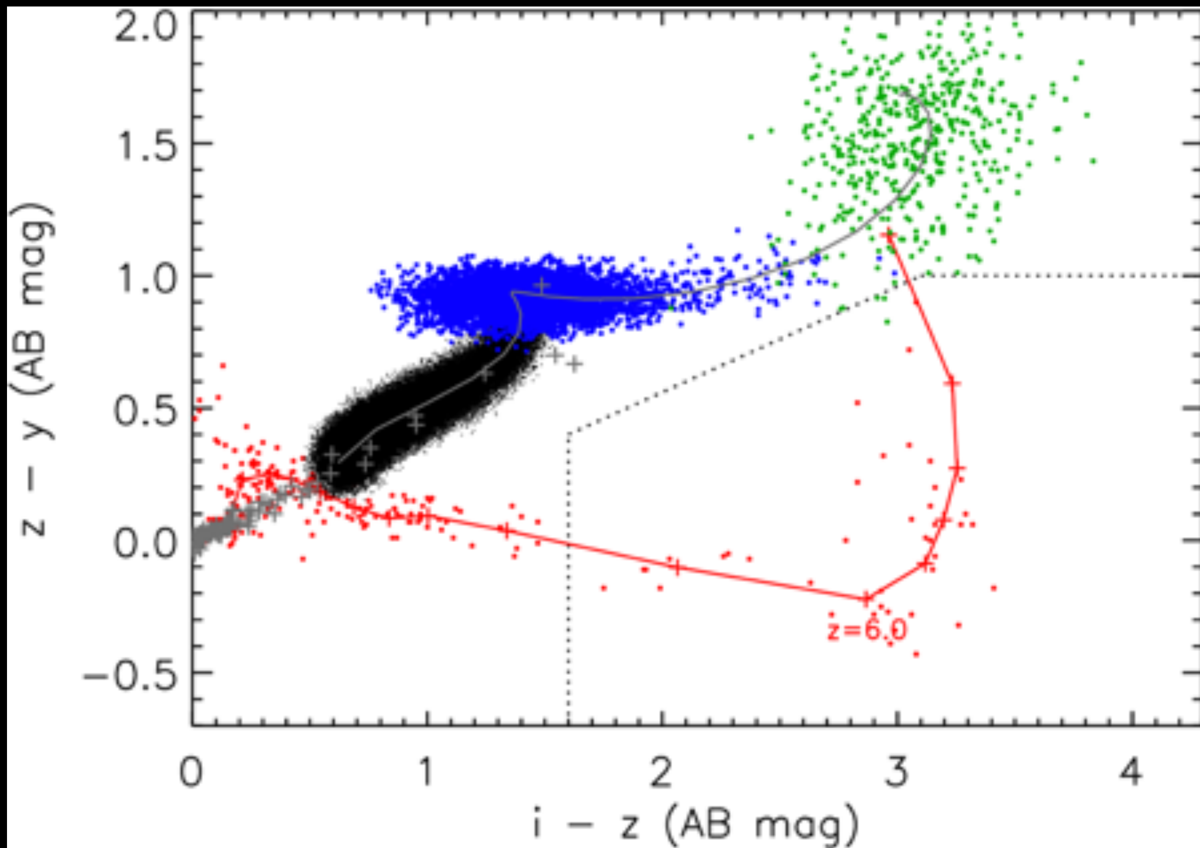
Quasars:

- LF of Willott+10
- 340 high-quality SDSS spectra at z~3.0
- GP absorption of Songaila04

Brown dwarfs:

- Galactic thin-disk model with local calibrations (Caballero+08)
- SpeX and CGS4 spectral library

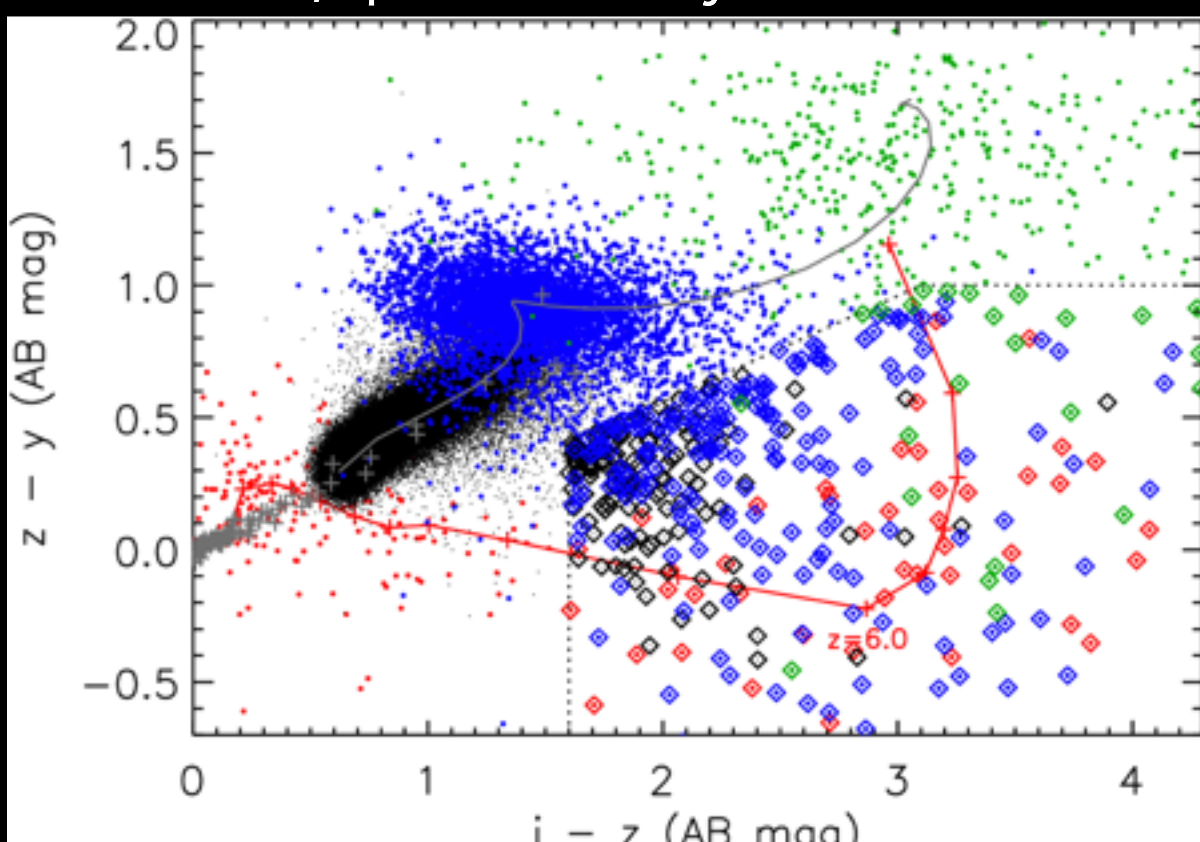
z_{AB} < 25 mag, 100 deg^2
w/o photometry errors



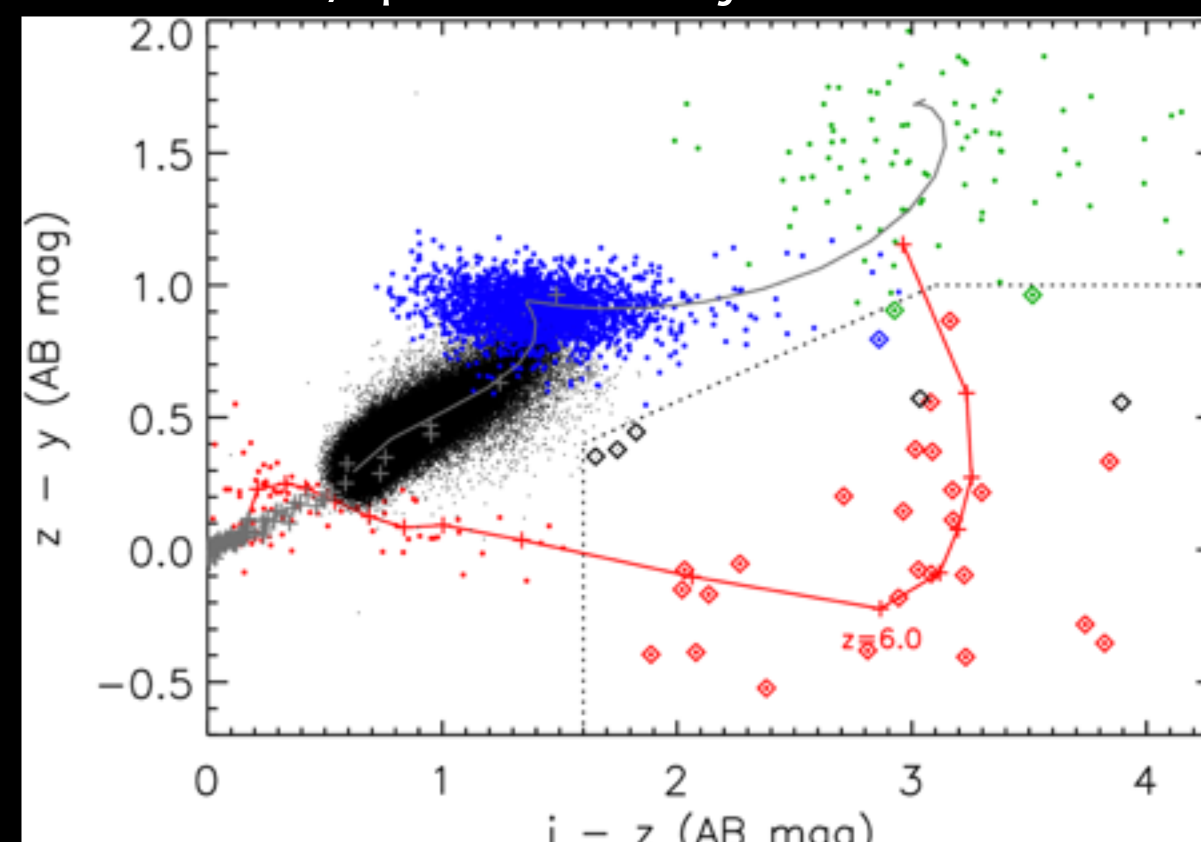
Legends:

- + O-M stars
- · Late-M dwarfs
- L dwarfs
- T dwarfs
- Quasars at z=5.0-6.5

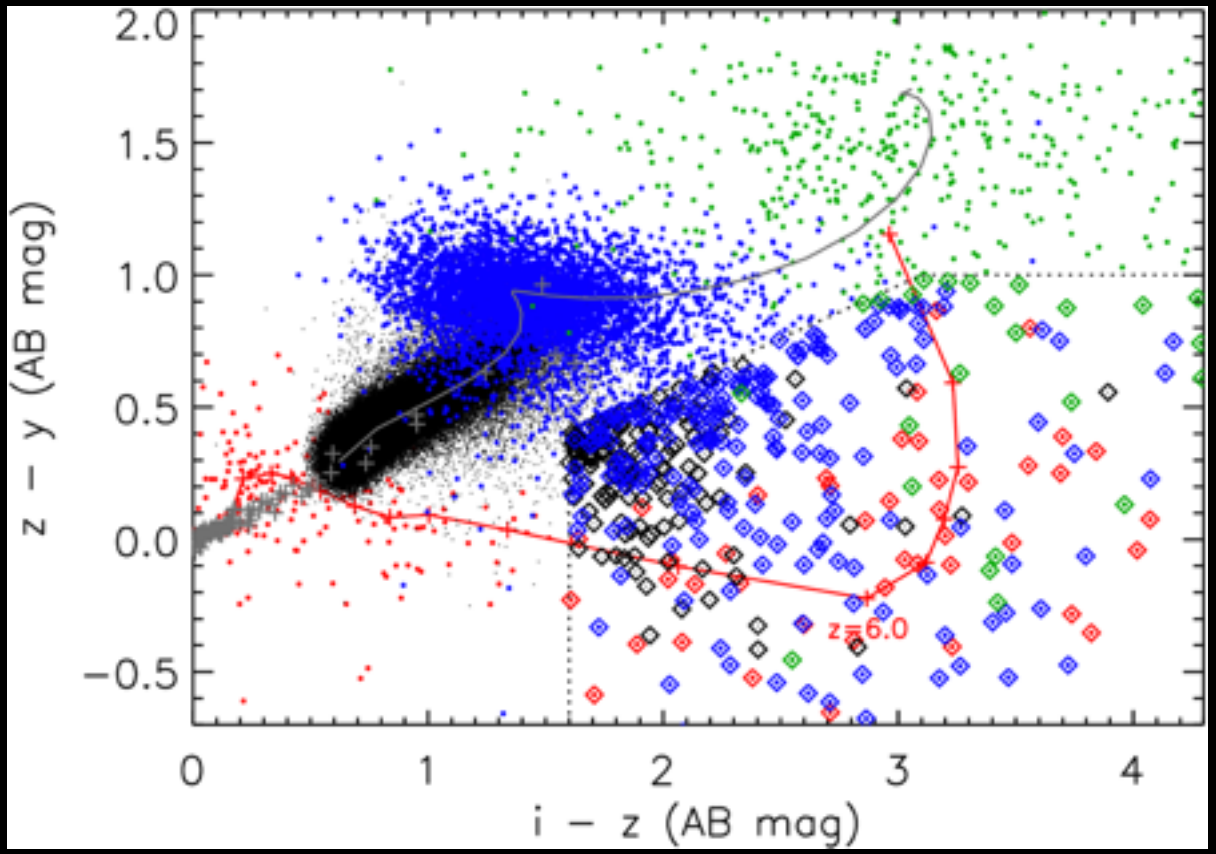
z_{AB} < 25 mag, 100 deg^2
w/ photometry errors



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



Follow-up Photometry



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

In most cases contaminants have catastrophic magnitudes in one of the three bands, which can be fixed by follow-up photometry.

Number of contaminants when we have correct magnitudes in

	none	i band	z band	y band	i, z, y bands
	$i_{obs}, z_{obs}, y_{obs}$	$i_{true}, z_{obs}, y_{obs}$	$i_{obs}, z_{true}, y_{obs}$	$i_{obs}, z_{obs}, y_{true}$	$i_{true}, z_{true}, y_{true}$
Late-M	146	105	26	142	0
L	195	189	18	181	0
T	24	32	5	20	3
Total	365	326	49	343	3

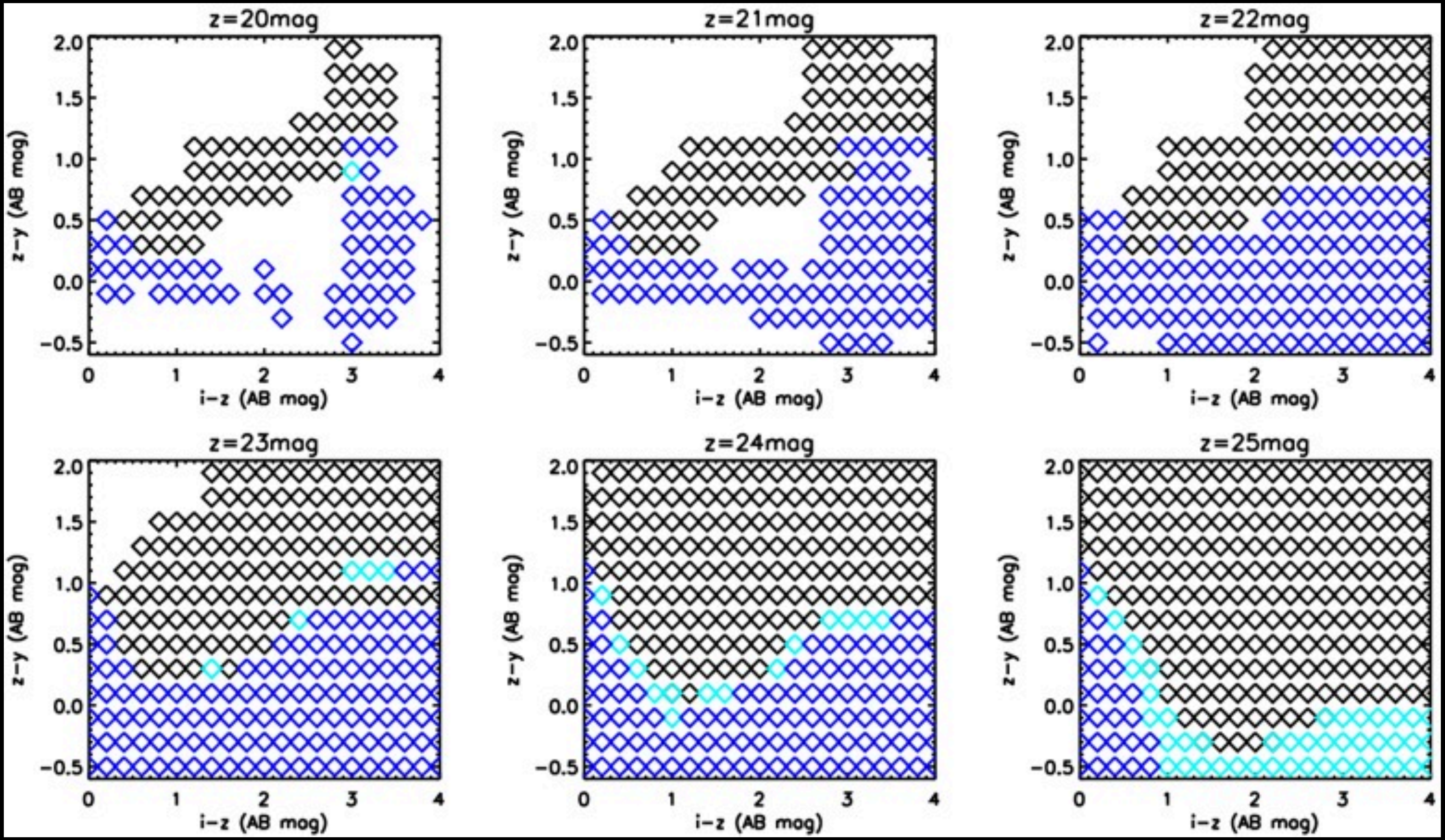
Probabilistic Selection

Bayesian probability P_q that a source ($\boldsymbol{d}$, det) is a quasar:

$$P_q = W_{qso}(\boldsymbol{d}, \text{det}) / \{W_{qso}(\boldsymbol{d}, \text{det}) + W_{bd}(\boldsymbol{d}, \text{det})\}, \text{ where}$$

$$W_{qso}(\boldsymbol{d}, \text{det}) = \int\int S_{qso}(z, \text{redshift}) \Pr(\text{det} \mid z, \text{redshift}) \Pr(i_{obs}, z_{obs}, y_{obs} \mid z, \text{redshift})\, dz\, d(\text{redshift})$$

$$W_{bd}(\boldsymbol{d}, \text{det}) = \int\int S_{bd}(z, \text{sptype}) \Pr(\text{det} \mid z, \text{sptype}) \Pr(i_{obs}, z_{obs}, y_{obs} \mid z, \text{sptype})\, dz\, d(\text{sptype}).$$



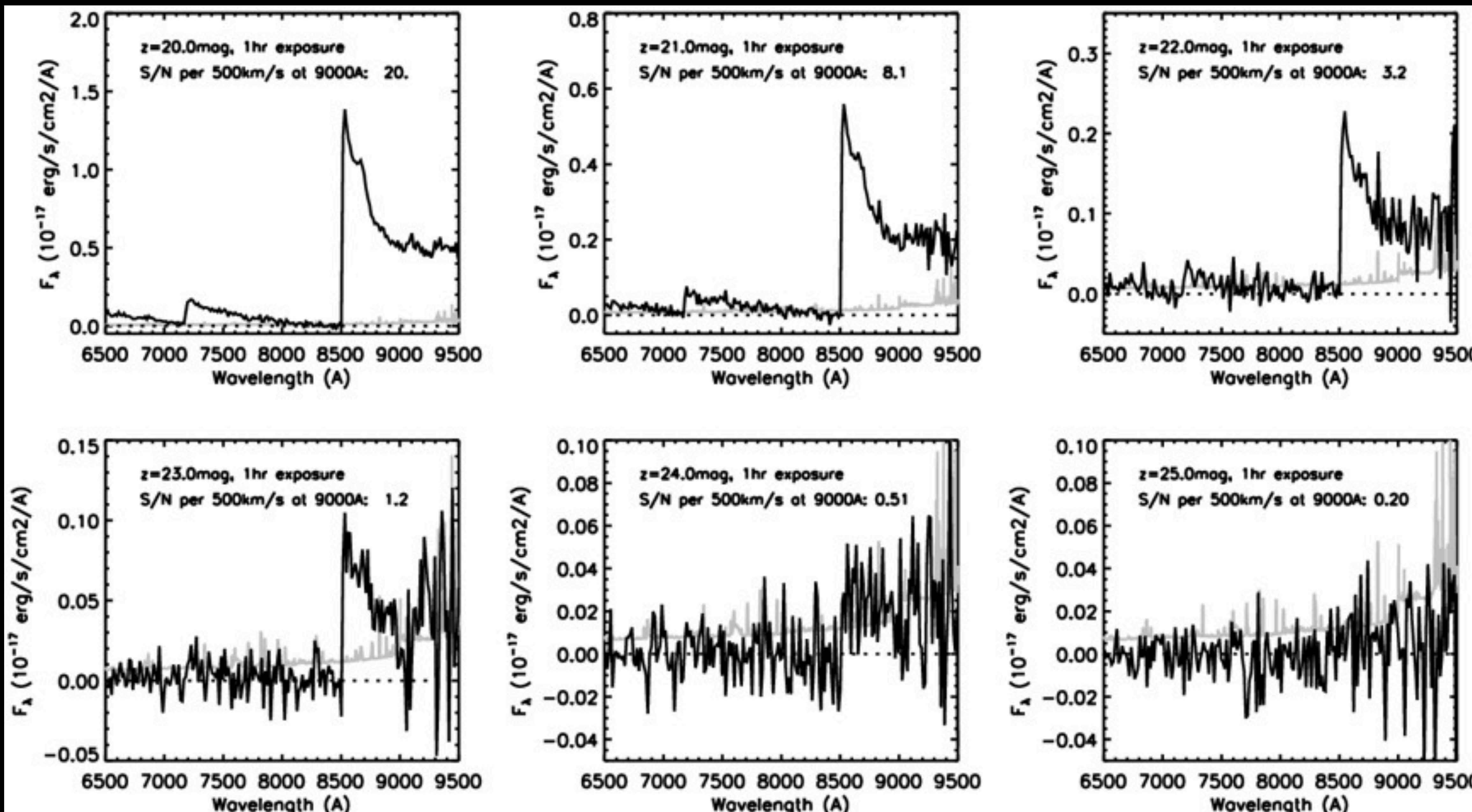
Black: $P_q < 0.01$

Light blue: $0.01 < P_q < 0.1$

Blue: $P_q > 0.1$

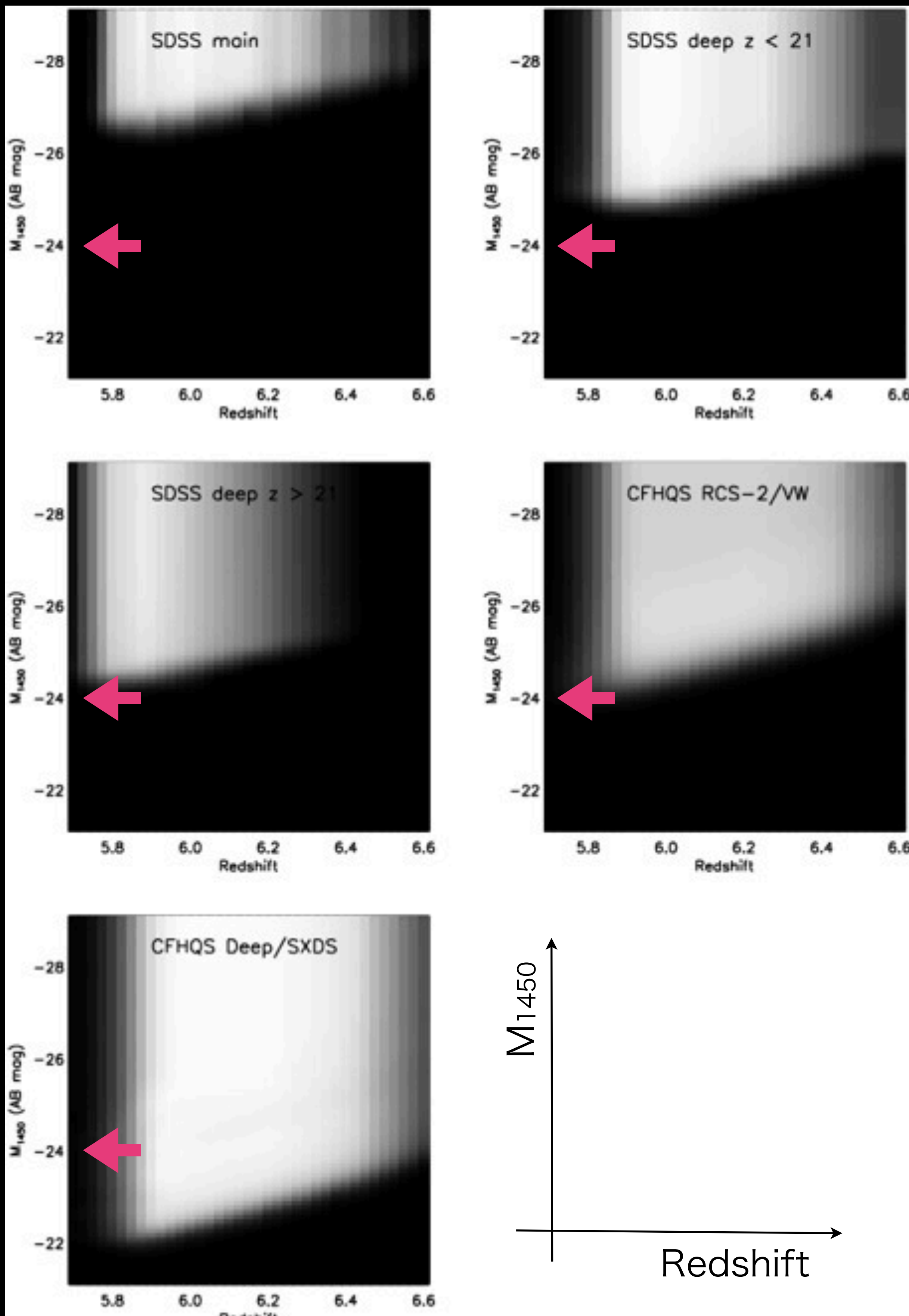
Follow-up Spectroscopy

Expected spectrum of a quasar, with 1-hr exposure using 8-m telescopes
(Sky background in the Gemini-N/GMOS ITC is assumed)



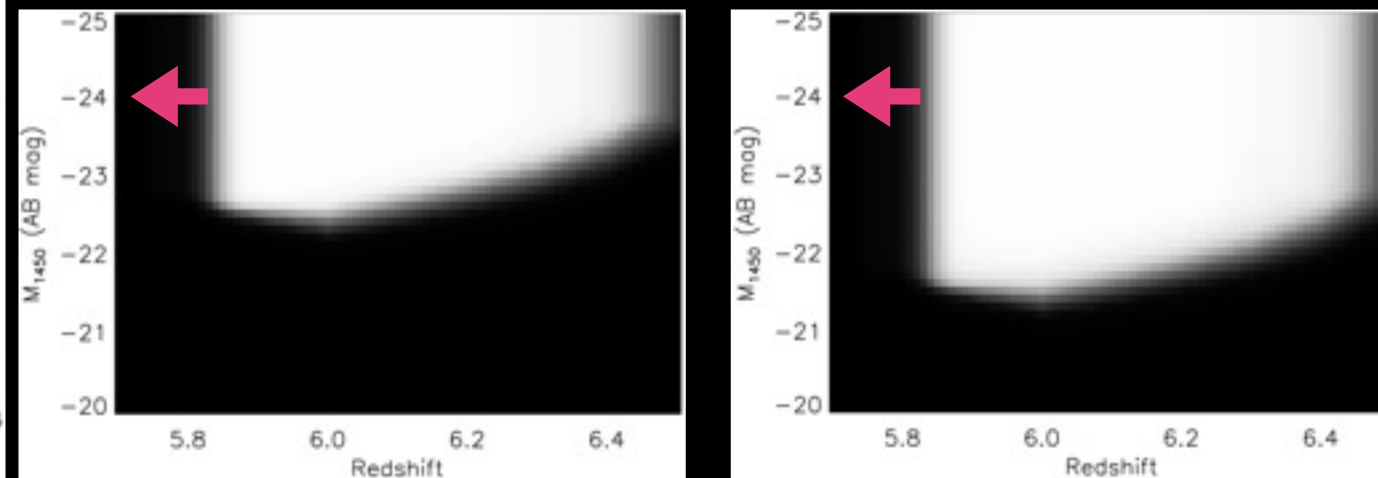
➔ Quasars at z_{AB} < 24 mag can be identified with < 4 hr exposures,
but the identification becomes challenging at fainter magnitudes.

Survey Completeness



zAB < 24 mag

zAB < 25 mag



HSC wide survey

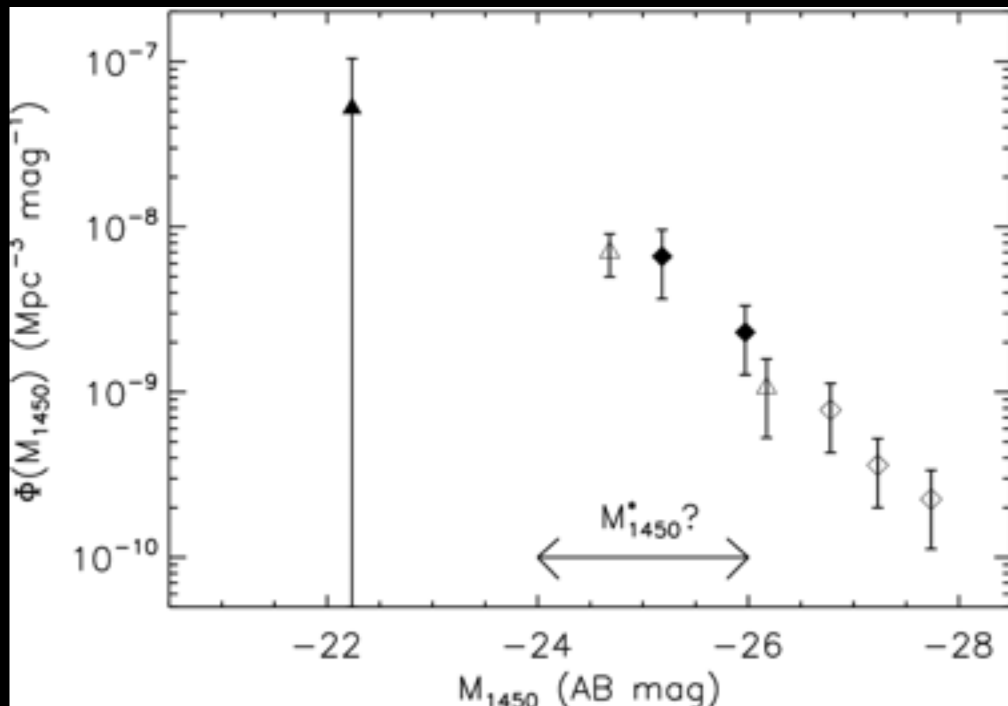
- z_{AB} < 24 mag: M_{1450} < -22.5 mag
- z_{AB} < 25 mag: M_{1450} < -21.5 mag

Previous surveys

- SDSS main: M_{1450} < -26.5 mag
- SDSS deep: M_{1450} < -24.5 mag
- CFHQS wide: M_{1450} < -24.0 mag
- CFHQS deep: M_{1450} < -22.0 mag
  (contains only a single quasar)

(Data courtesy of Chris Willott)

A Science Case: Luminosity Function



Legends:
- ◇ SDSS main
- ◆ SDSS deep
- △ CFHQS wide
- ▲ CFHQS deep (contains a single quasar)

LF form at lower z: $\Phi(M_{1450}) = 10^{k(z-6)}\,\Phi^* / [10^{0.4(\alpha+1)(M1450-M1450^*)} + 10^{0.4(\beta+1)(M1450-M1450^*)}]$

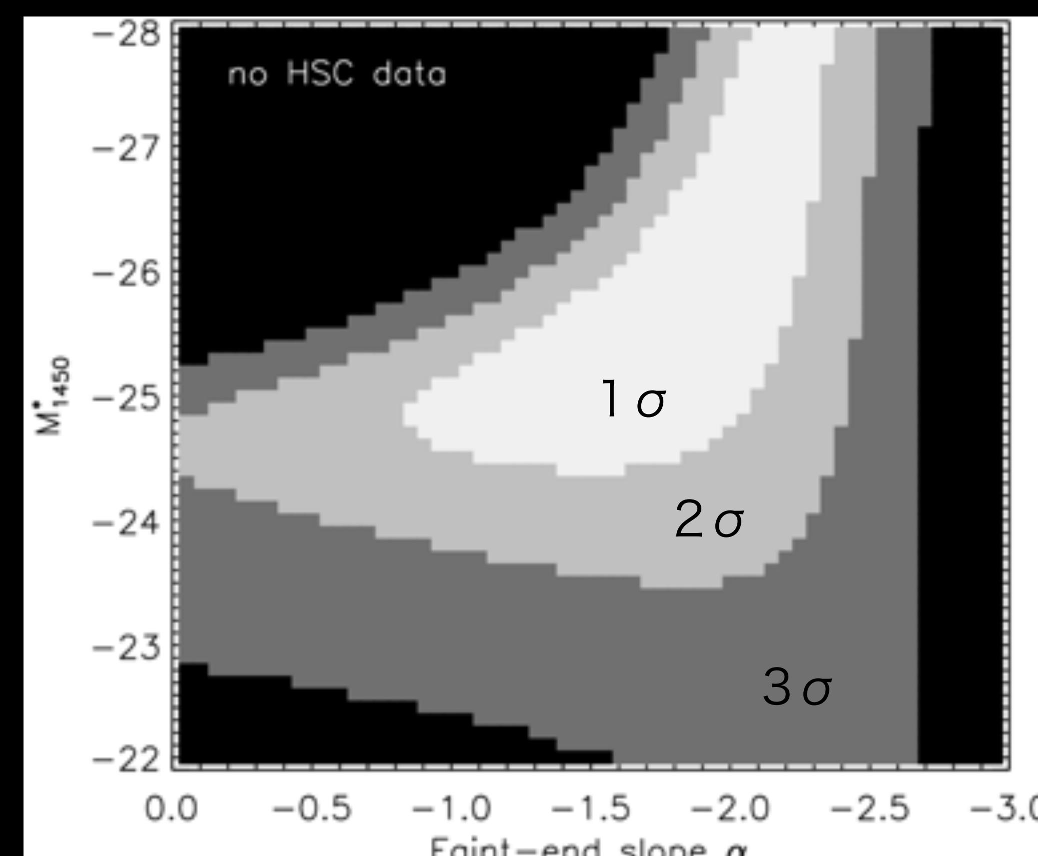
Constraints on the parameters: minimize

$S = -2 \ln L$

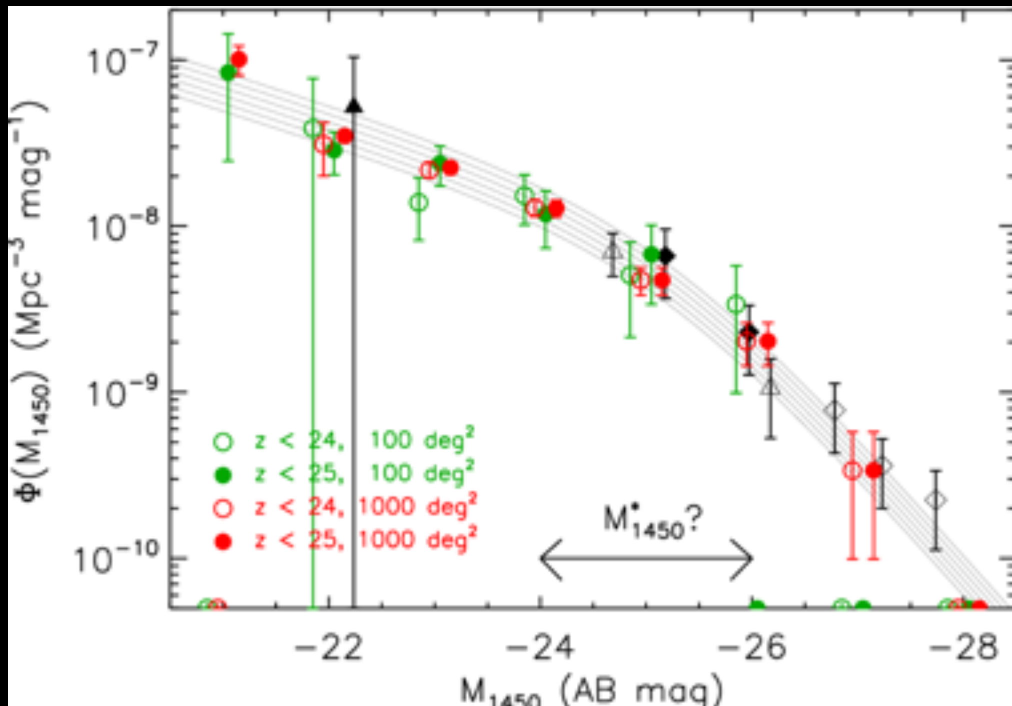
$= -2\, \Sigma_{i=1,N} \ln[\Phi(M_{1450,i}, z_i)\, p(M_{1450,i}, z_i)]$

$+ 2 \int\int \Phi(M_{1450}, z)\, p(M_{1450}, z)\, dV/dz\, dz\, dM_{1450}$

where L is the likelihood (ML method).

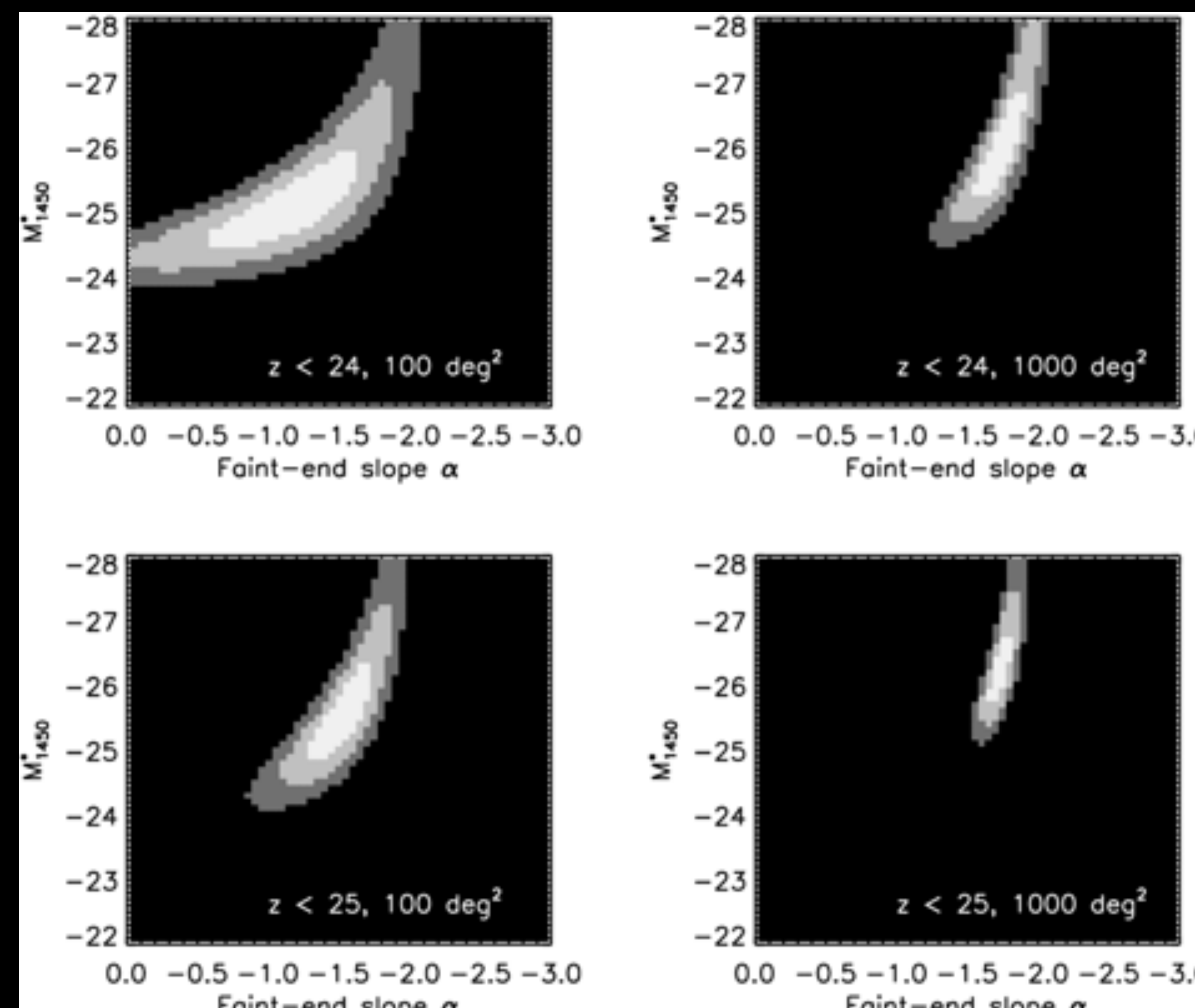


A Science Case: Luminosity Function



Legends:

- ◇ SDSS main
- ◆ SDSS deep
- △ CFHQS wide
- ▲ CFHQS deep (contains a single quasar)
- ○○ HSC survey, $z_{AB} < 24$ mag
- ●● HSC survey, $z_{AB} < 25$ mag



LF probed down to

M_{1450} = -22 mag (z_{AB} < 24 mag)

M_{1450} = -21 mag (z_{AB} < 25 mag)

Deep enough to catch the break magnitude M_{1450}^* if it is not far from the expected values.

Summary

- HSC provides an unprecedented opportunity to search for high-z quasars.
- The expected numbers of quasars per 1000 deg^2 are 200/400 (z_{AB} < 24/25 mag) at z~6, 30/70 (y_{AB} < 23.5/24.5 mag) at z~7.
- Initial selection of candidates can suffer from numerous contaminants when S/N of the photometry < 5, but they are much reduced when S/N > 10.
- Follow-up photometry in a single band (z band in the case of z~6) and/or the probabilistic selection can be powerful. Whether or not to take these steps depends on the actual number of initial candidates and available resources.
- Spectroscopic follow-up is challenging at z_{AB} > 24 mag with 8-m telescopes.
- By reaching down to M_{1450} < -22 mag, we can put a stringent constraint on the break magnitude M_{1450}^* of the luminosity function.

- We are also discussing about a systematic search for brown dwarfs (~20,000/2,000 objects of L/T dwarfs expected at z_{AB} < 24 mag, 1000 deg^2).

- Publication plan: we aim to discover the first set of high-z quasars within a year of the first data release of the HSC survey.