

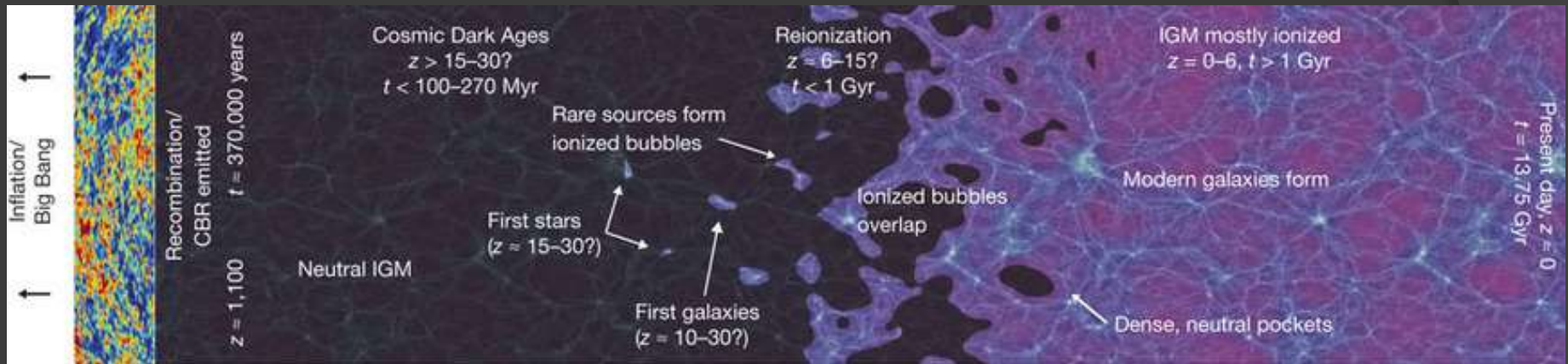
FAINT QUASARS AS RE-IONIZATION SOURCES OF EARLY UNIVERSE: AN OBSERVATIONAL CONSTRAINT

Myungshin Im

(Seoul National University)

Yongjung Kim, Yiseul Jeon, Hyunsung Jun, Dohyeong Kim, Marios
Karouzos, Jae-Woo Kim, Seong-Kook Lee, Changsu Choi, Minhee Hyun,
Yoonchan Taak, Yongmin Yoon, Soojong Pak,
& IMS team

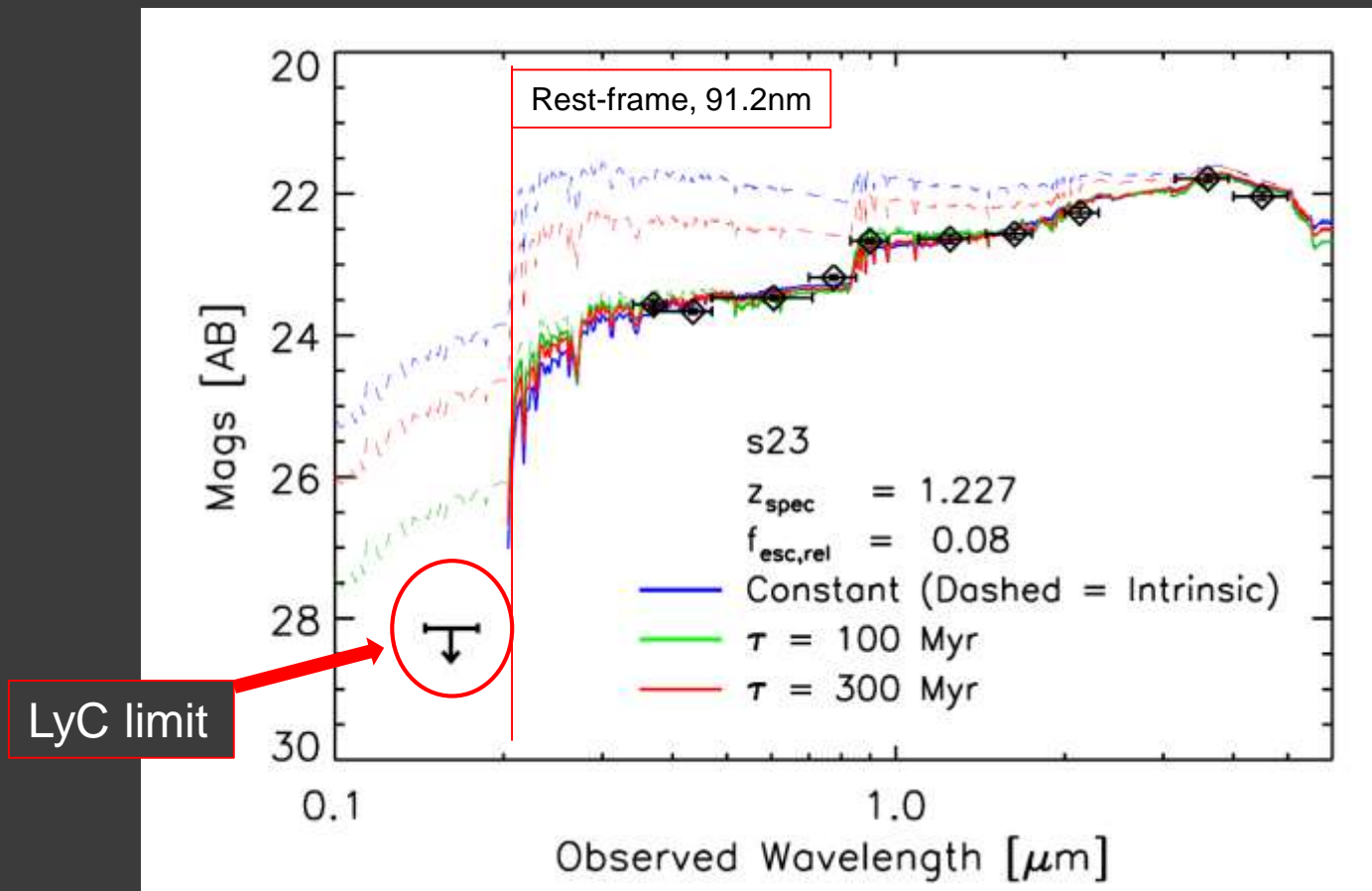
Cosmic IGM re-ionization



Robertson et al. (2010)

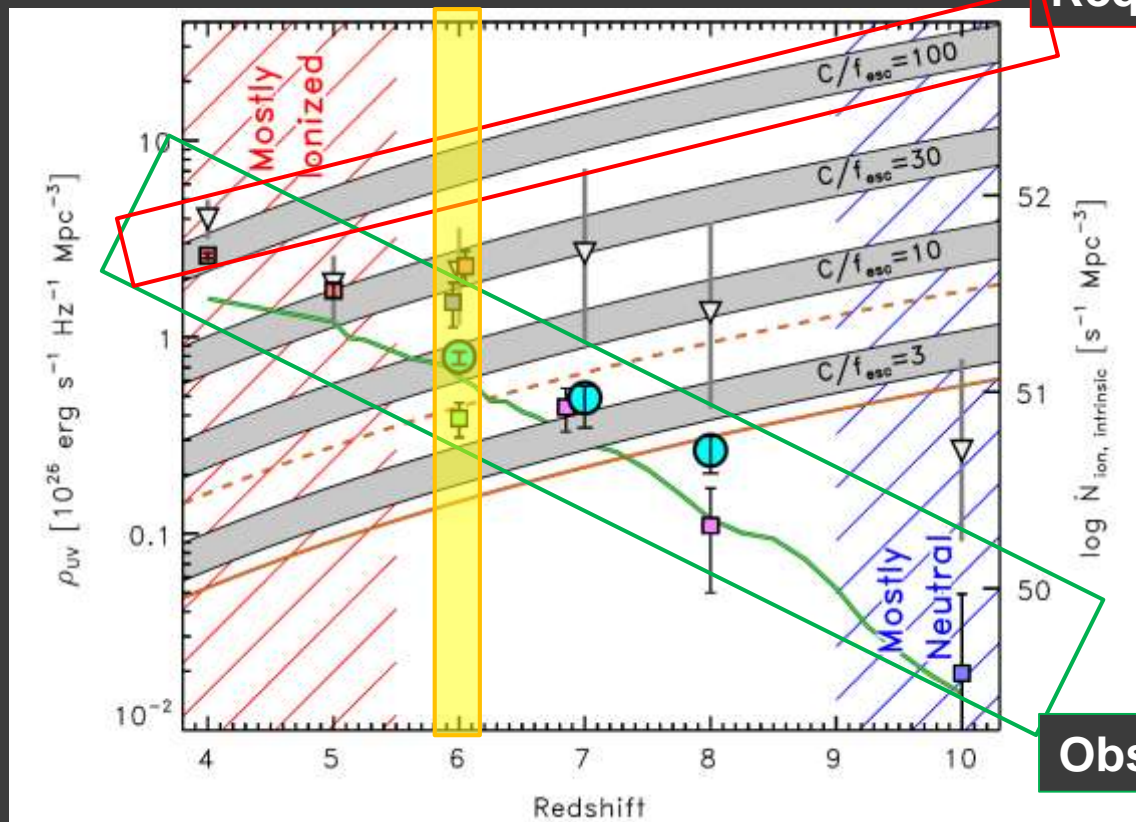
- UV photons (LyC, at $\lambda < 91.2$ nm)
- Possible sources: galaxies, quasars

Galaxies: Numerous, but UV photons ($< 91.2\text{nm}$) very few ($f_{\text{esc}} \sim 1\%$)



LyC in LBG at $z=3$, with $f_{\text{esc}} < 0.03$ (Siana et al. 2010)

UV photons from galaxies, not enough for IGM ionization



Required UV flux ($C=3$, $f=0.03$)

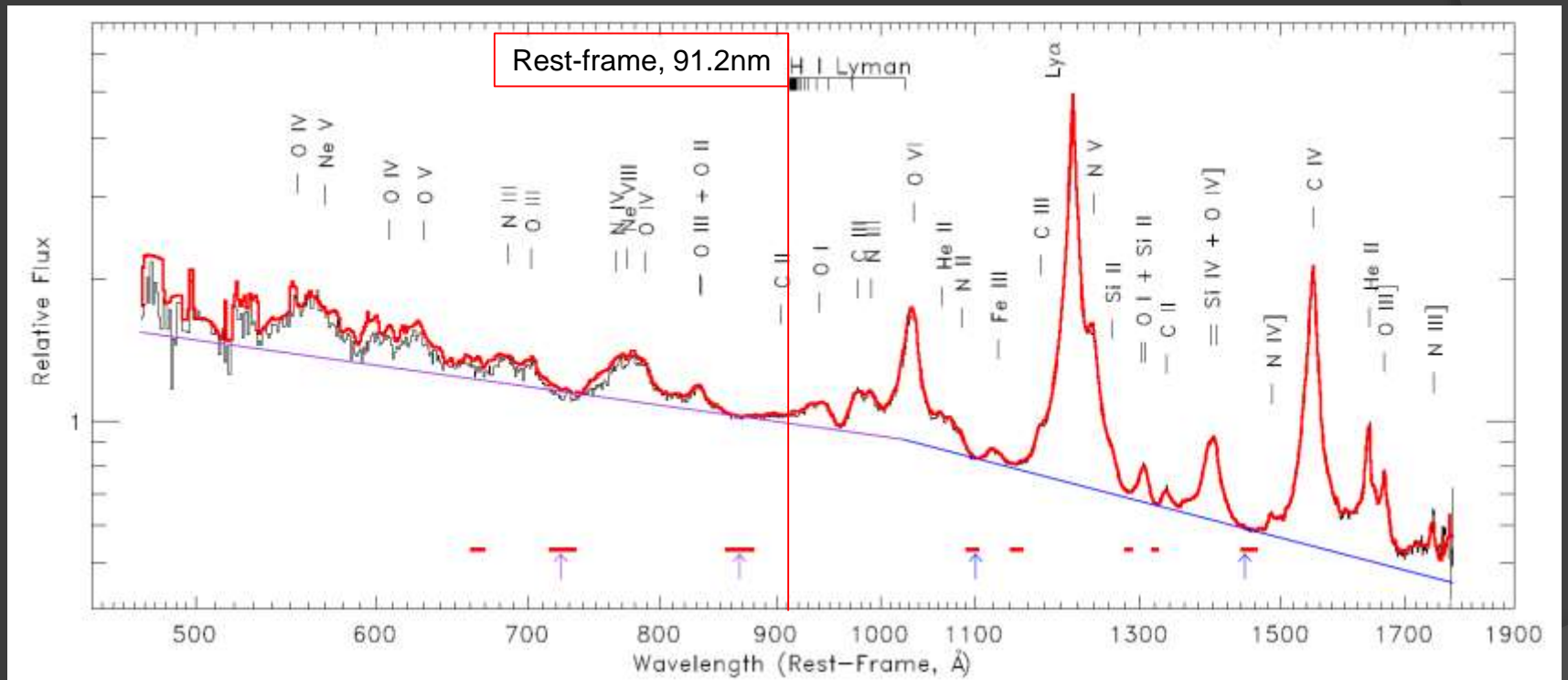
Covering factor
 $C \sim 1 - 30$
(Gnedin & Ostriker 1997;
Faucher-Giguere et al. 2008)

Escape fraction
 $f_{\text{esc}} < 0.01 - 0.1$
(Siana et al. 2010;
Faucher-Giguere et al. 2008;
Yajima et al. 2011)

Observed galaxy contribution

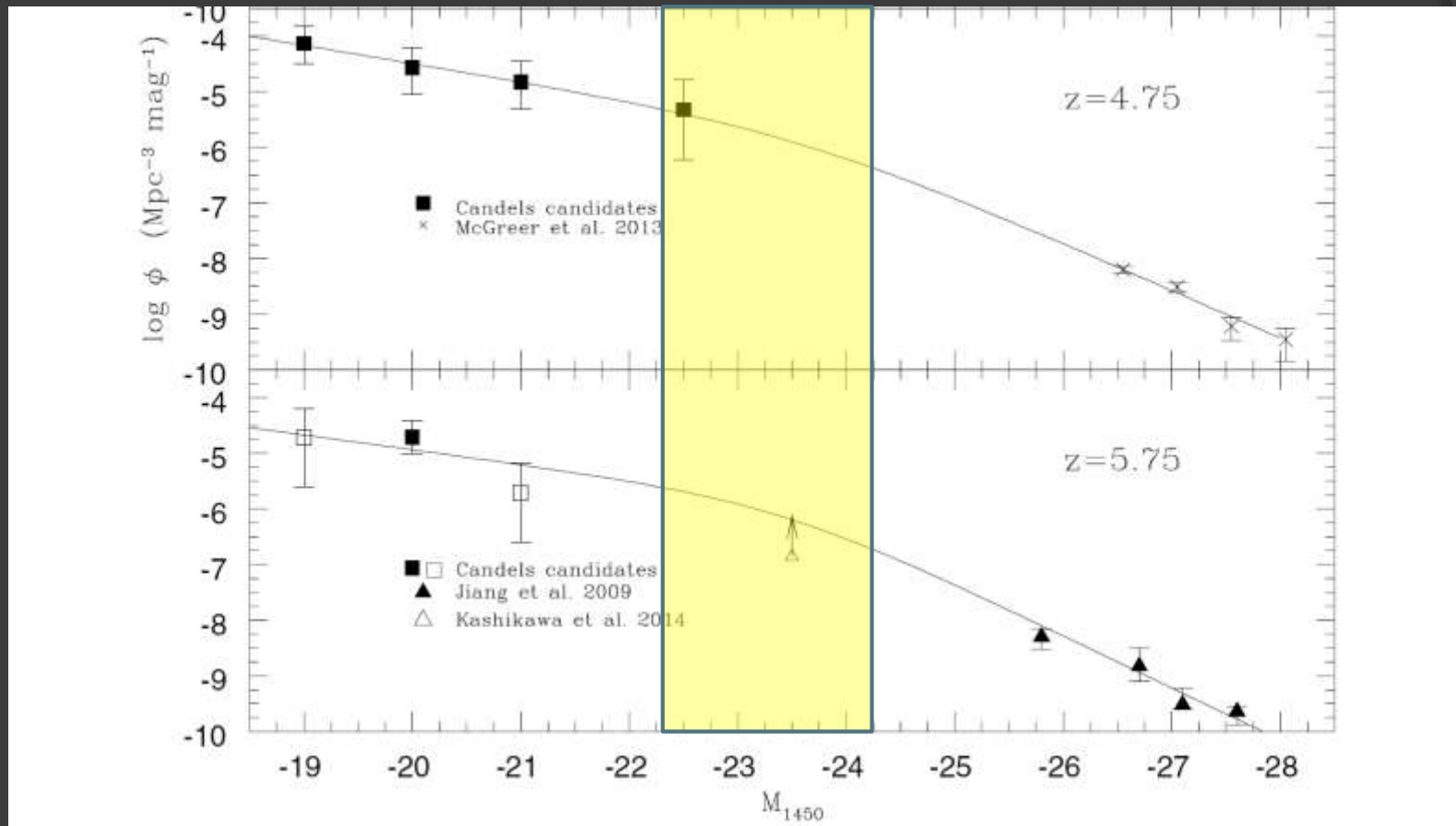
Finkelstein et al. (2012)

Quasars: Not many, but strong UV flux at $\lambda < 91.2\text{nm}$



Composite UV spectra of 159 AGNs from HST COS (Stevans et al. 2014)

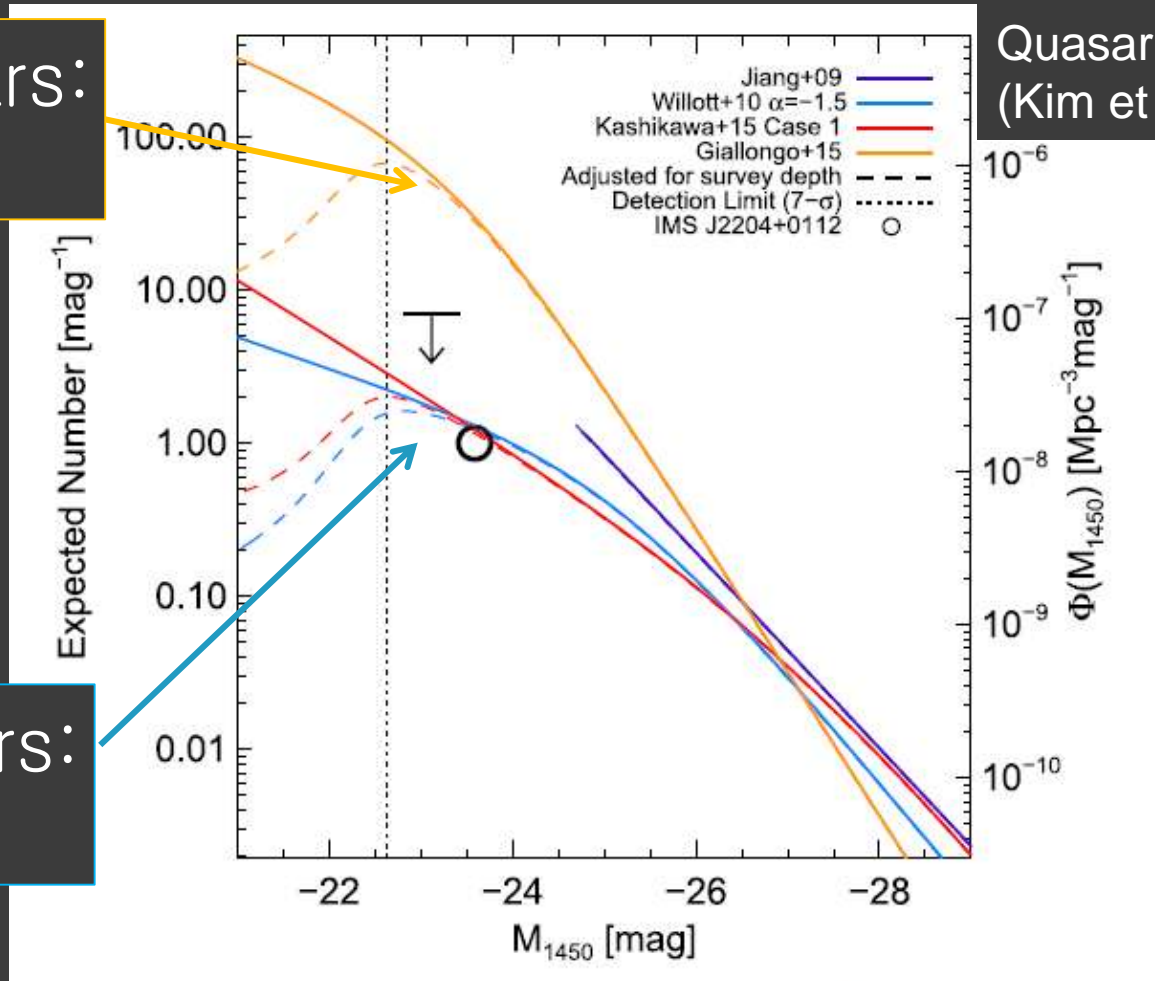
UV luminosity function of quasars



What are the main sources that illuminated the early universe?

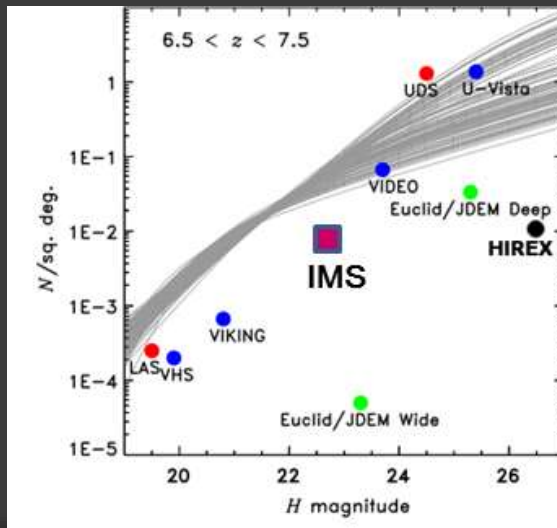
Many quasars:
Quasars

Few Quasars:
Galaxies

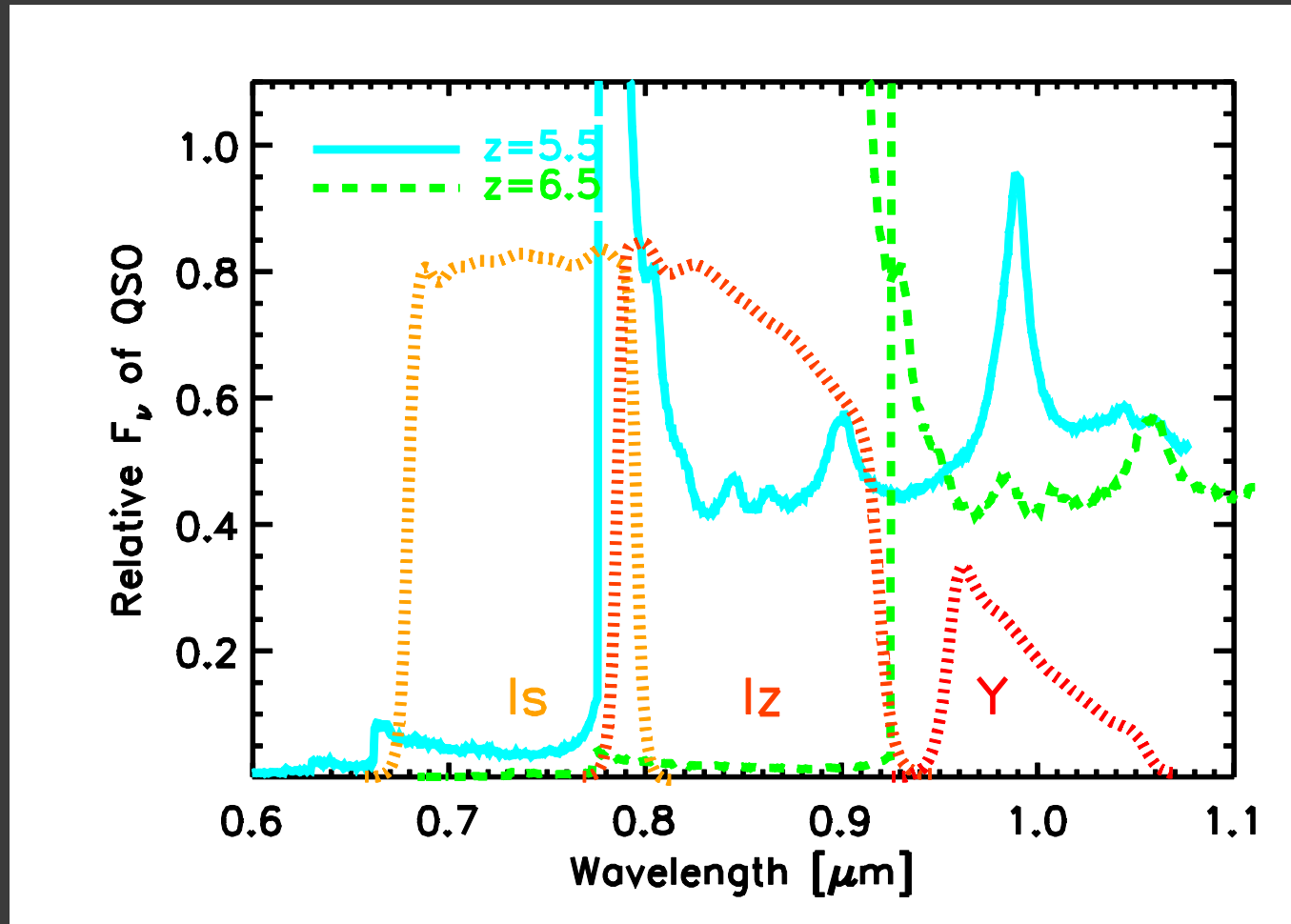


Infrared Medium-deep Survey (IMS)

- ◉ Imaging survey at $J < 23$ AB mag, 120 deg² (+ Y-band data)
- ◉ UKIRT WFCAM observation (2009 ~ 2013)
- ◉ CFHT ugriz imaging data ($z \sim 25$ AB mag)
- ◉ High- z quasars, galaxy clusters, transients

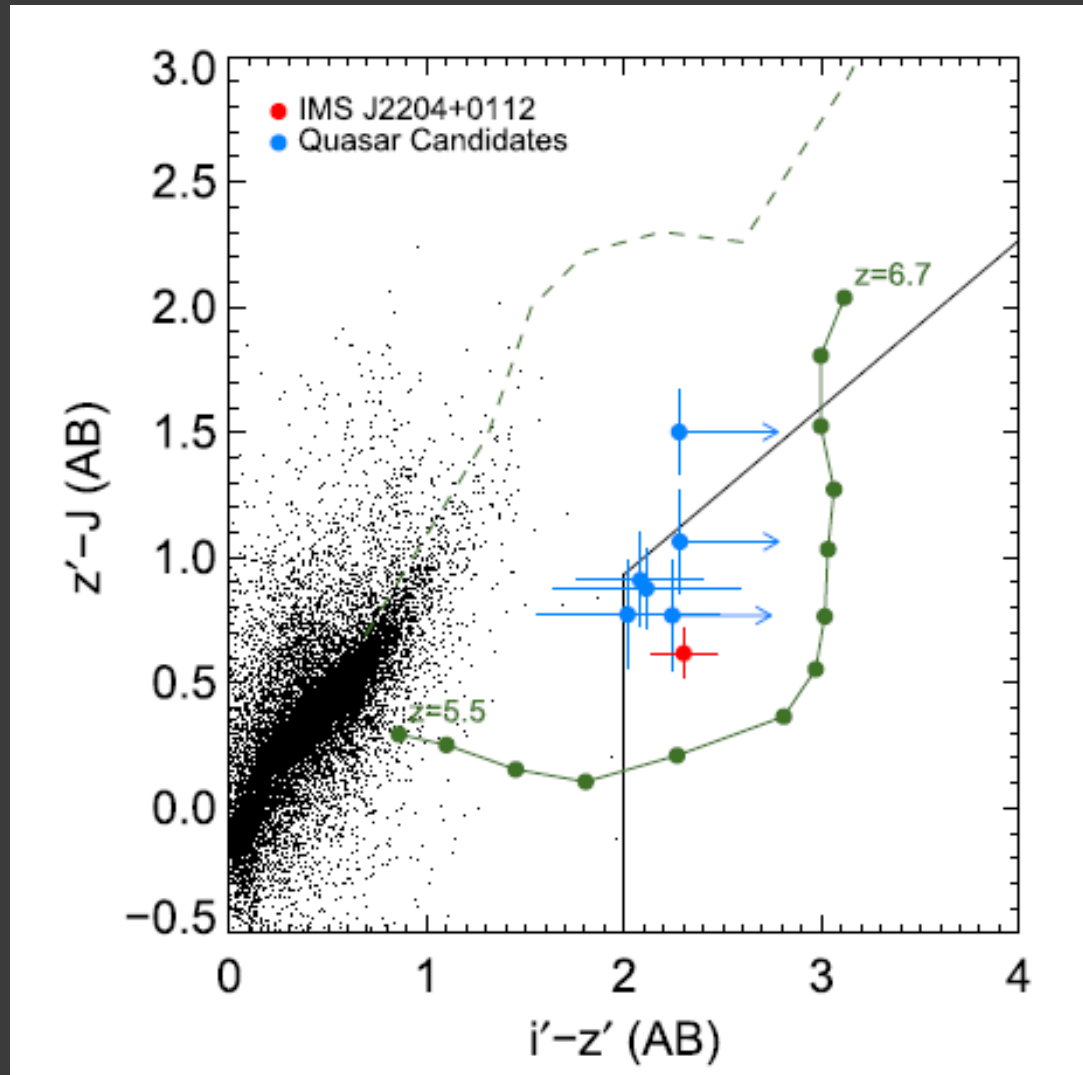


High redshift quasar selection: Strong break at 121.6 nm ($\text{Ly}\alpha$)



Jeon, Y. et al.
(2016)

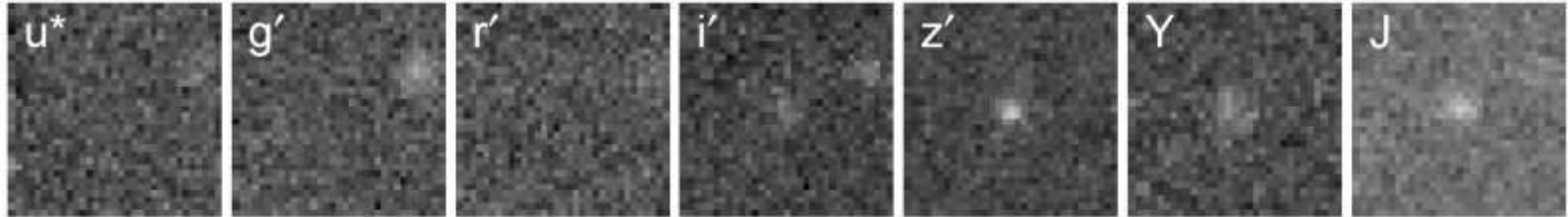
High redshift quasars have a peculiar color



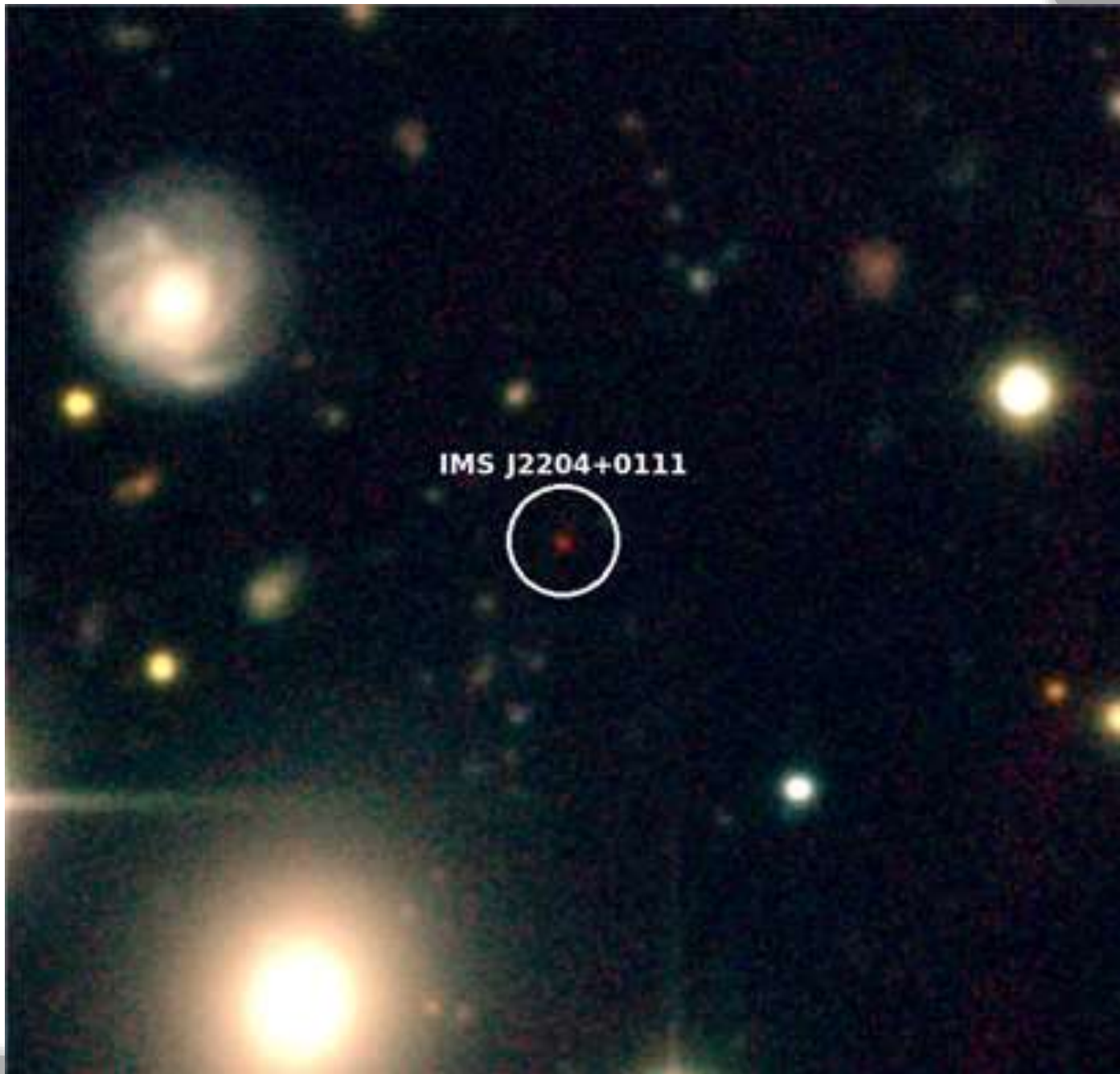
Kim, Y. et al. (2015)

Faint quasar candidate at $z \sim 6$

IMS J2204+0112



R.A. Dec. (J2000.0)	i'	z'	Y	J	Redshift	M_{1450}
22:04:17.92 +01:11:44.8	25.26 ± 0.15	22.95 ± 0.07	23.10 ± 0.09	22.34 ± 0.08	5.944 ± 0.002	-23.59 ± 0.10

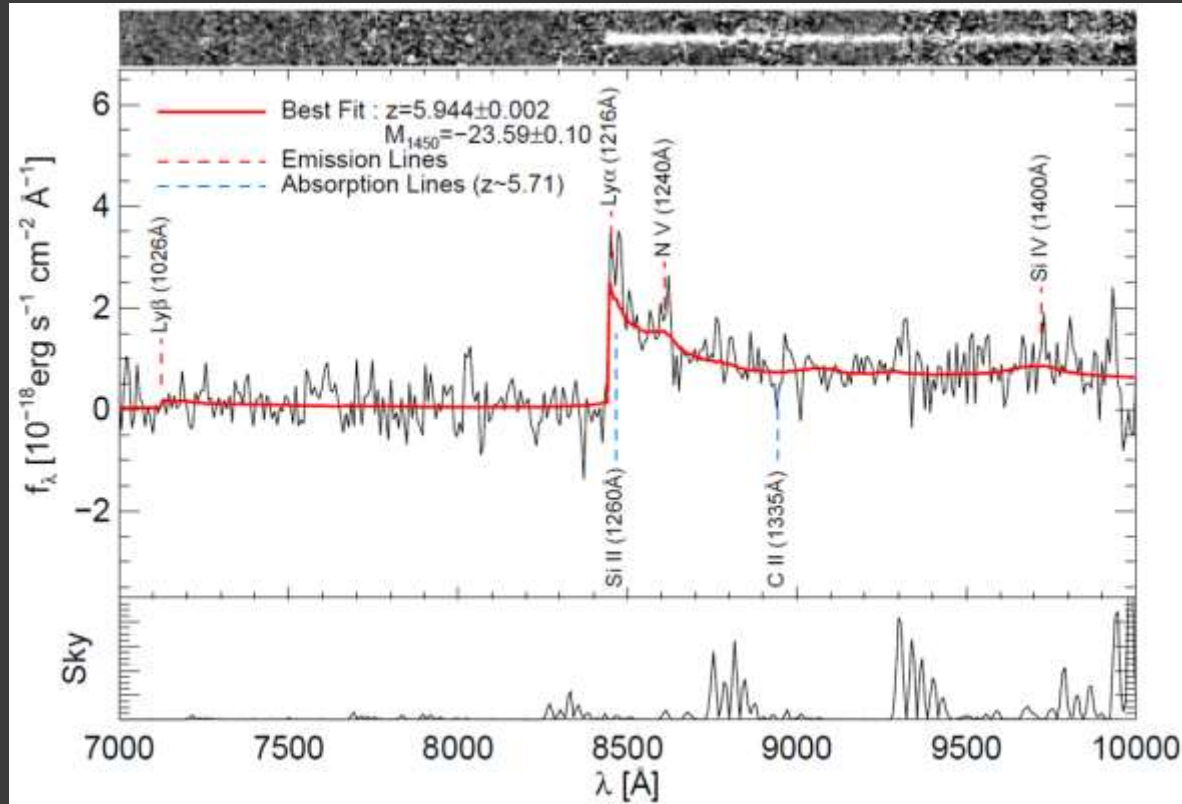


Spectroscopic observation

- ◉ Gemini/GMOS-S Observation (2015A)
 - Supported by **K-GMT Science Program** of KASI
 - **Nod & Shuffle longslit** (1" width) mode with R150_G5326 grating
 - 4x4 binning → **7.72 Å/pixel** (~290 km/s)
 - RG610_G0331 filter to avoid the order-overlap
 - 12 sequences of 968 s (~3 hr)
 - Use five frames (~1.3 hr) with seeing < 1"



Spectrum of IMS J2204+0112

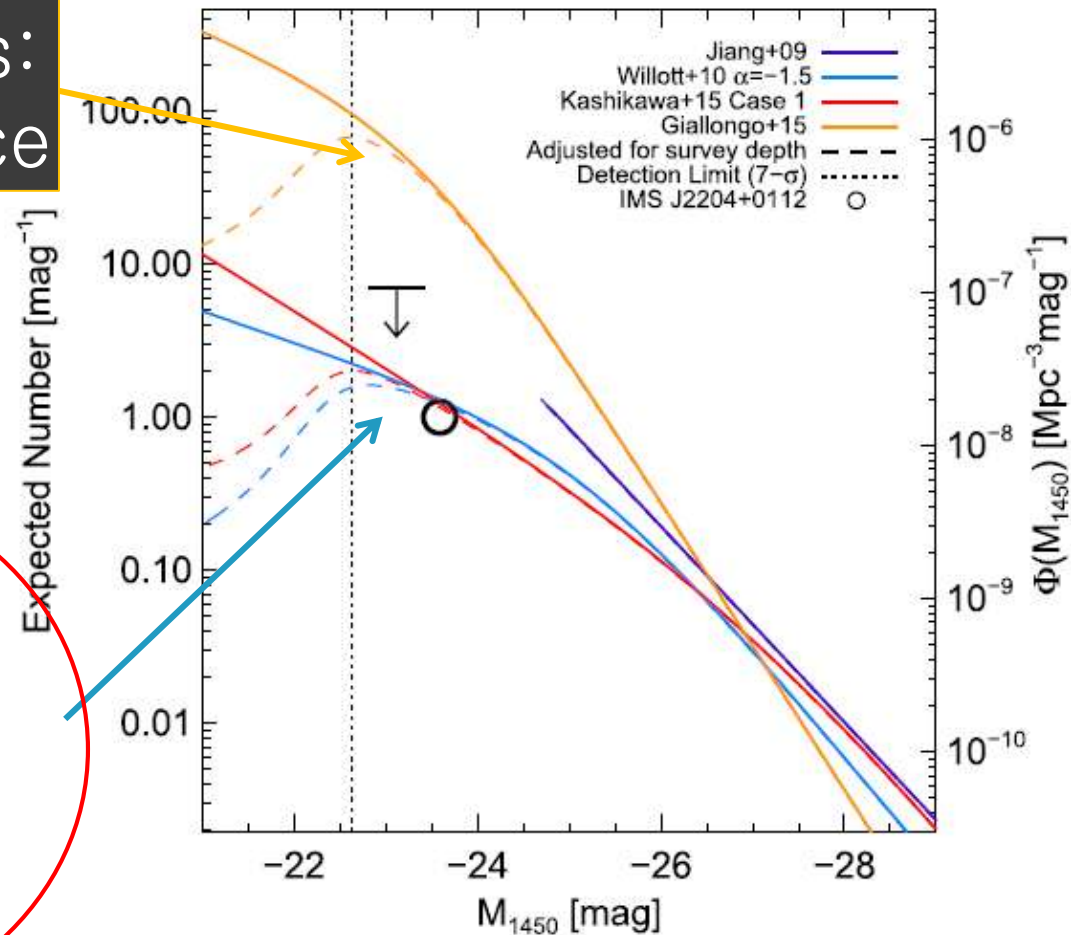


- Clear break at $\sim 8443 \text{ \AA}$ (identified as Ly α)
 - $z = 5.944 \pm 0.002$, $M_{1450} = -23.59 \pm 0.10 \text{ mag}$

Quasar contribution is likely to be <10% of ionizing photons

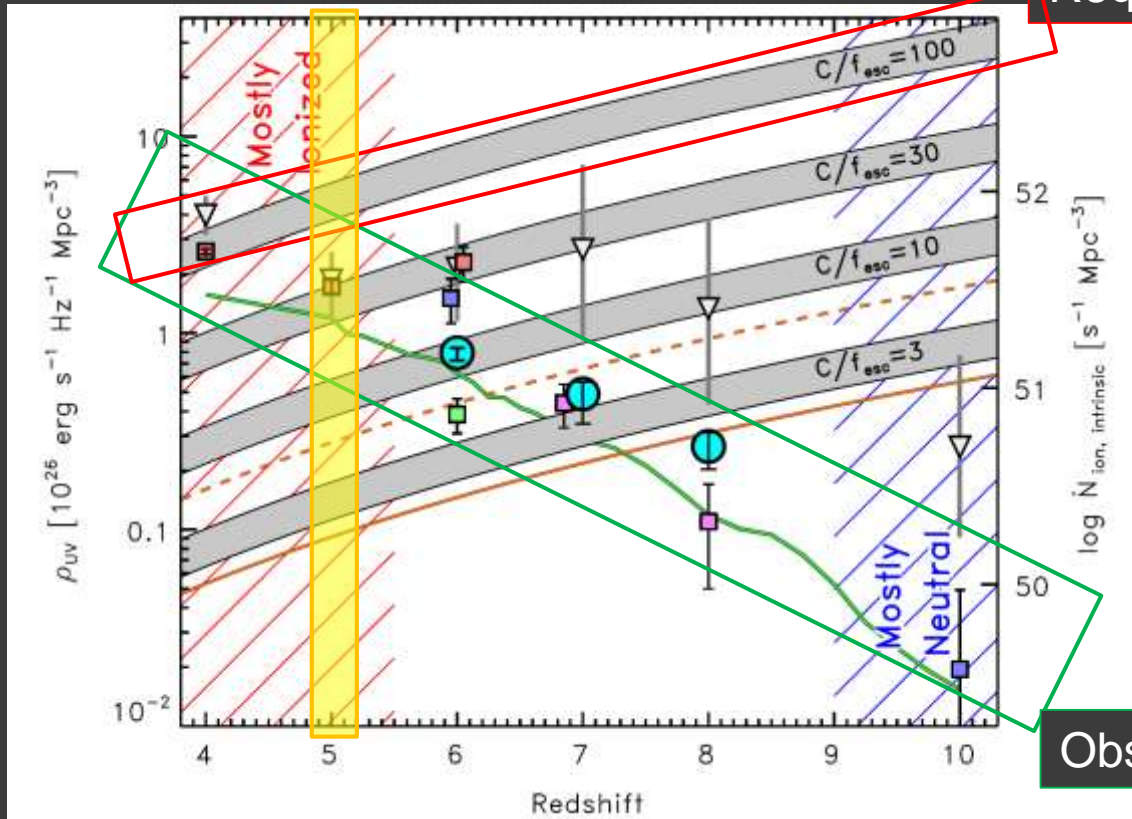
Many quasars:
ionizing source

Few
quasars



Quasar LF
(Kim et al. 2015)

UV photons at $z=5$



Required UV ($C=3, f=0.03$)

Covering factor

$C \sim 1 - 30$

(Gnedin & Ostriker 1997;
Faucher-Giguere et al. 2008)

Escape fraction

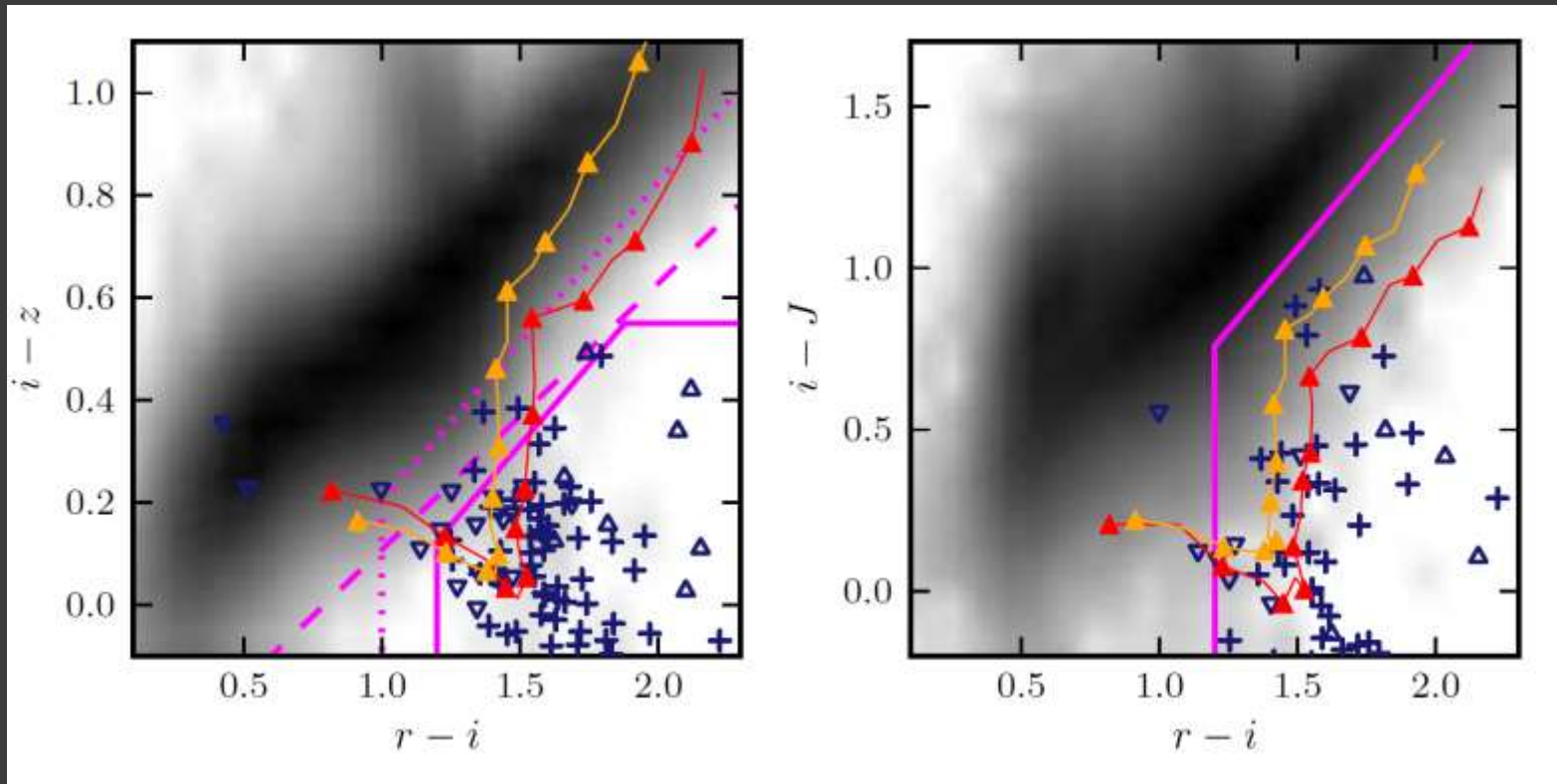
$f_{\text{esc}} < 0.01 - 0.1$

(Siana et al. 2010;
Faucher-Giguere et al. 2008;
Yajima et al. 2011)

Observed galaxy contribution

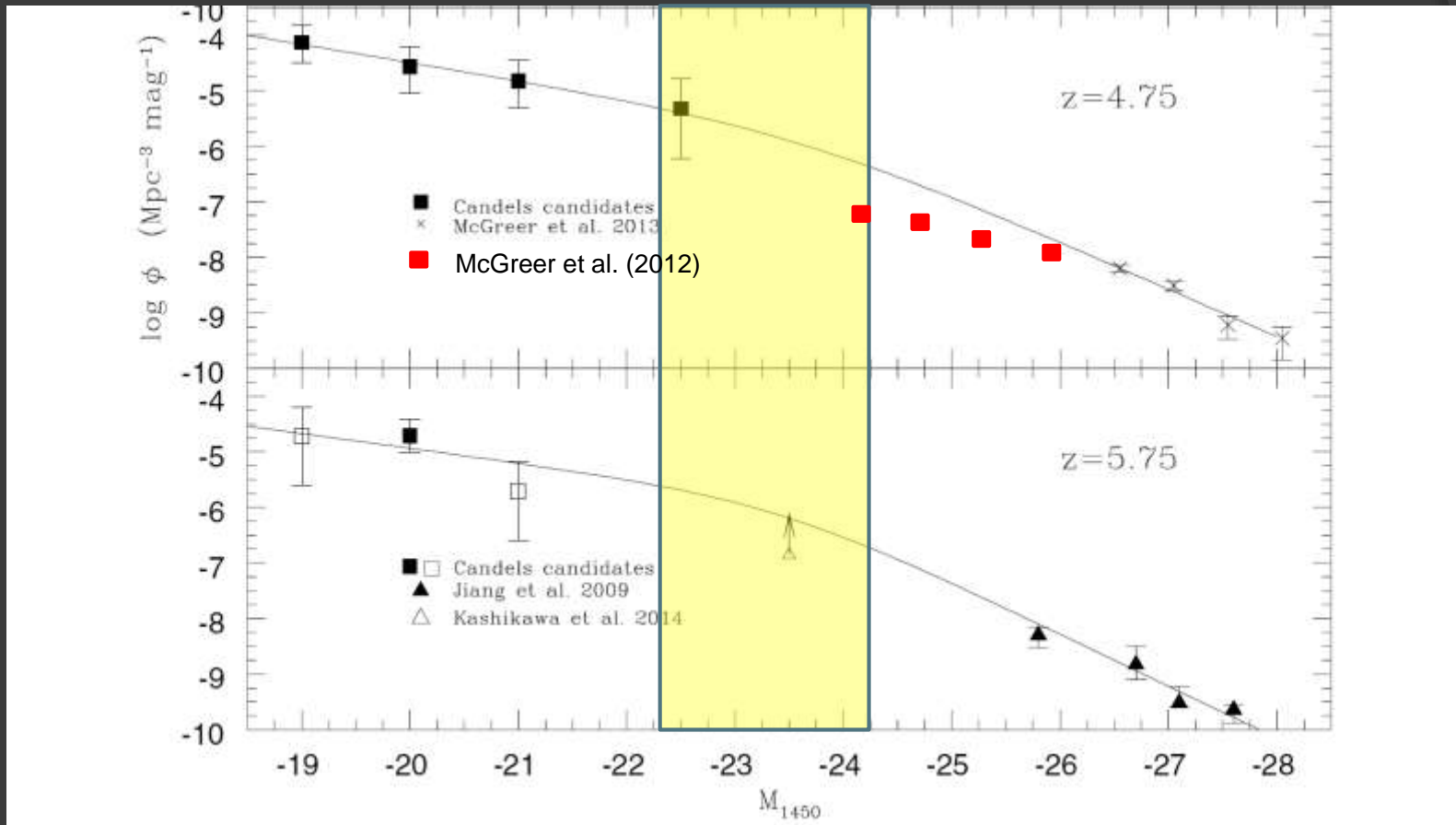
Finkelstein et al. (2012)

Selection of $z \sim 5$ quasars: Stellar contamination is a concern



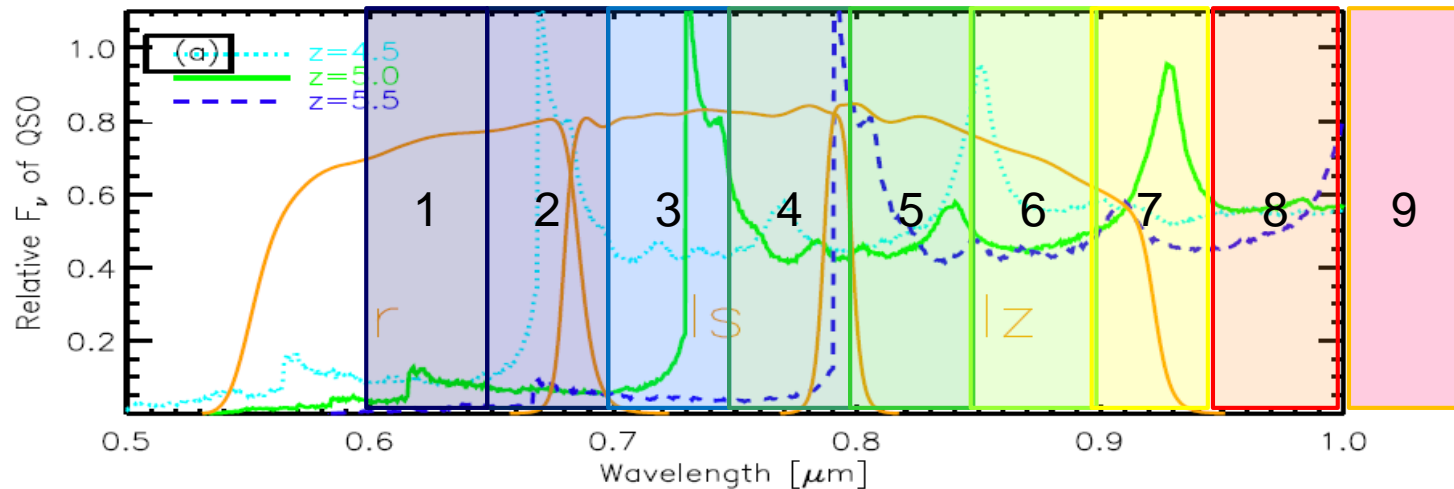
McGreer et al. (2012)

UV luminosity function of quasars at $z \sim 5$

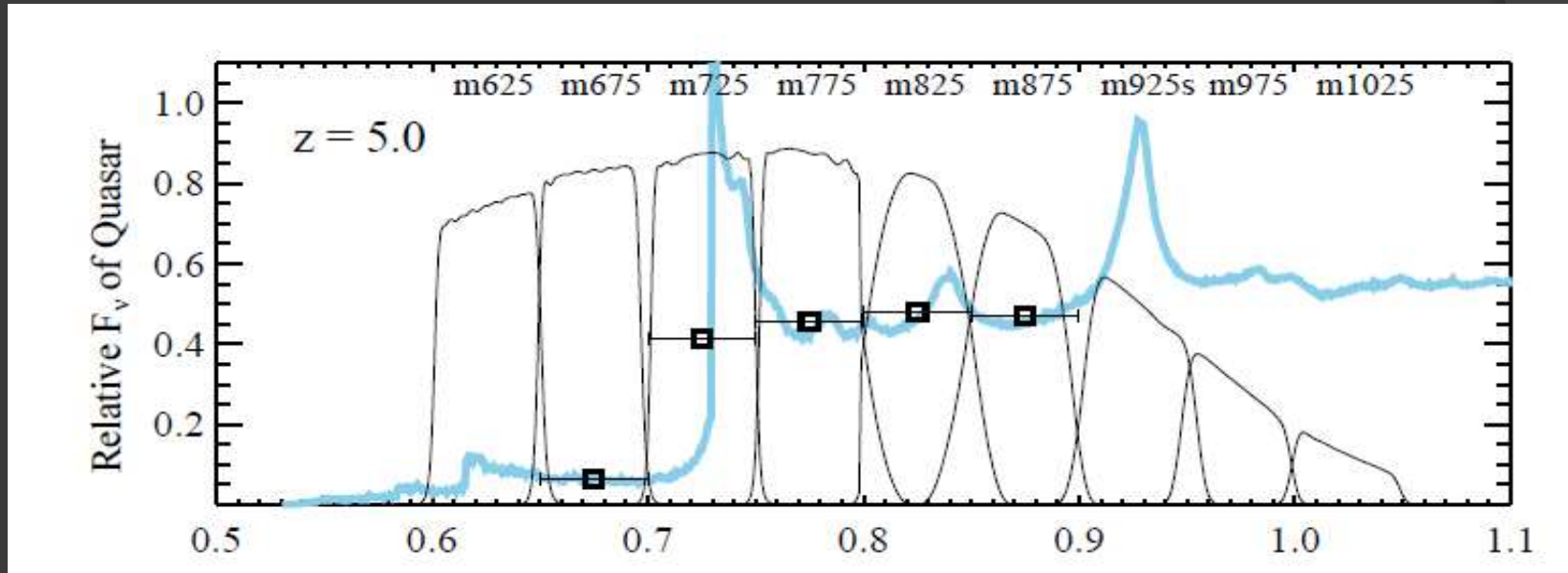


SQUEAN: SED Machine for Quasars in Early Universe

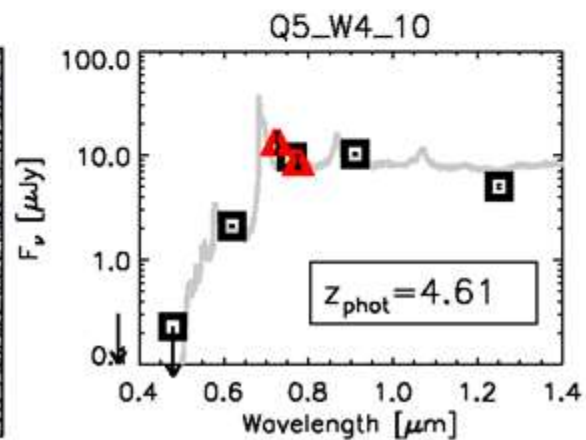
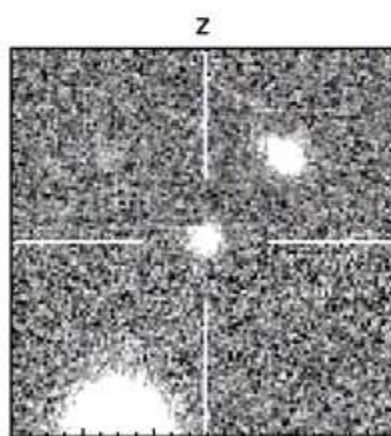
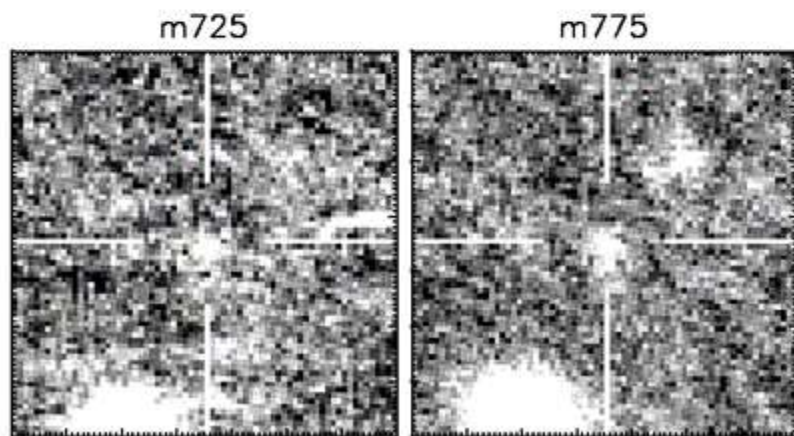
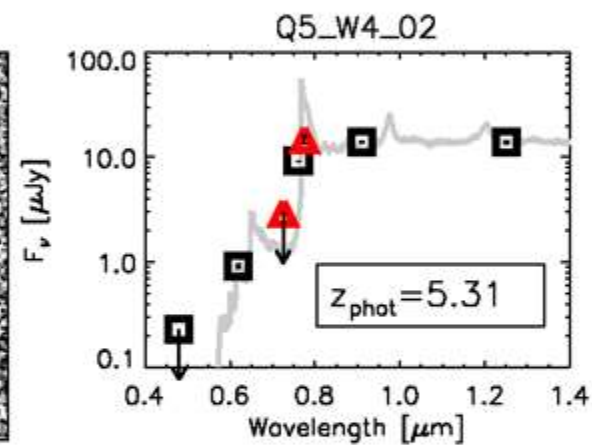
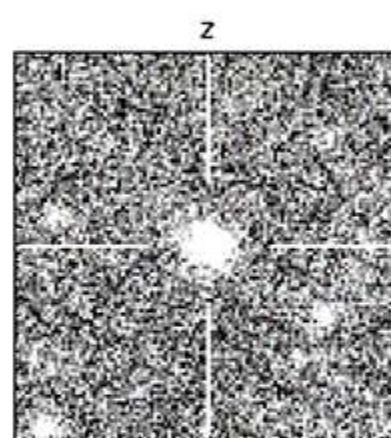
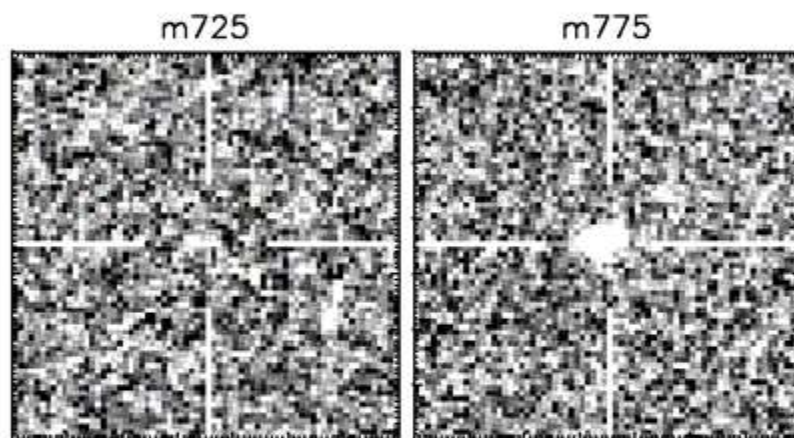
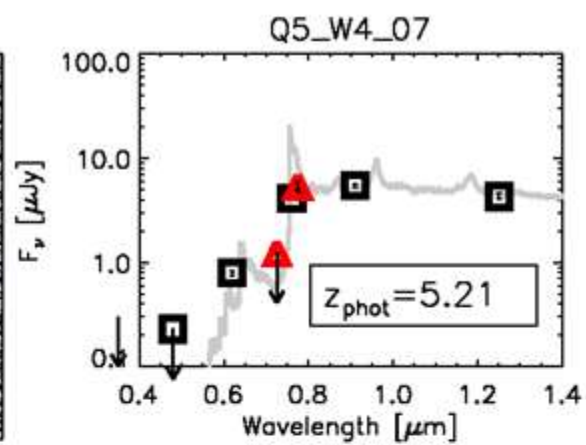
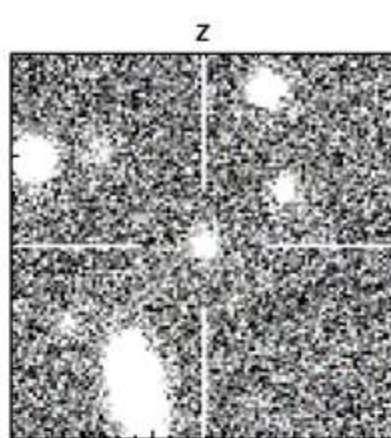
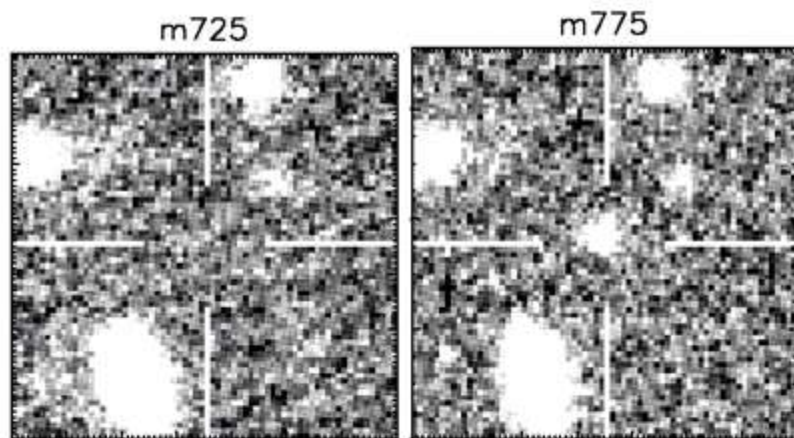
- Medium-band filters with 50nm with from 600-1000 nm
- 2.1m telescope at McDonald observatory



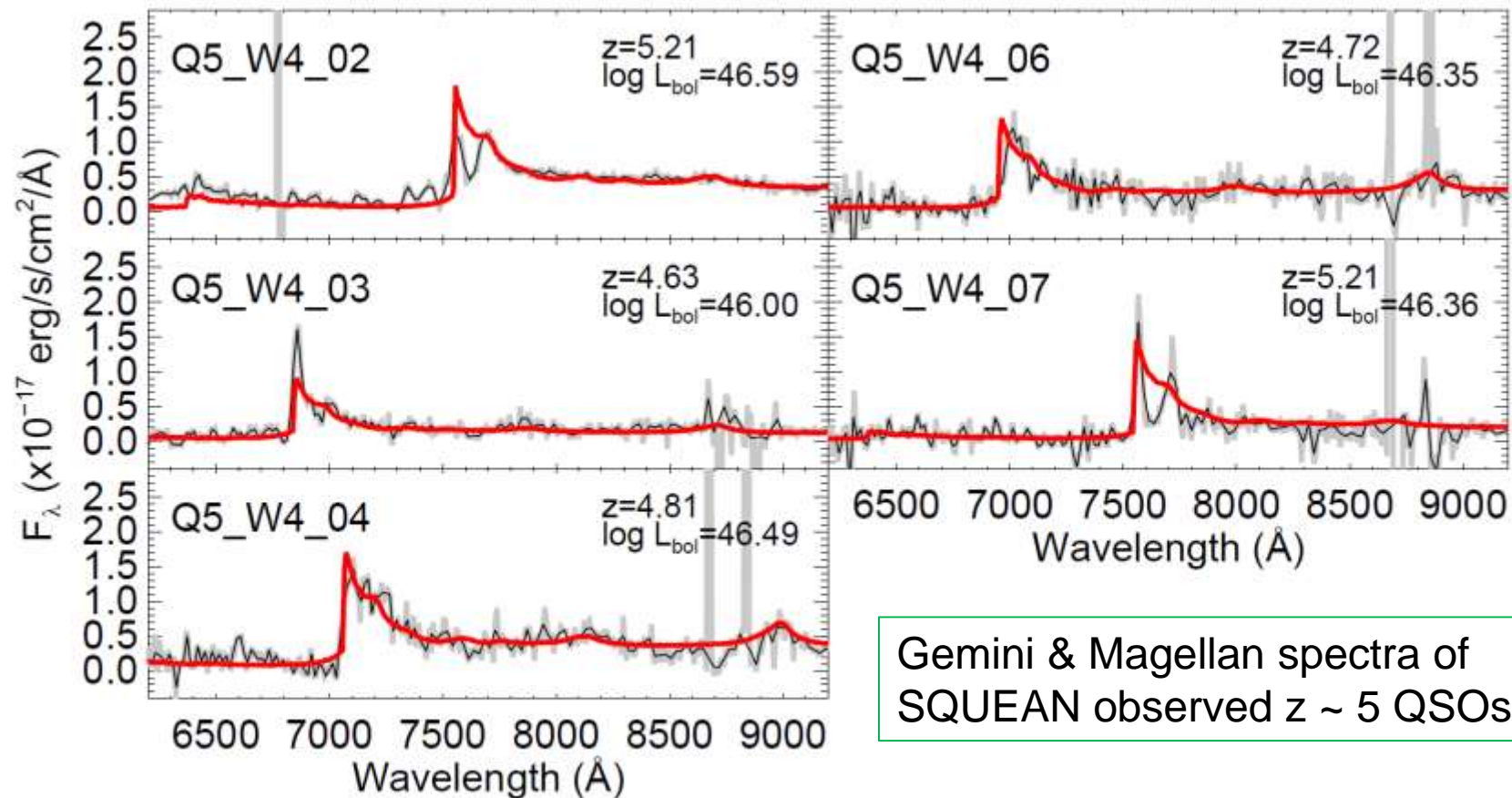
SQUEAN medium-band observation



- Multi-color selection (grizJ)
- Follow-up observation with SQUEAN

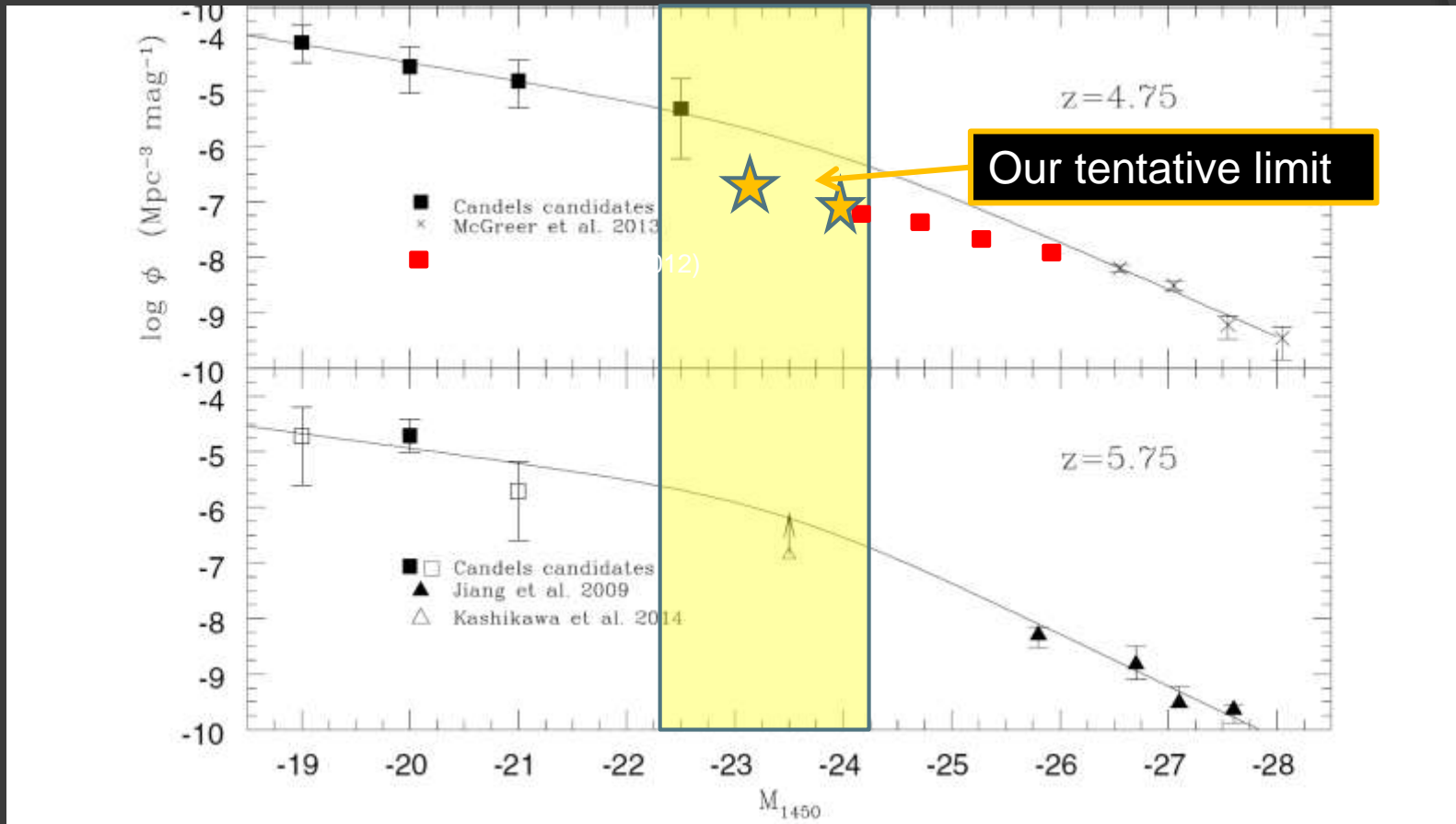


Spectroscopic confirmation (60% \rightarrow >90% success rate)



Gemini & Magellan spectra of
SQUEAN observed $z \sim 5$ QSOs

UV luminosity function of quasars at $z \sim 5$: our limit



Summary

- ⦿ Faint quasars: IGM ionization source?
- ⦿ We discovered one $z \sim 6$ quasar and a number of $z \sim 5$ ($J \sim 23$ AB mag)
- ⦿ The number of faint quasar: probably too few to fully account for the IGM ionization at $z \sim 5$ and 6