What do we know about the first black holes and the first quasars?

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Reionization In The Red Centre
Uluru
July 2013

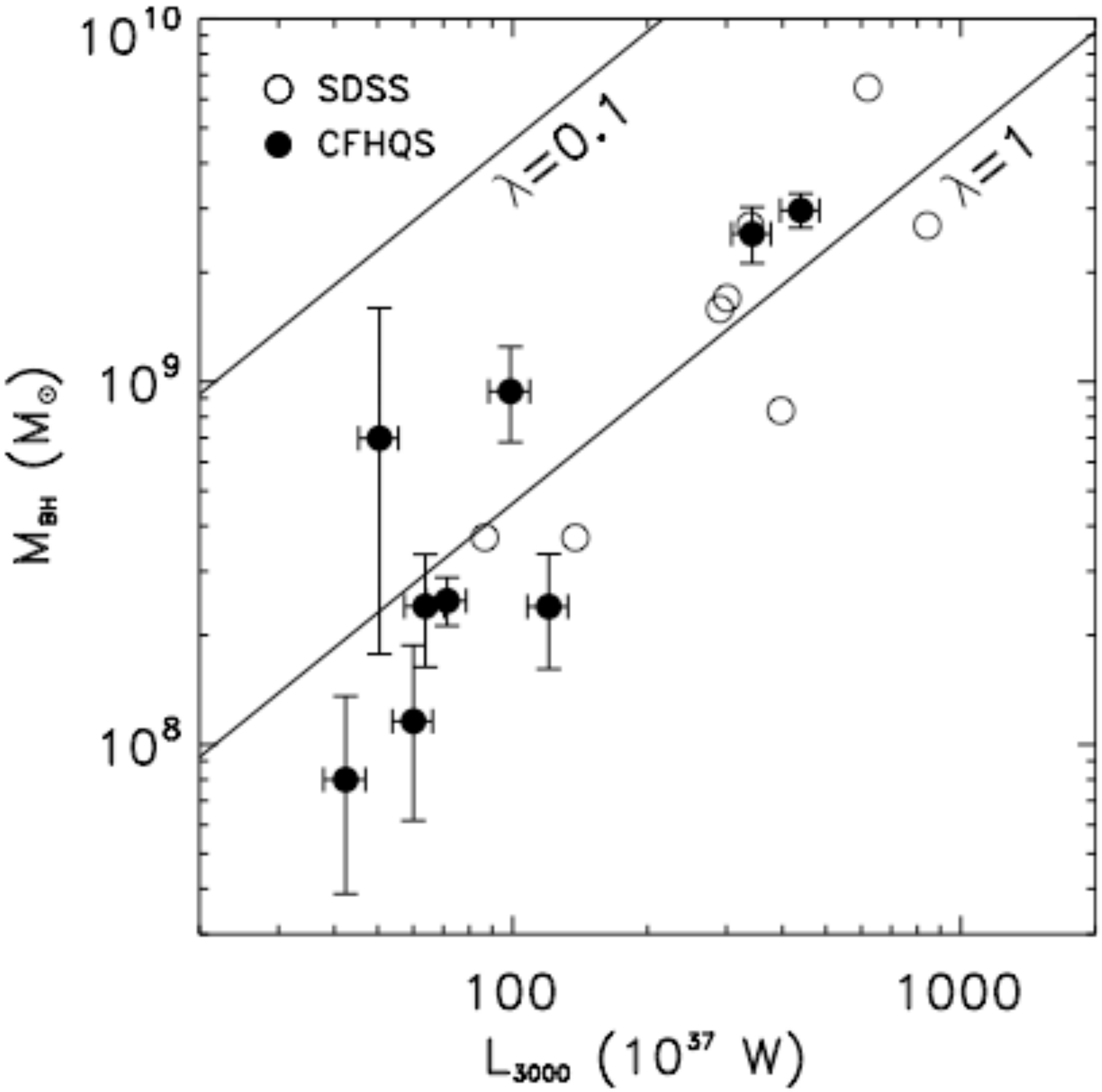
Quasars

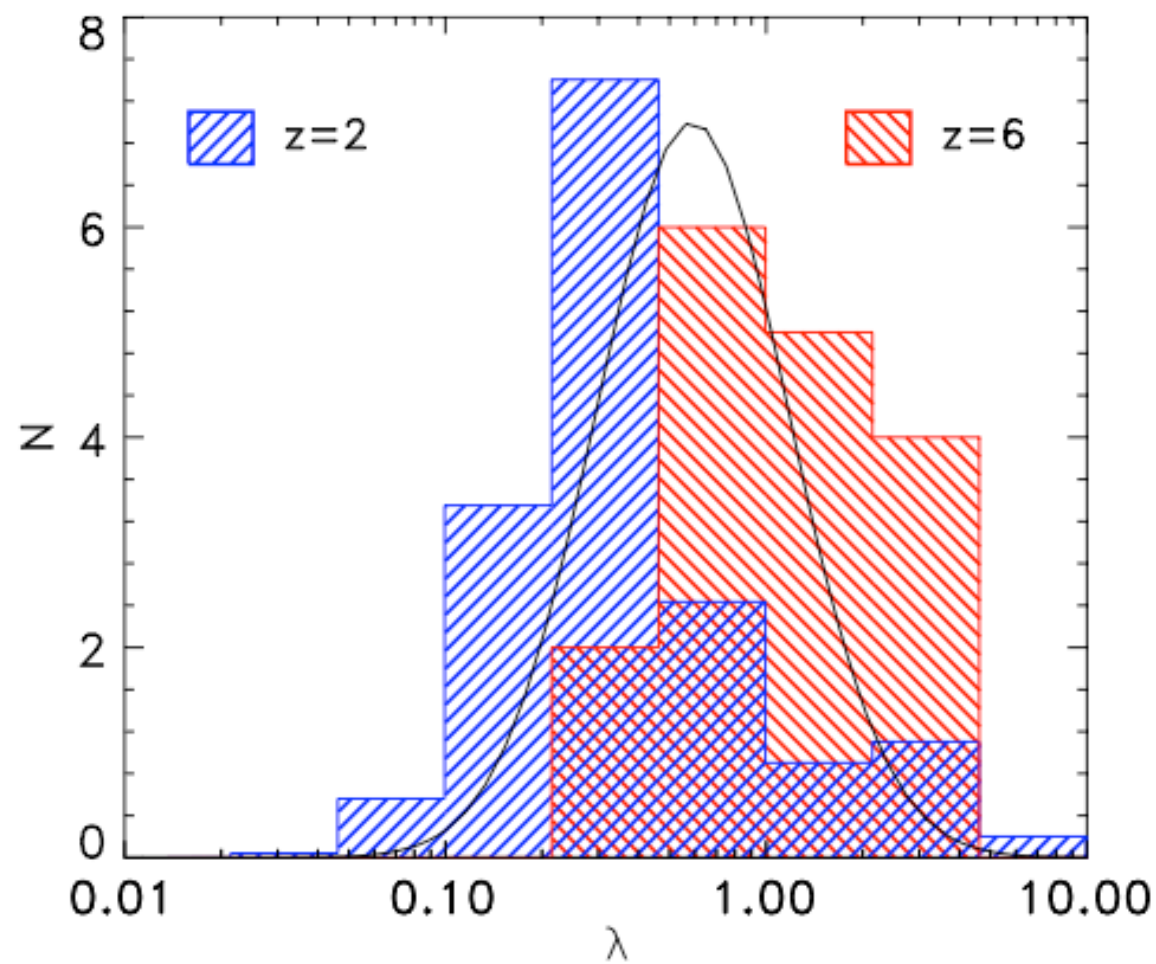
Fuelled by accretion onto super-massive black holes;

Numbers decreasing sharply with redshift from z ~ 2 - decrease by a factor of ~3 per unit z.

"First quasars" or HZQs defined here as z >~ 5.8 (i.e., i-band drop-outs) seen as they were <~ 1 Gyr after the Big Bang

HZQ black hole masses

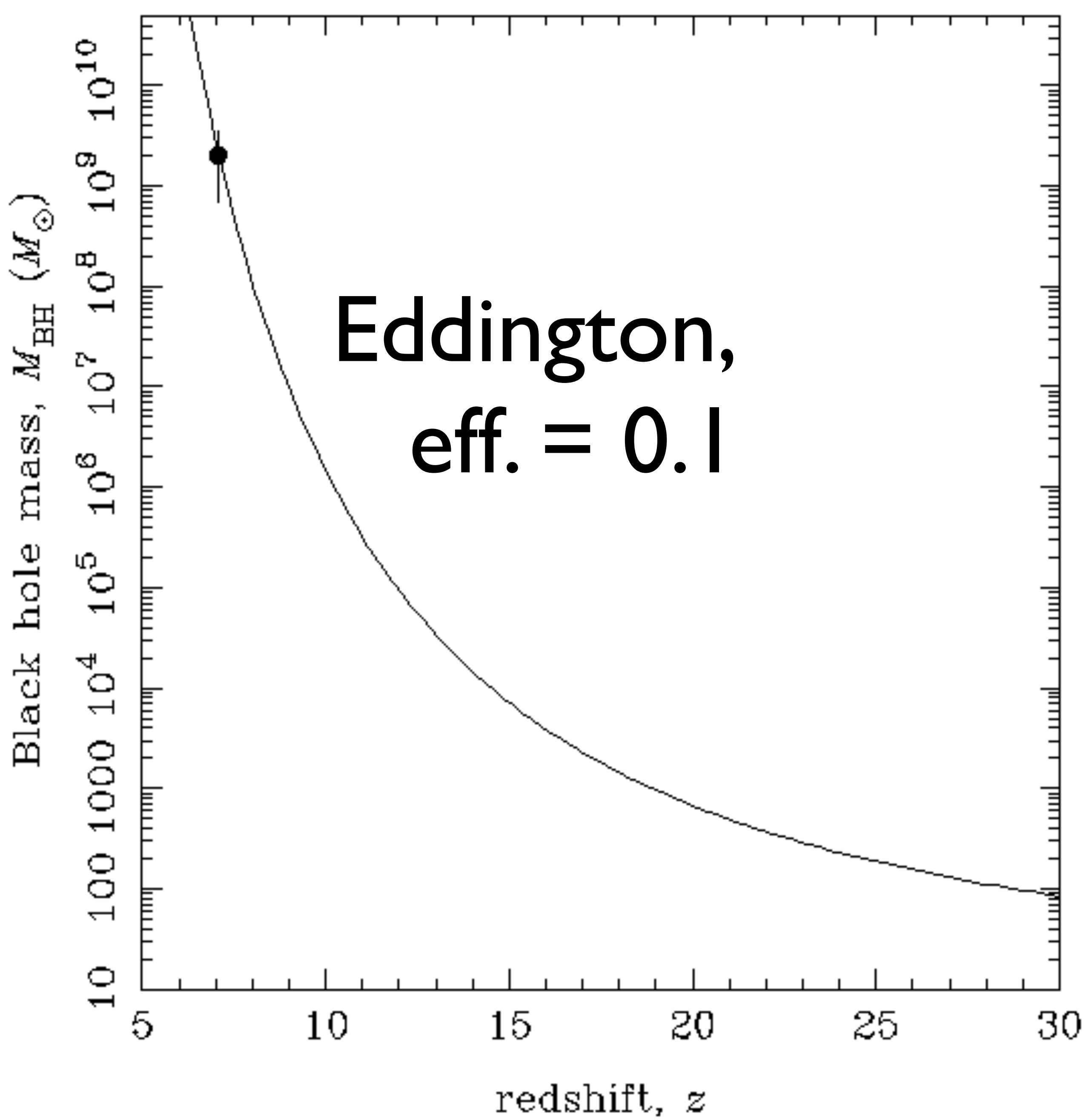


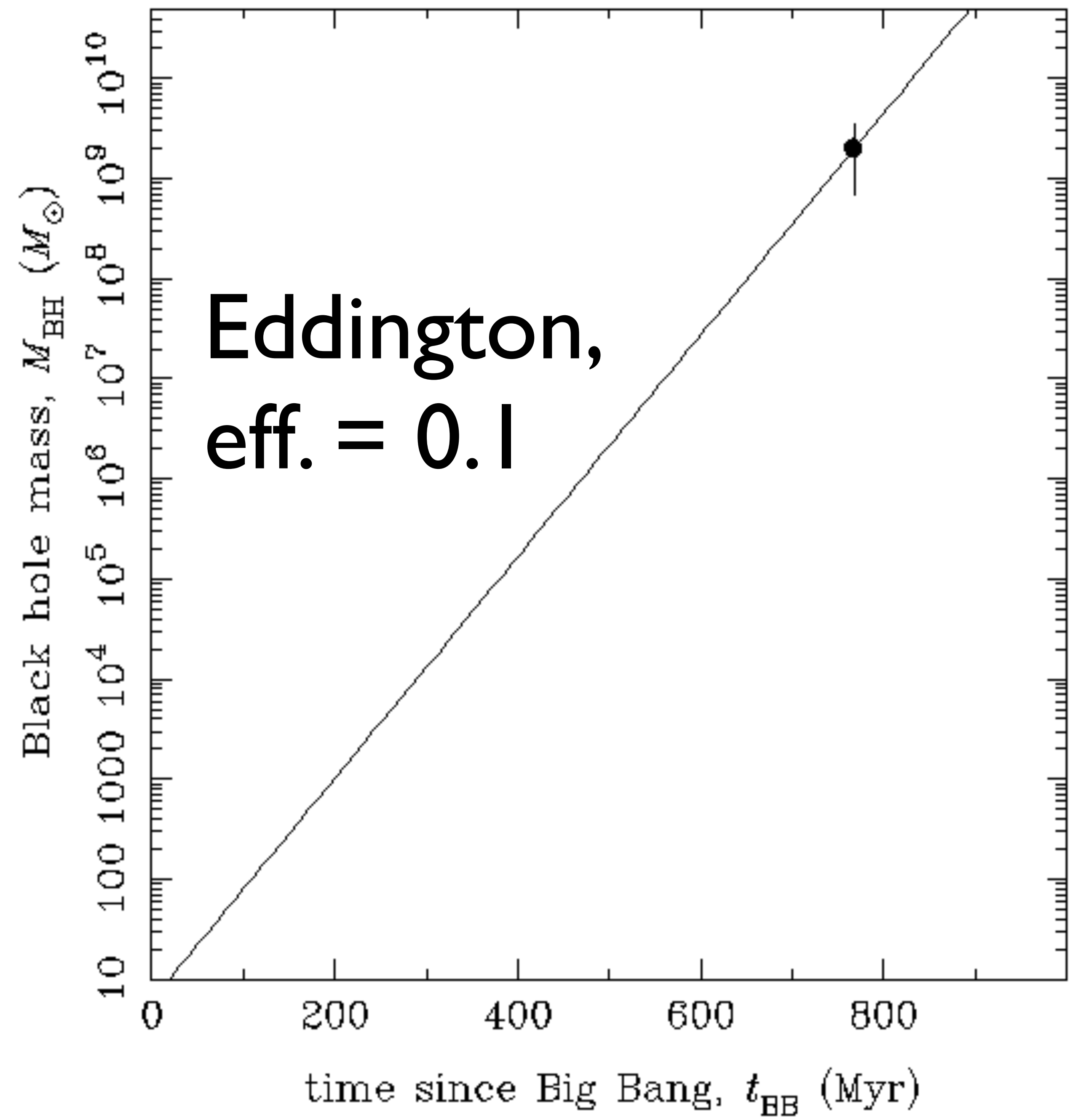


(Willott et al. 2010)

Instantaneous super-Eddington accretion at z ~ 6.

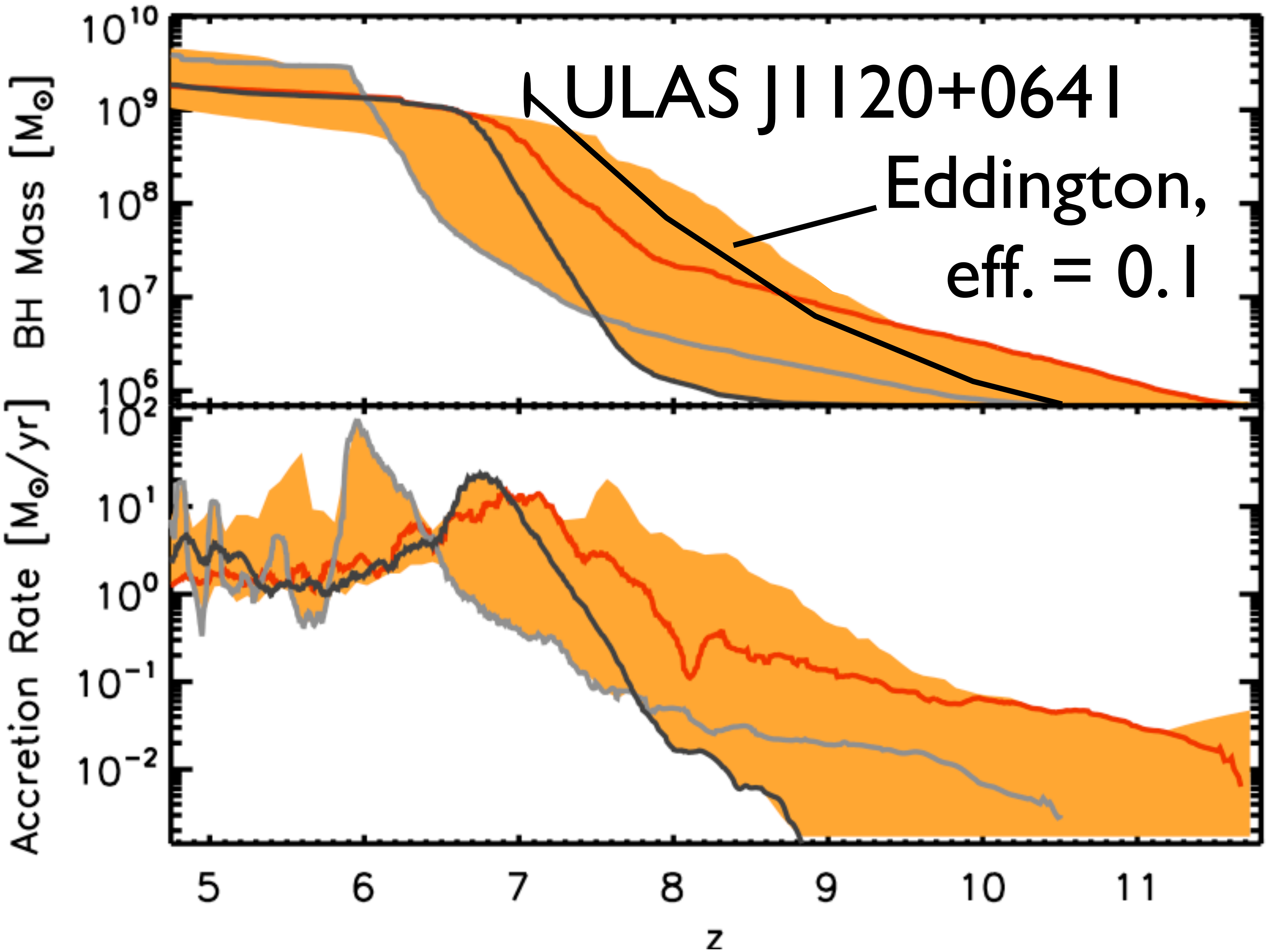
ULAS J1120+0641's BH





Can BHs get onto (and stay on) this line?
Are the first BHs actually on this line?

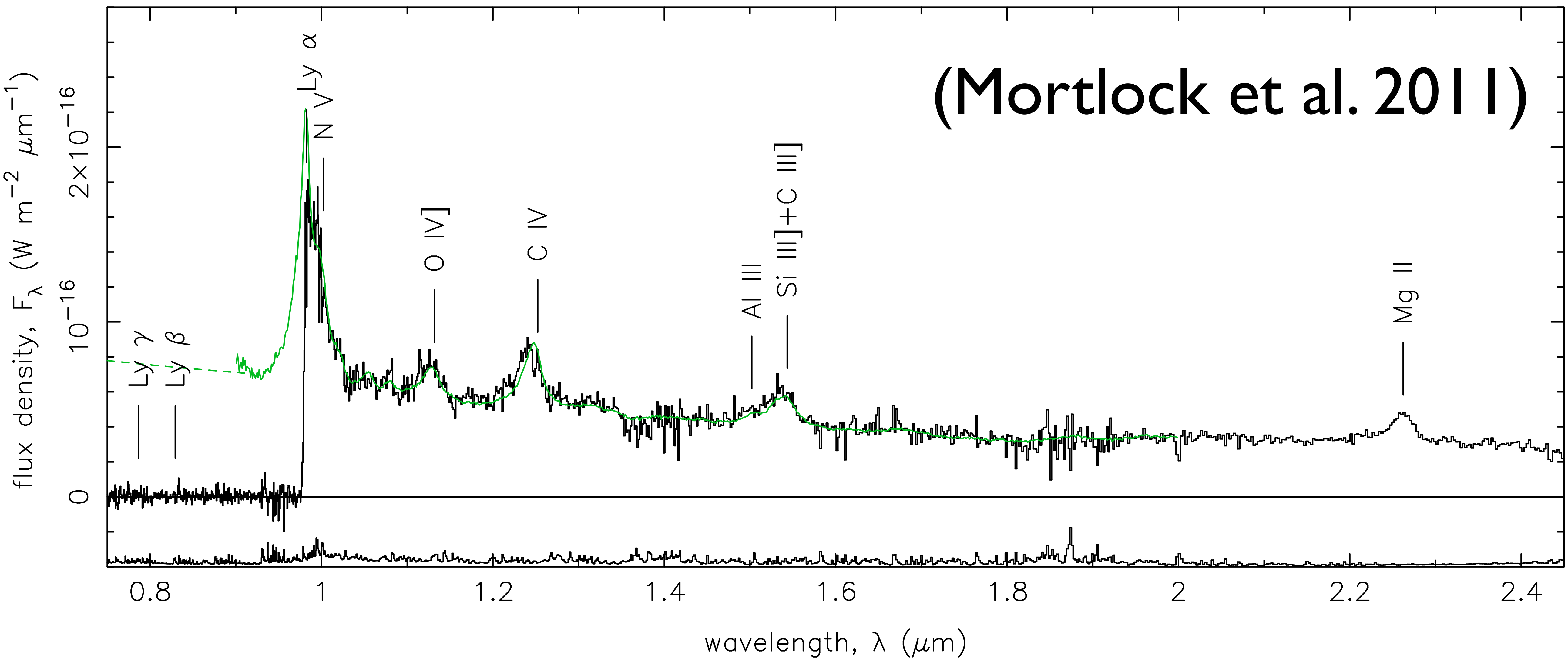
Super-massive black holes



(10^5 M_Sun seeds; accretion limit; Di Matteo et al. 2012)

More in this in Zoltan Haiman's talk.

HZQ SMBHs

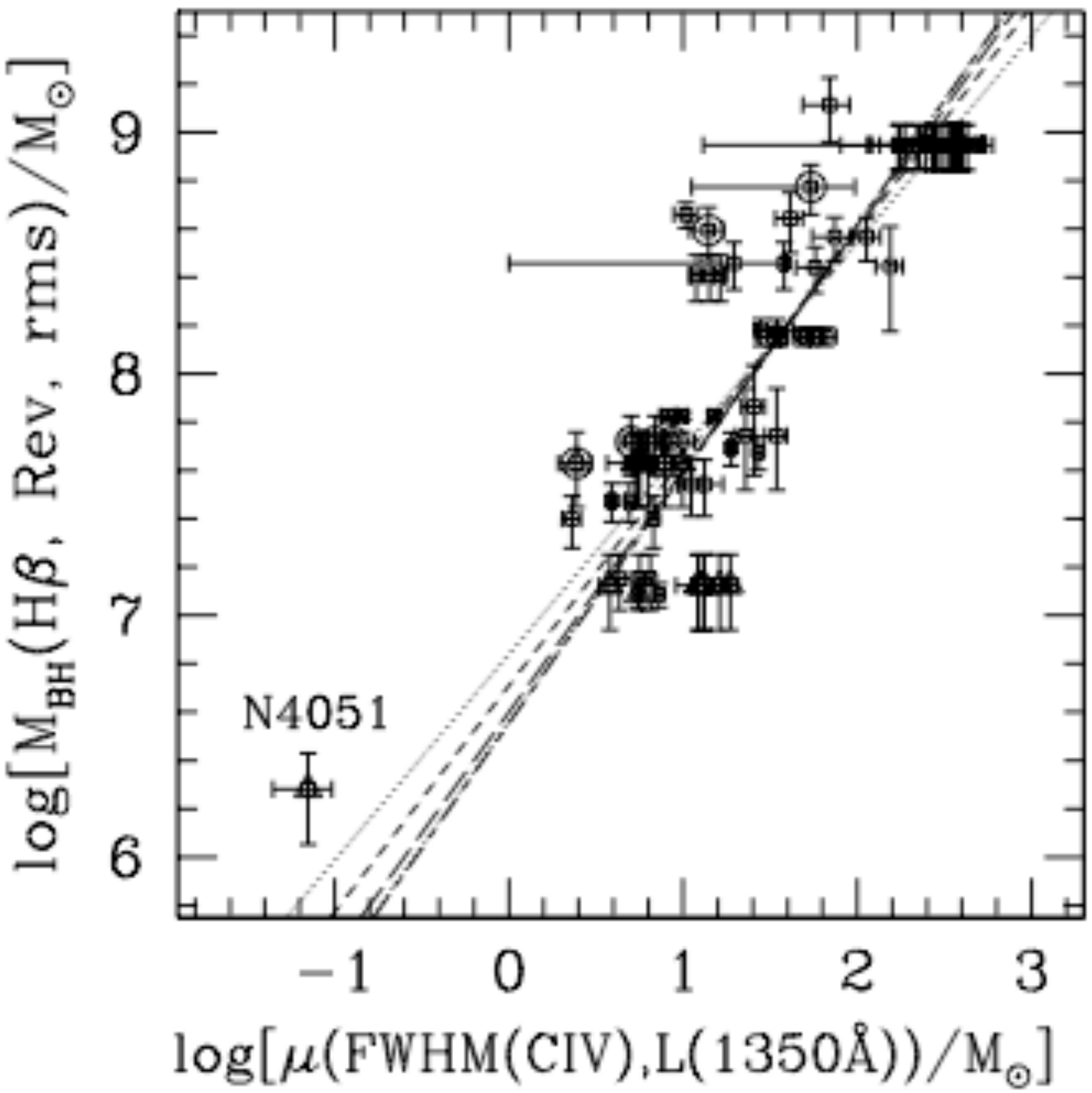


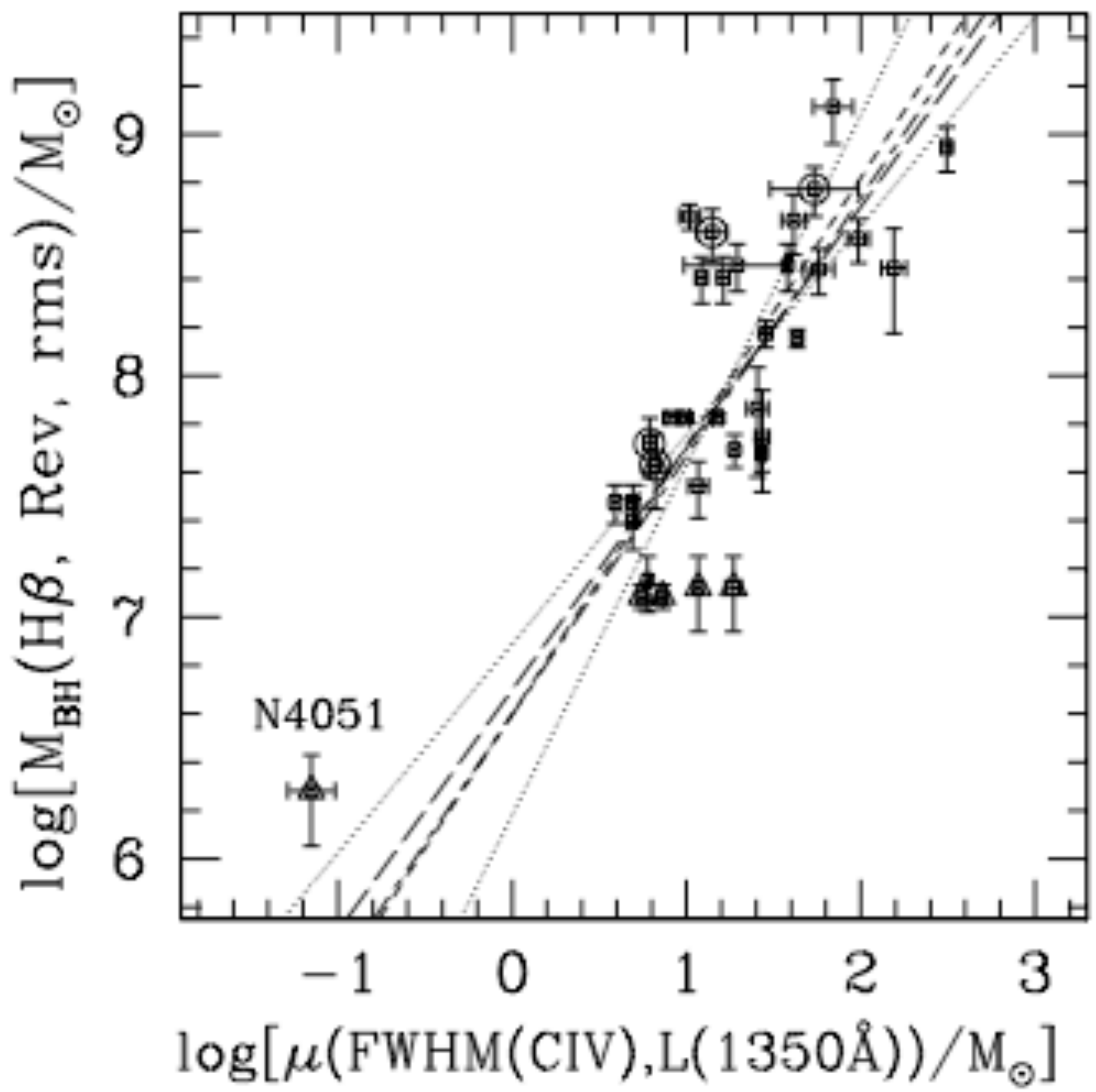
Unabsorbed spectrum very similar to low-z quasars

Data from FORS2@VLT and GNIRS@Gemini

Luminosity and Mg II line width => 2x10^9 M_Sun BH

Quasar black hole masses



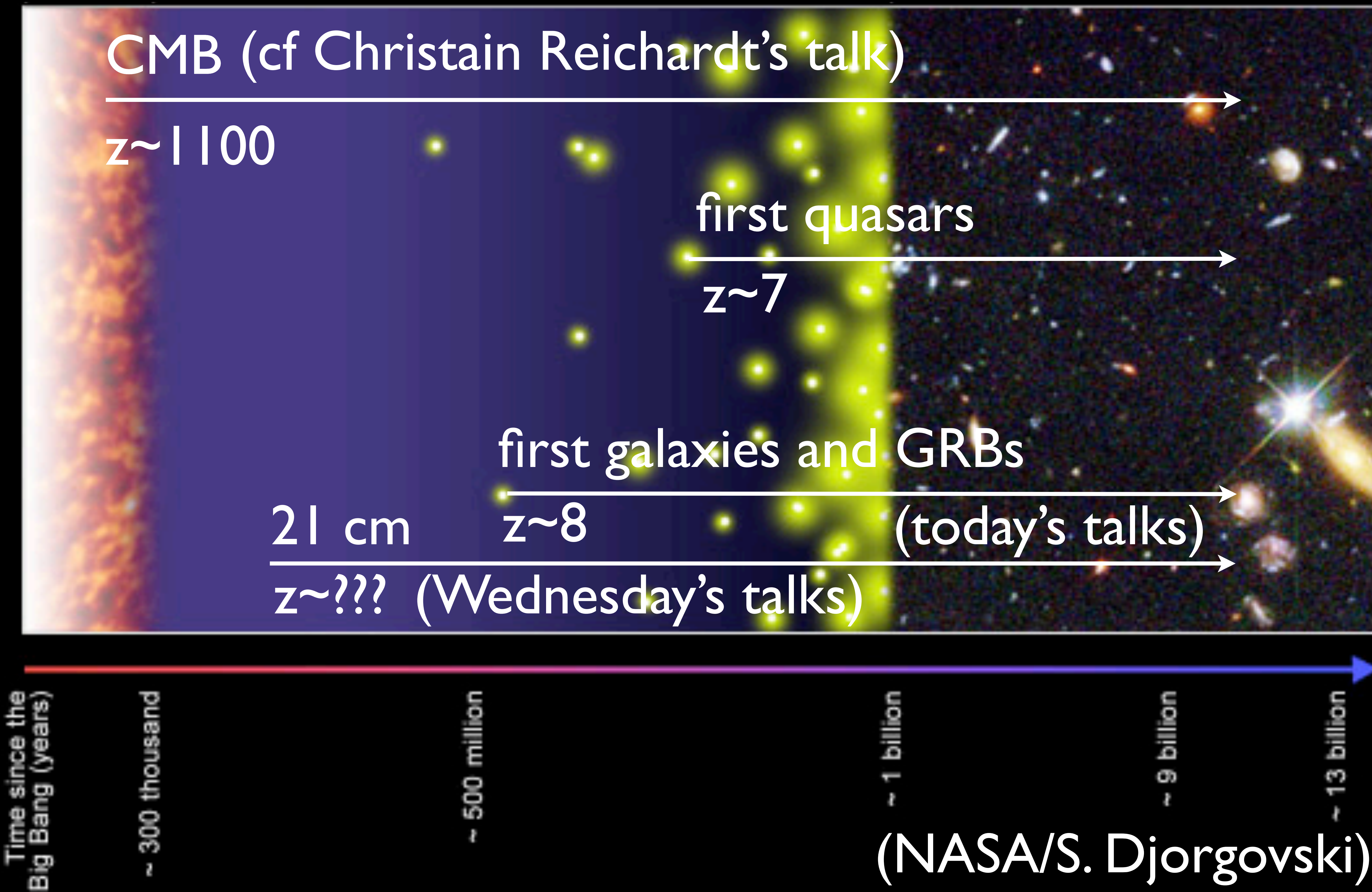


Rev. map + virial thm. (Vestergaard & Peterson 2006)

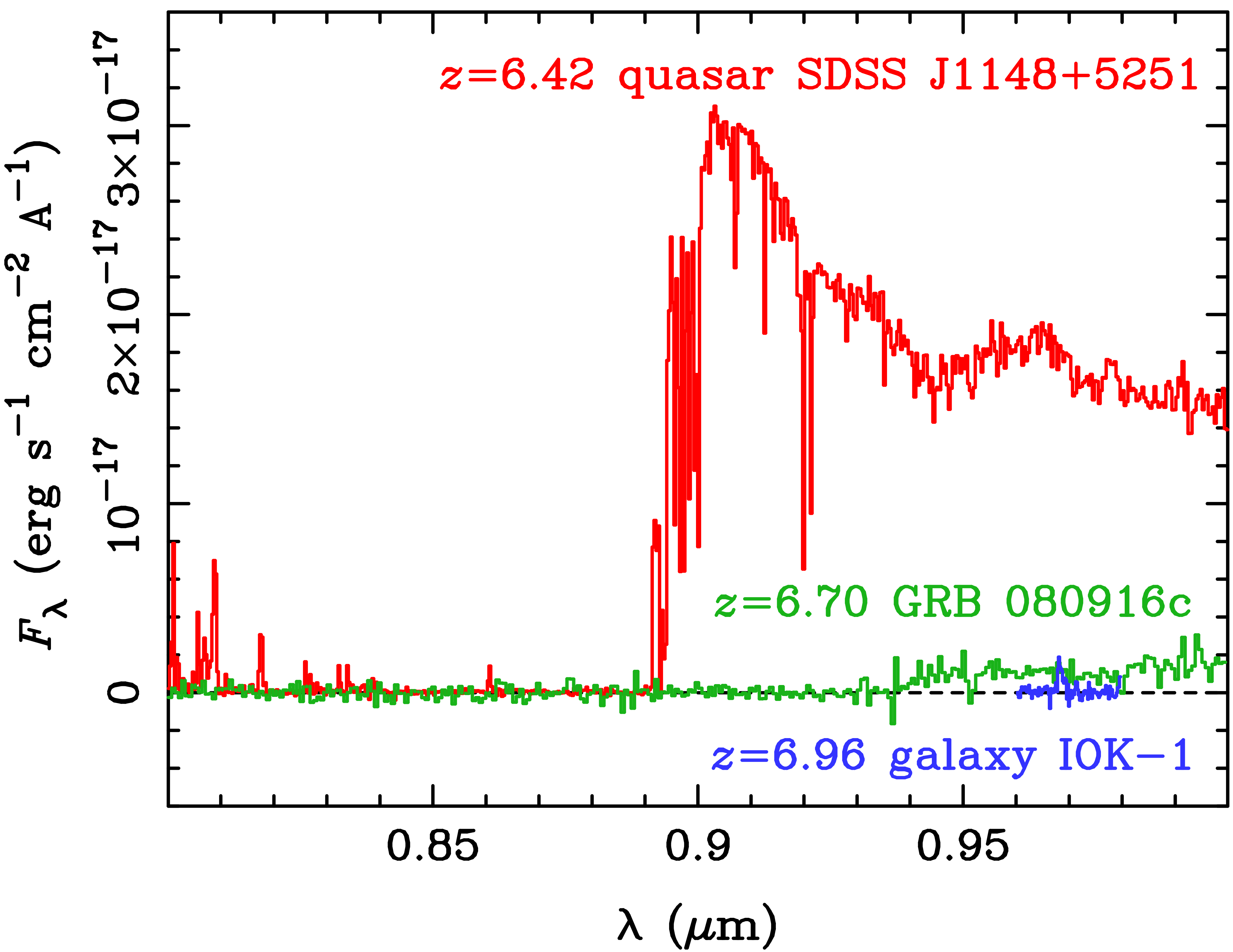
Eddington-like bias at high mass end?

Prior forces lower BH masses?

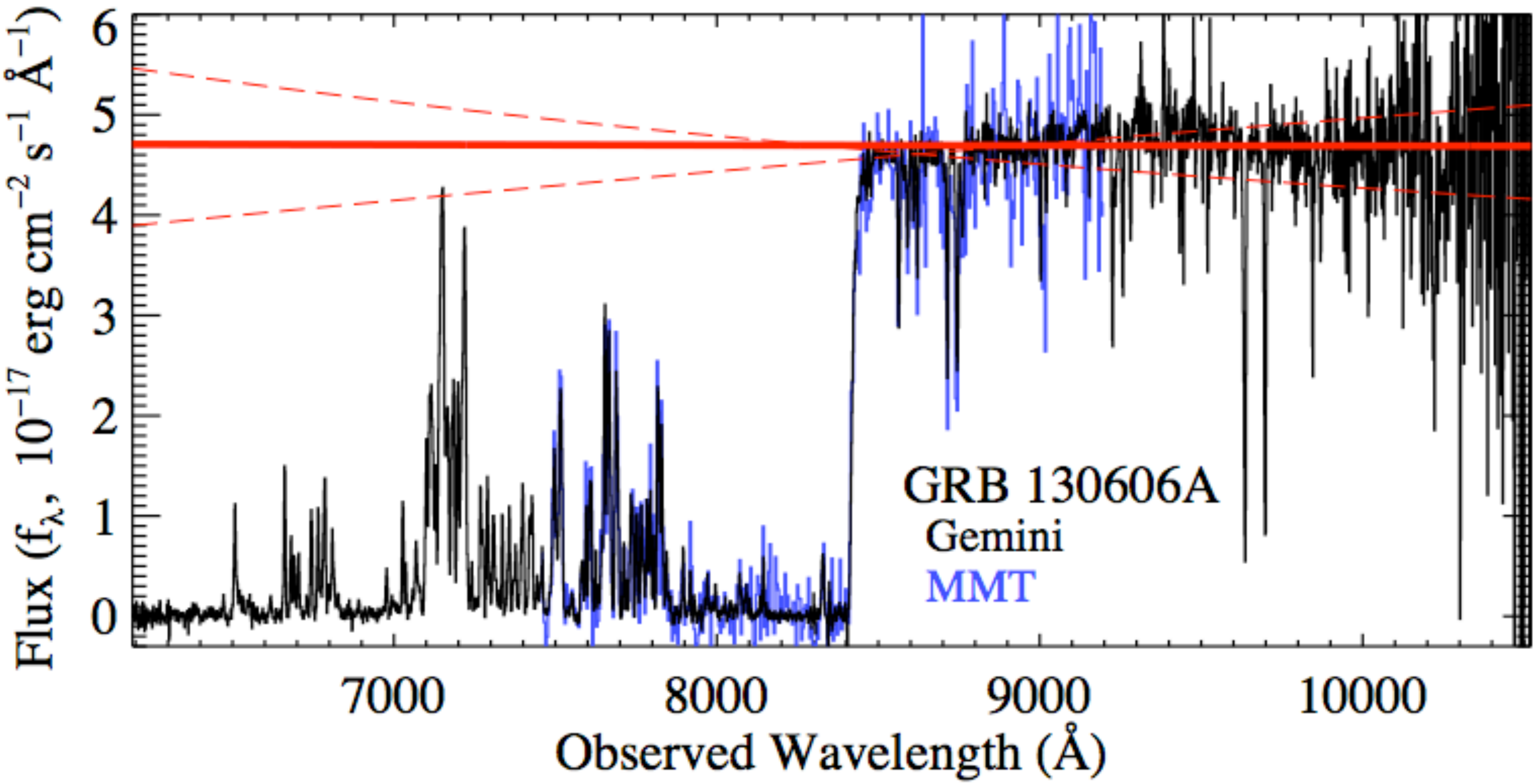
Observational probes of reionization



High-redshift sources



(GRB update)



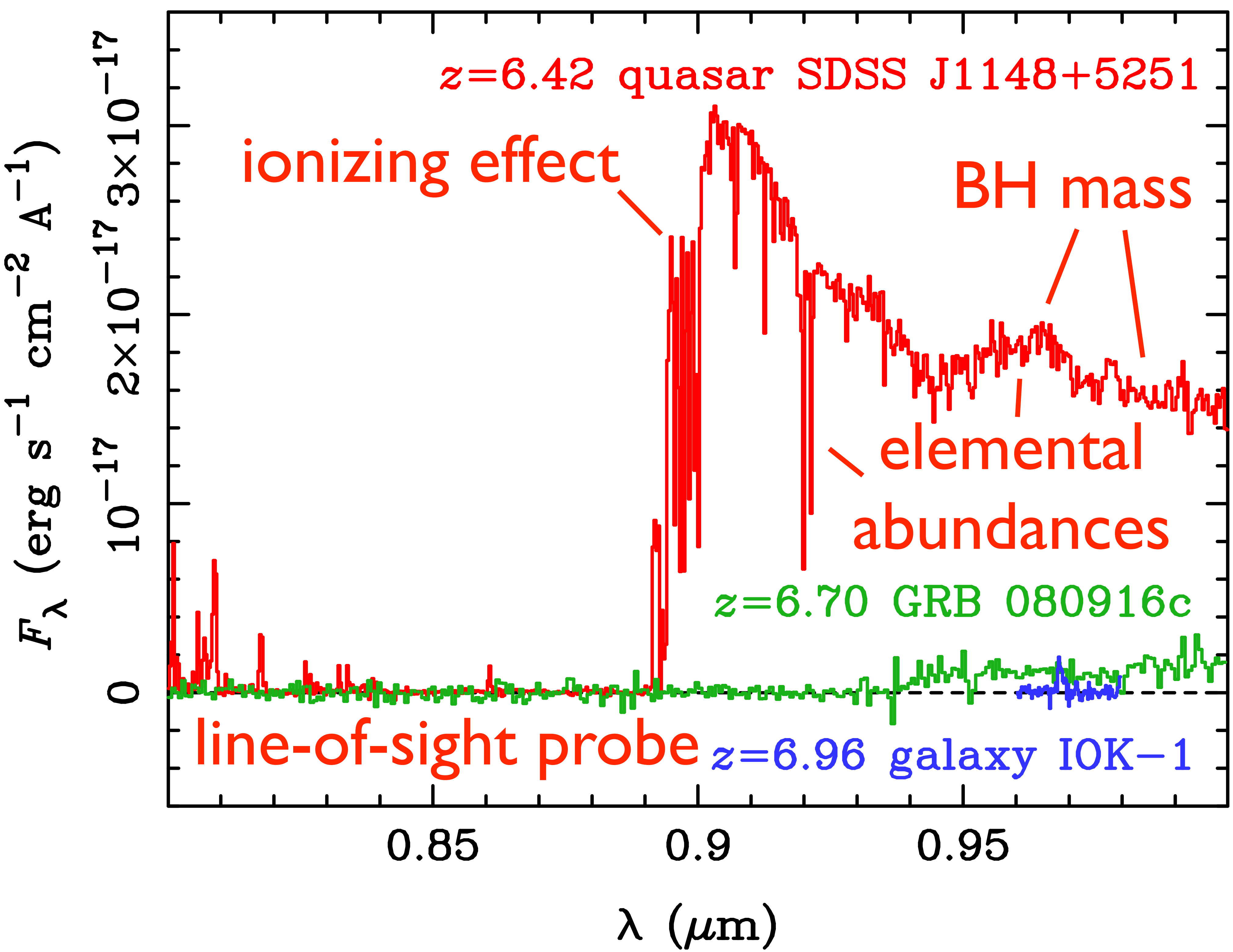
Spectra taken ~13 hr after burst (Chornock et al. 2013).

(GRB was brighter than any known HZQ at the time.)

High-redshift sources

source type	luminosity	persistence	numbers	effect
quasars	high	long	low	large
galaxies	low	long	high	small
GRBs	high	short	low	tiny
(CMB)	high enough	long	all-sky	tiny
(21cm)	(foregrounds)	long	high?	zero?

What do HZQs tell us?



Ly alpha absorption

If it turns out that 3C 9 has a continuum below 3660 Å, then either the mean density of hydrogen is exceedingly low, or its ionization is very complete. The conditions required to produce such complete ionization will be examined elsewhere. A third possibility, that the redshift of 3C 9 is not cosmological[3], cannot be ruled out at present.

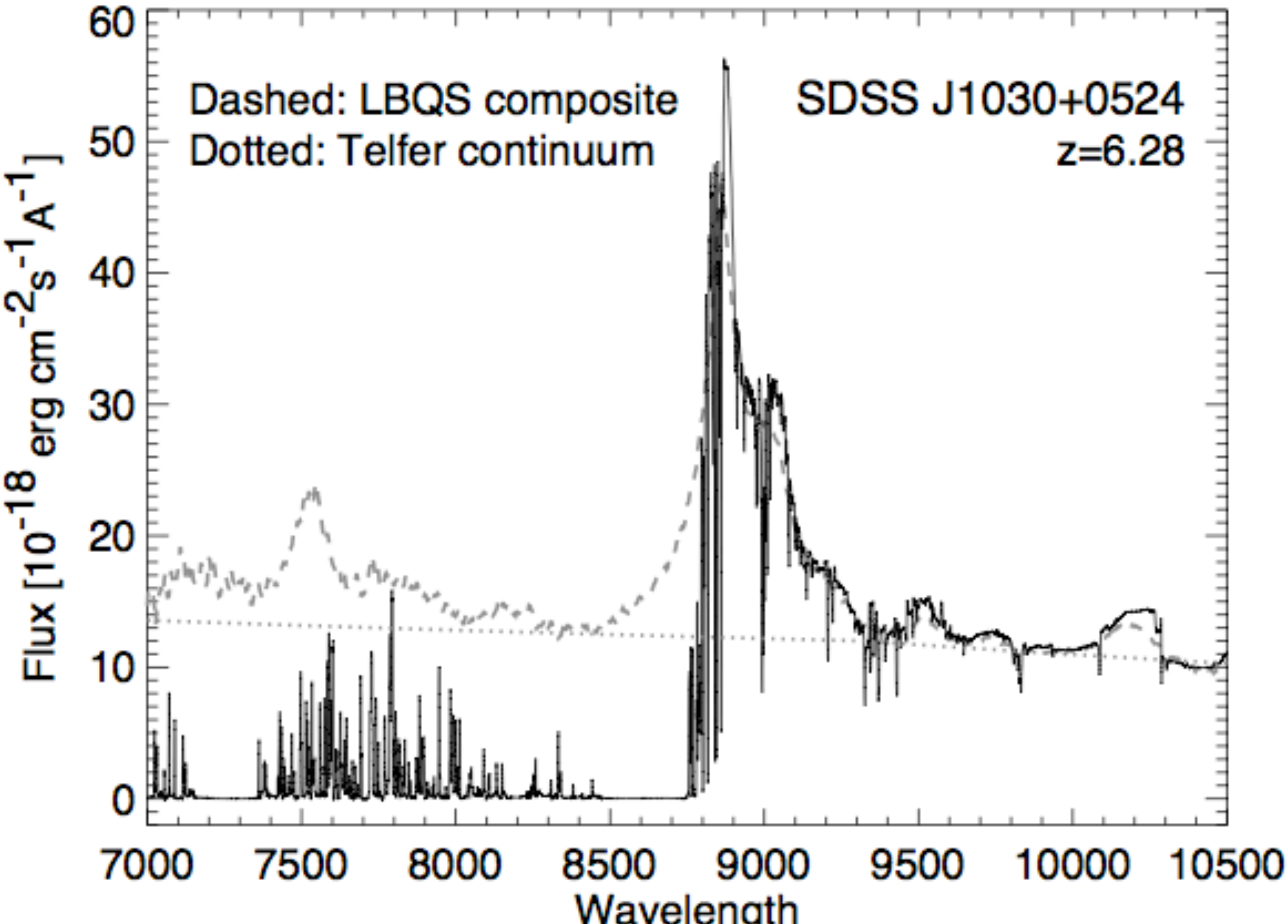
(Scheuer 1965)

Recent spectroscopic observations by Schmidt (1965) of the quasi-stellar source 3C 9, which is reported by him to have a redshift of 2.01, and for which Lyman-α is in the visible spectrum, make possible the determination of a new very low value for the density of neutral hydrogen in intergalactic space. It is observed that the continuum of the source continues (though perhaps somewhat weakened) to the blue of Ly-α; the line as seen on the plates has some structure but no obvious asymmetry. Consider, however, the fate of photons emitted to the blue of Ly-α. As we move away from the source along the line of sight, the source becomes redshifted to observers locally at rest in the expansion, and for one such observer, the frequency of any such photon coincides with the rest frequency of Ly-α in his frame and can be scattered by neutral hydrogen in his vicinity.

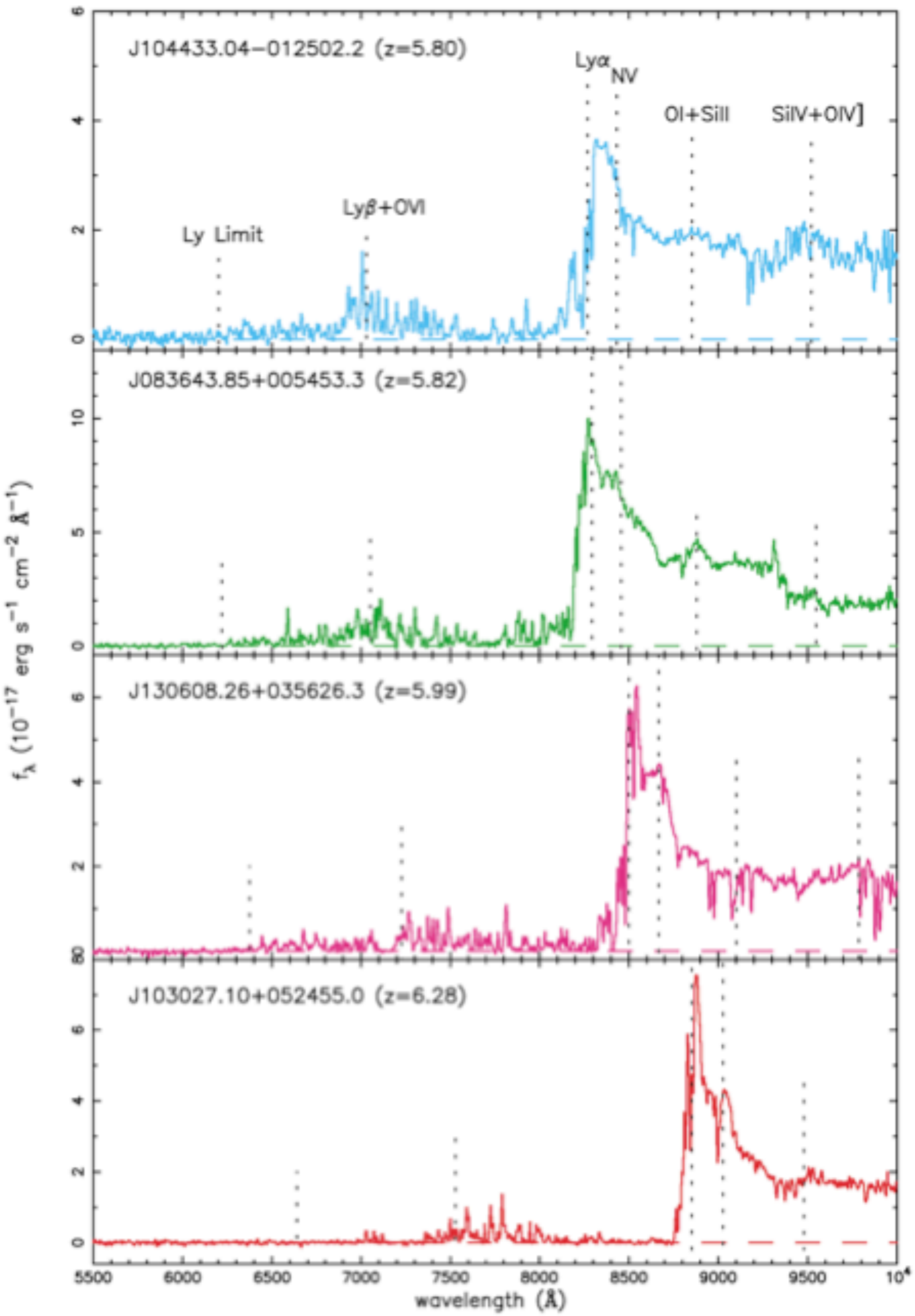
(Gunn & Peterson 1965)

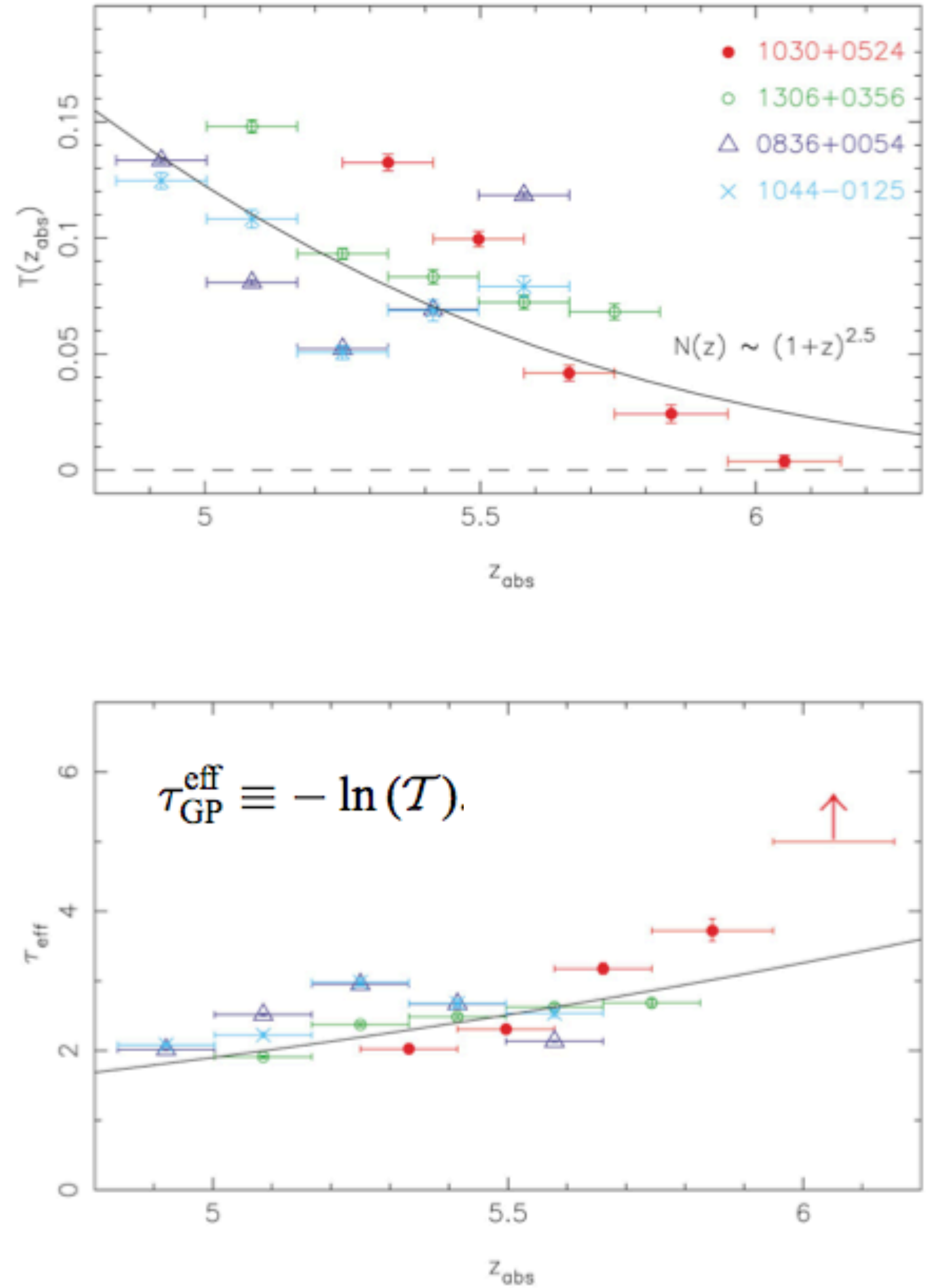
$$\tau_{GP}(z) = 1.8\times10^5 h^{-1}\Omega_m^{-1/2}\left(\frac{\Omega_b h^2}{0.02}\right)\left(\frac{1+z}{7}\right)^{3/2}\left\langle\frac{n_{\rm H\,I}}{n_{\rm H}}\right\rangle$$

Gunn-Peterson effect



Bin > transmission > optical depth (White et al. 2003)

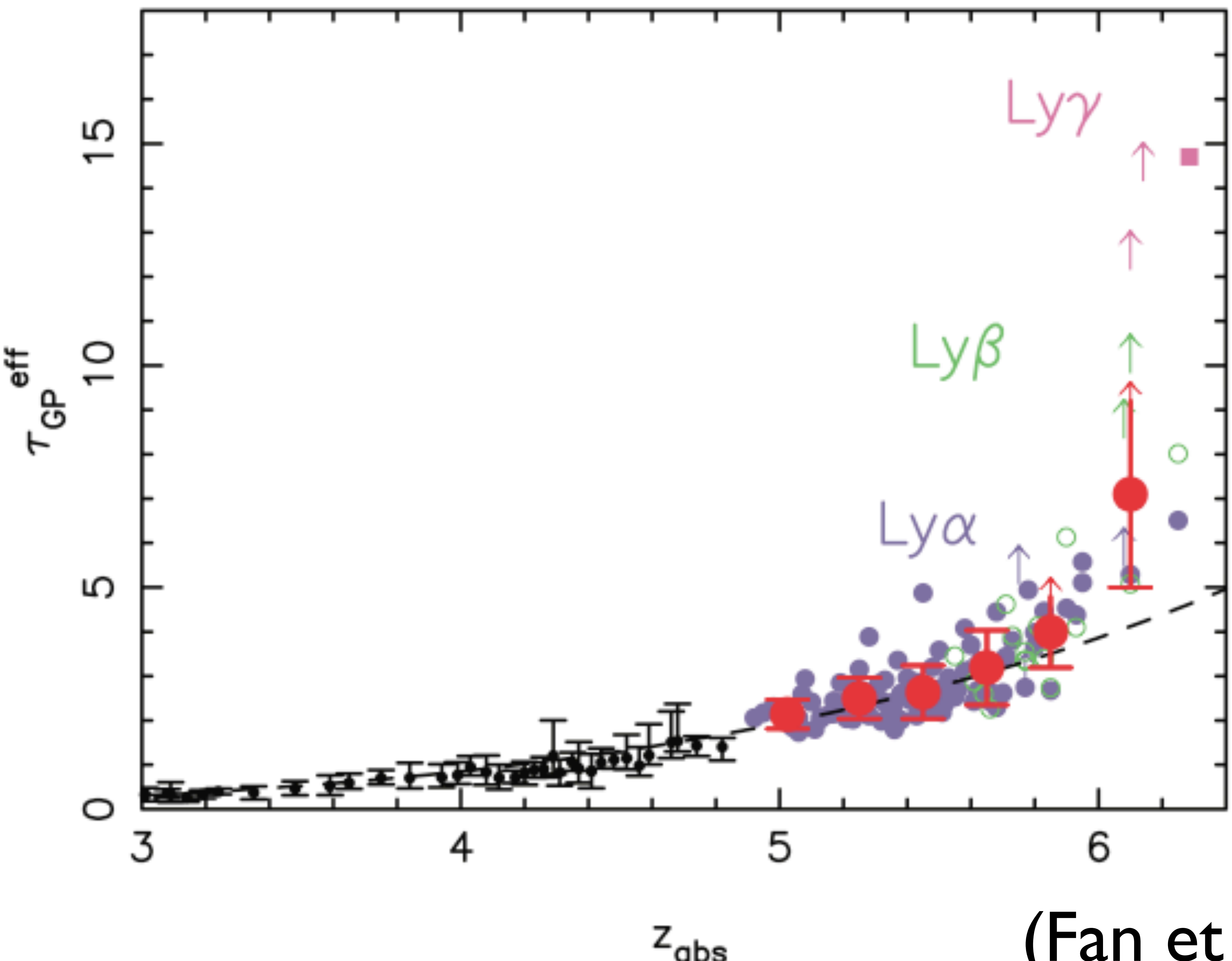




(Becker et al. 2001)

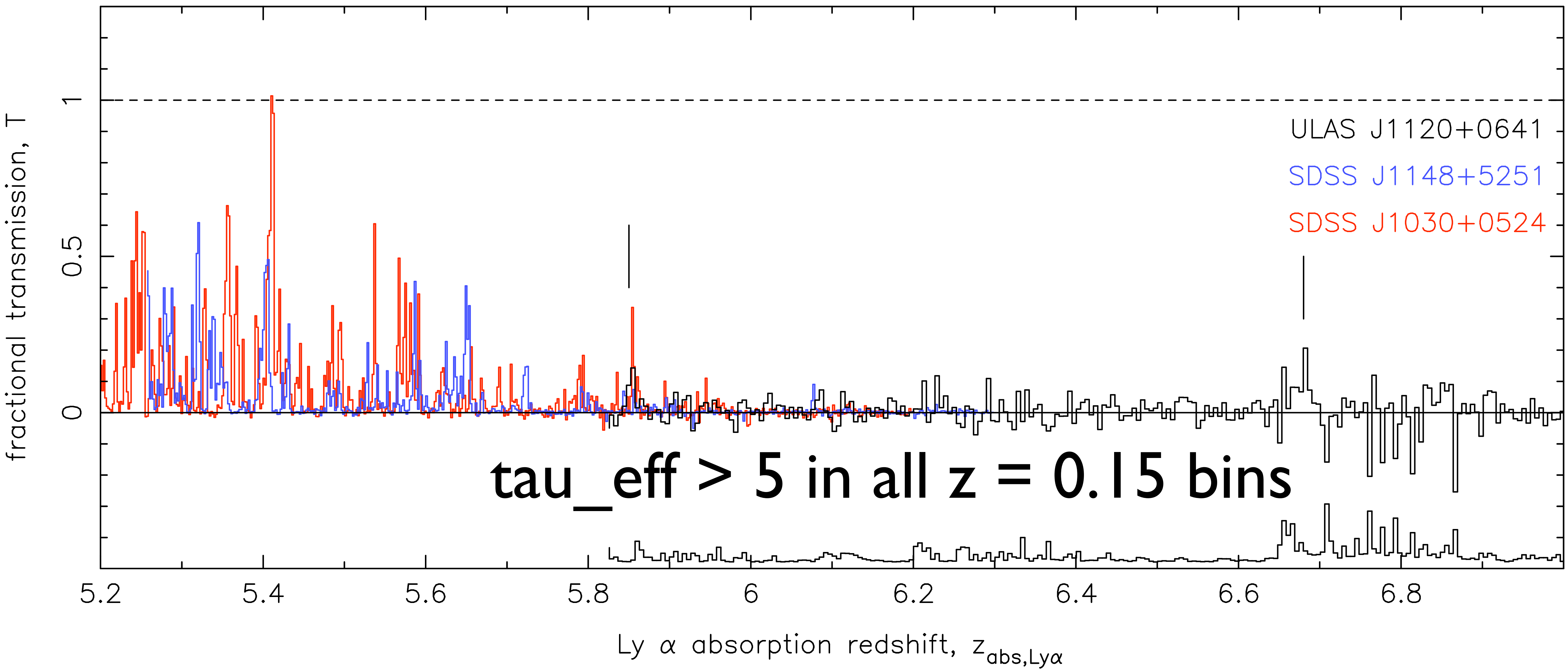
Simple measure of n_HI

Optical depth evolution



(Fan et al. 2006)

GP troughs at z>6



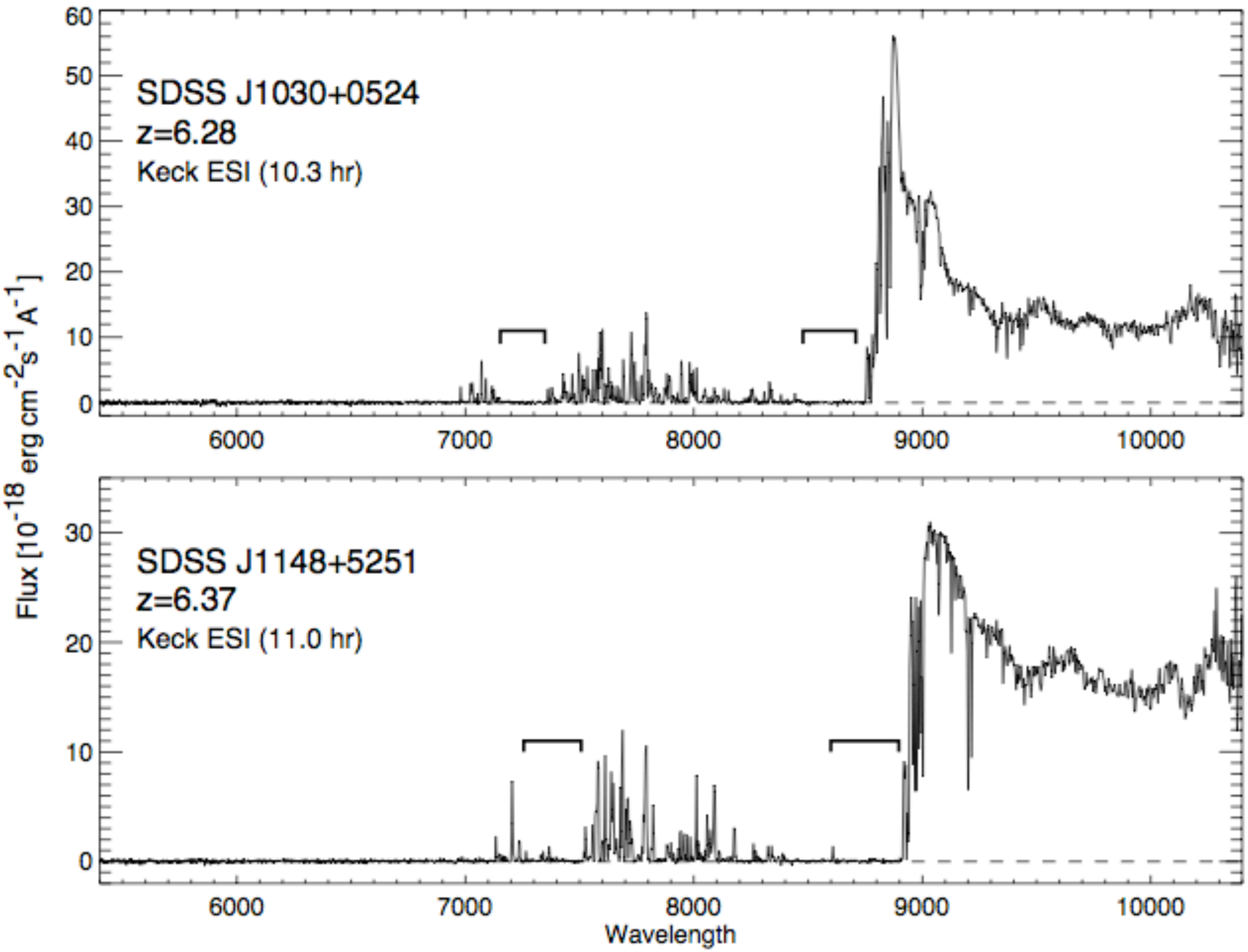
(Mortlock et al. 2011)

Density of neutral hydrogen too high to probe through GP optical depth at z > 6.

Dark gaps

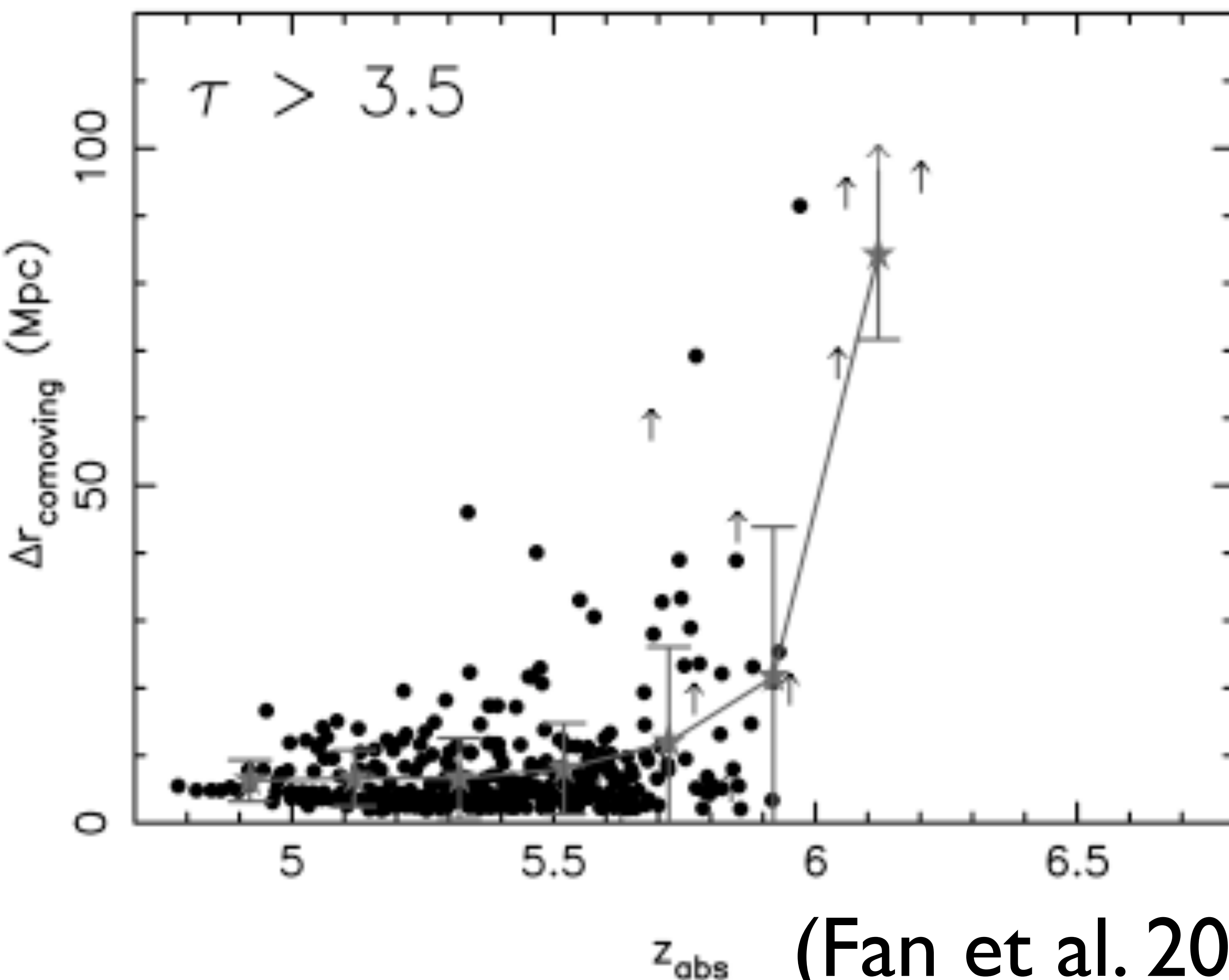
- Go beyond Ly alpha optical depth in wavelength/redshift ranges.
- Exploit structure in the spectra (which are the opposite of Ly alpha forest).
- Look at distribution of (co-moving) lengths of low transmission regions (GP troughs or dark gaps).
- Sensitive to higher n_HI and hence can probe reionization to higher z.

Dark gaps



(White et al. 2003)

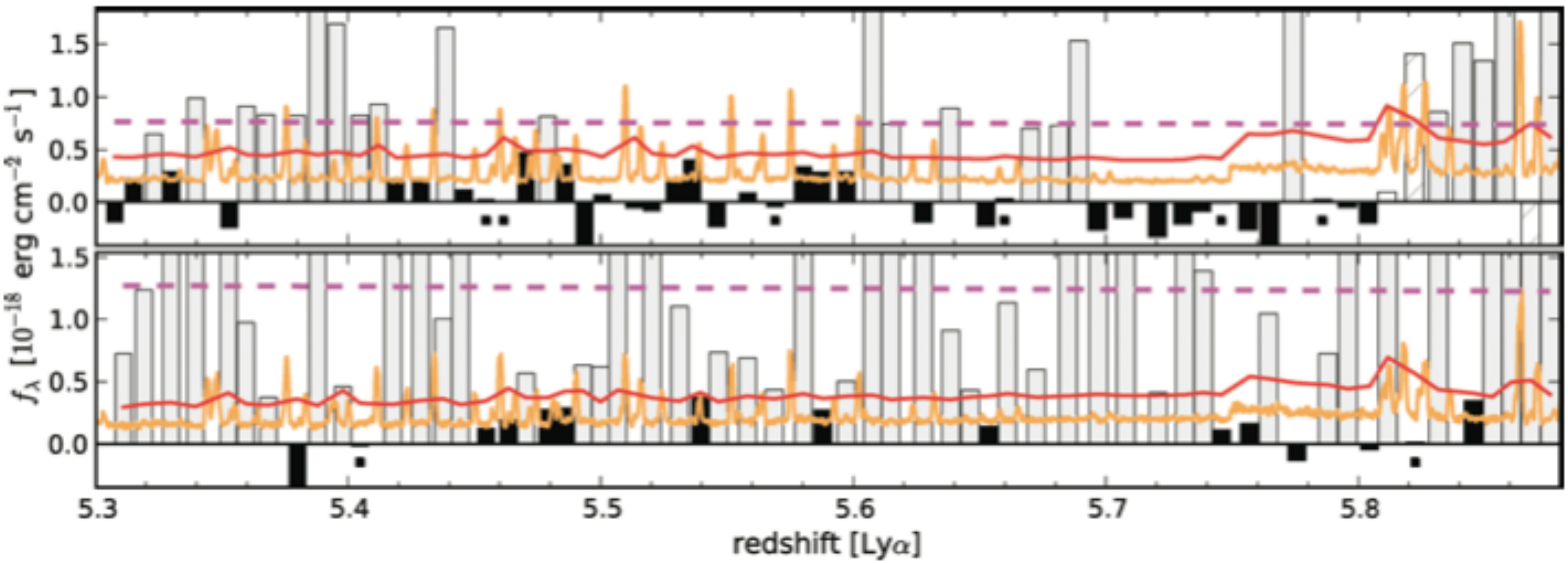
Dark gaps



(Fan et al. 2006)

Dark gap in front of ULAS J1120+0641 at z = 7.1 has r ~ 500 (co-moving) Mpc.

Dark gap statistics



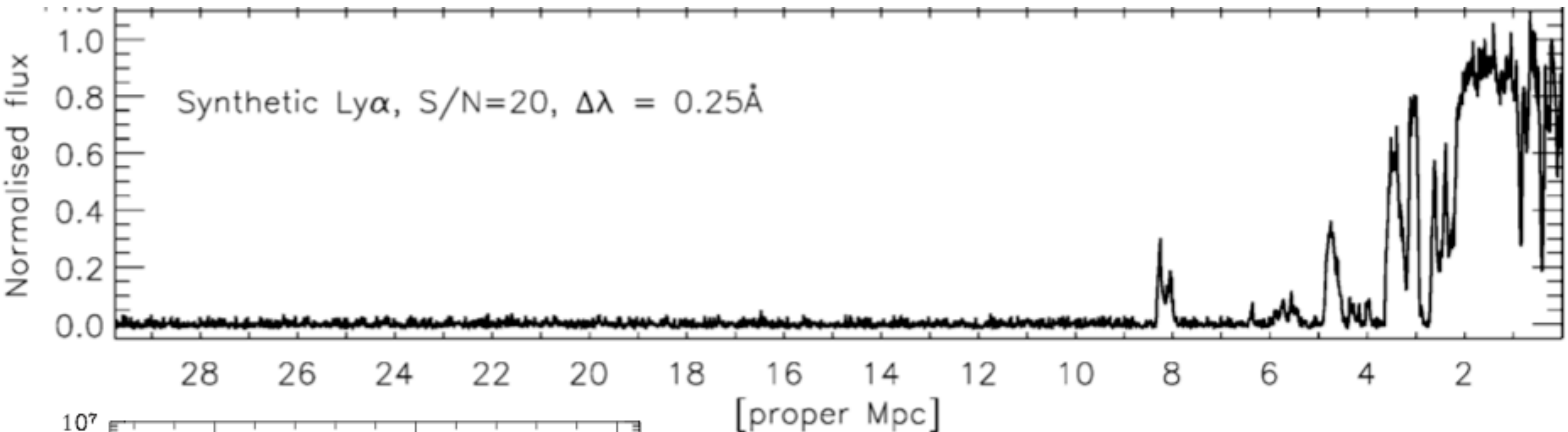
(McGreer et al. 2011)

Can only sample from simulations - no easy likelihood.

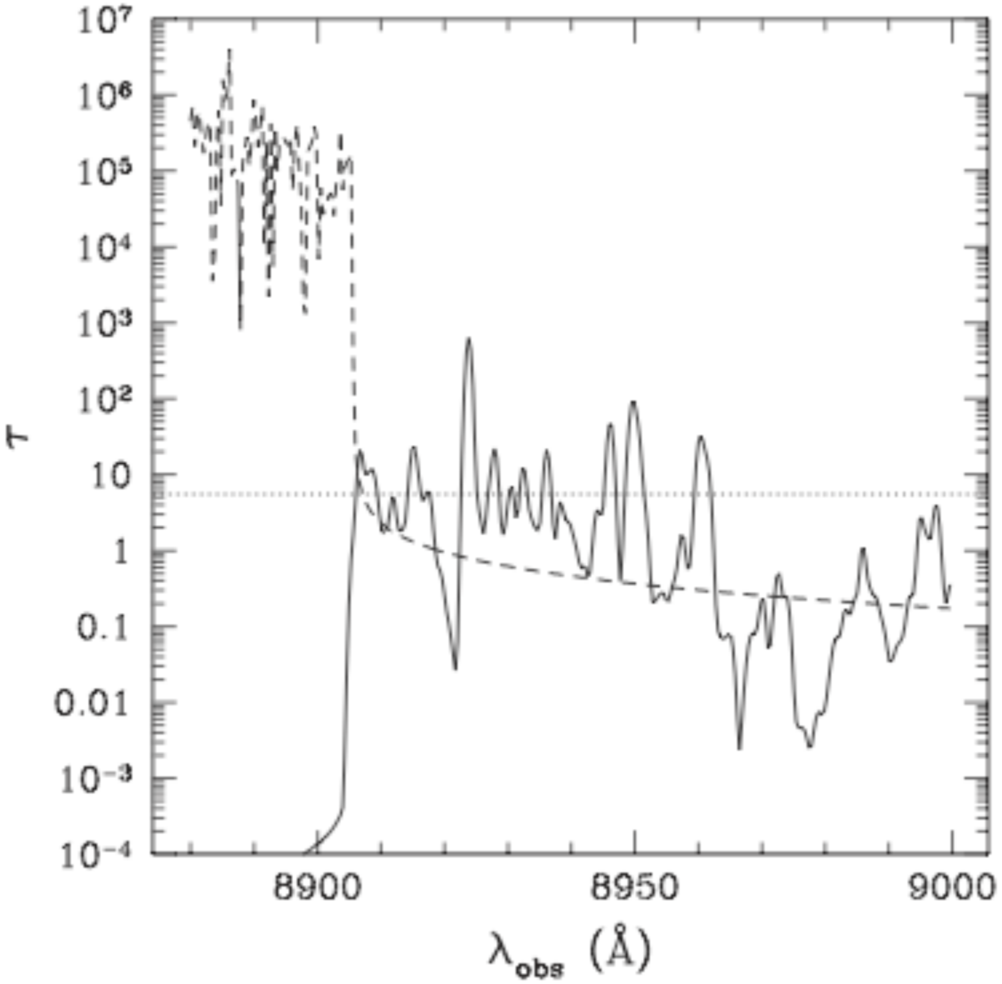
Noise wavelength-dependent (mainly due to sky lines).

Definition of low-transmission regions not robust.

Dark gap simulations

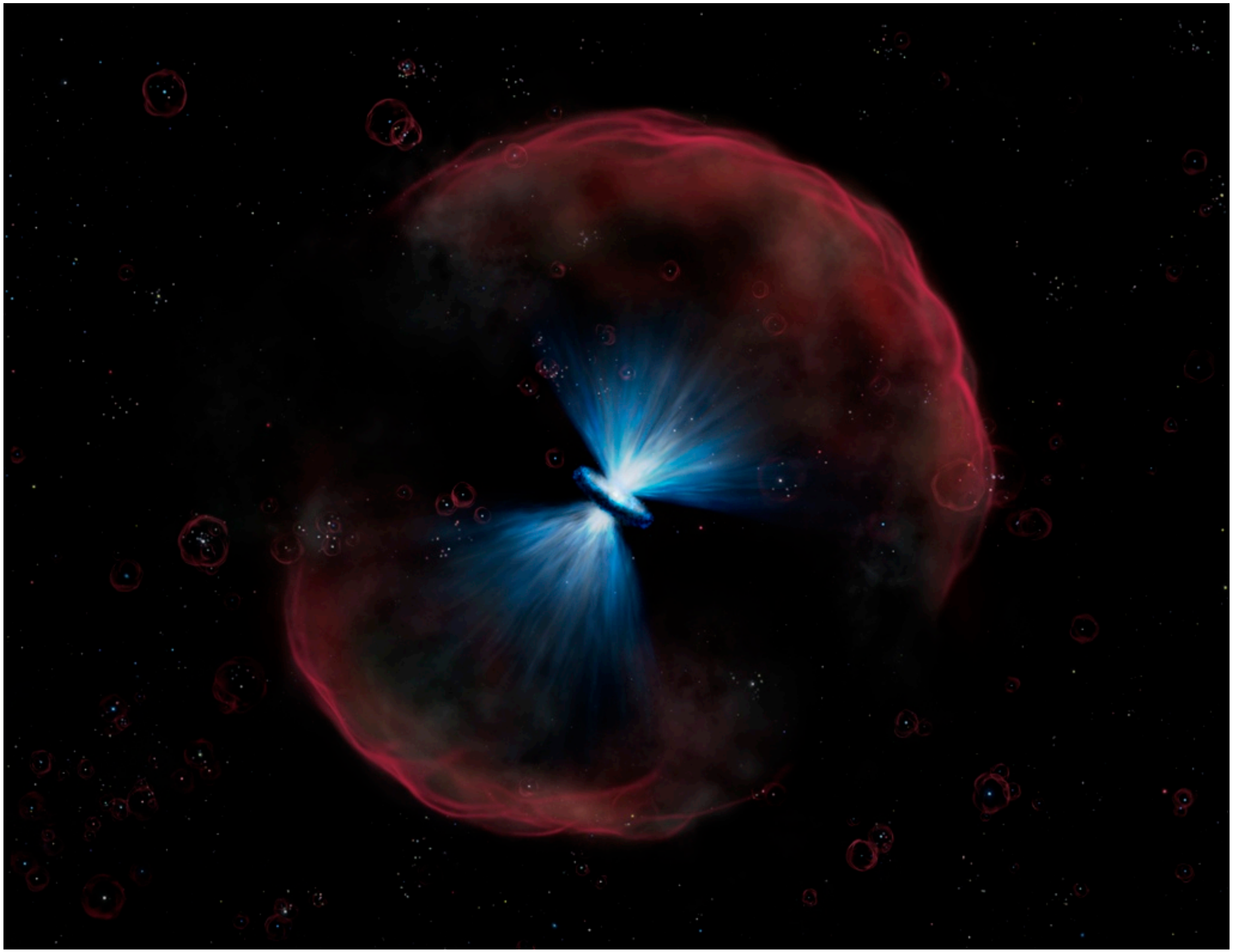


(Bolton & Haenhalt 2007)



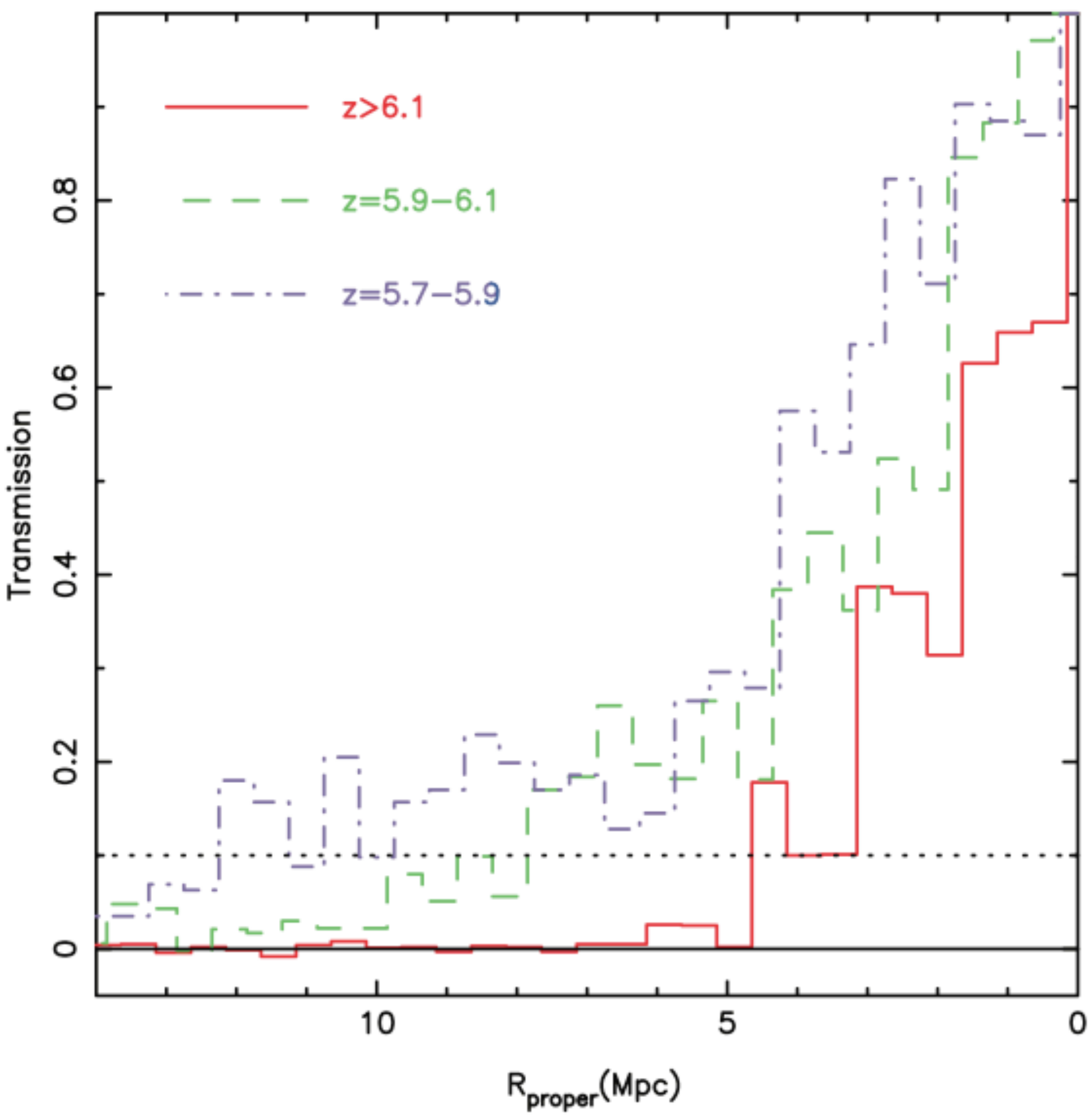
(Mesinger & Haiman 2007)

Quasar near zones

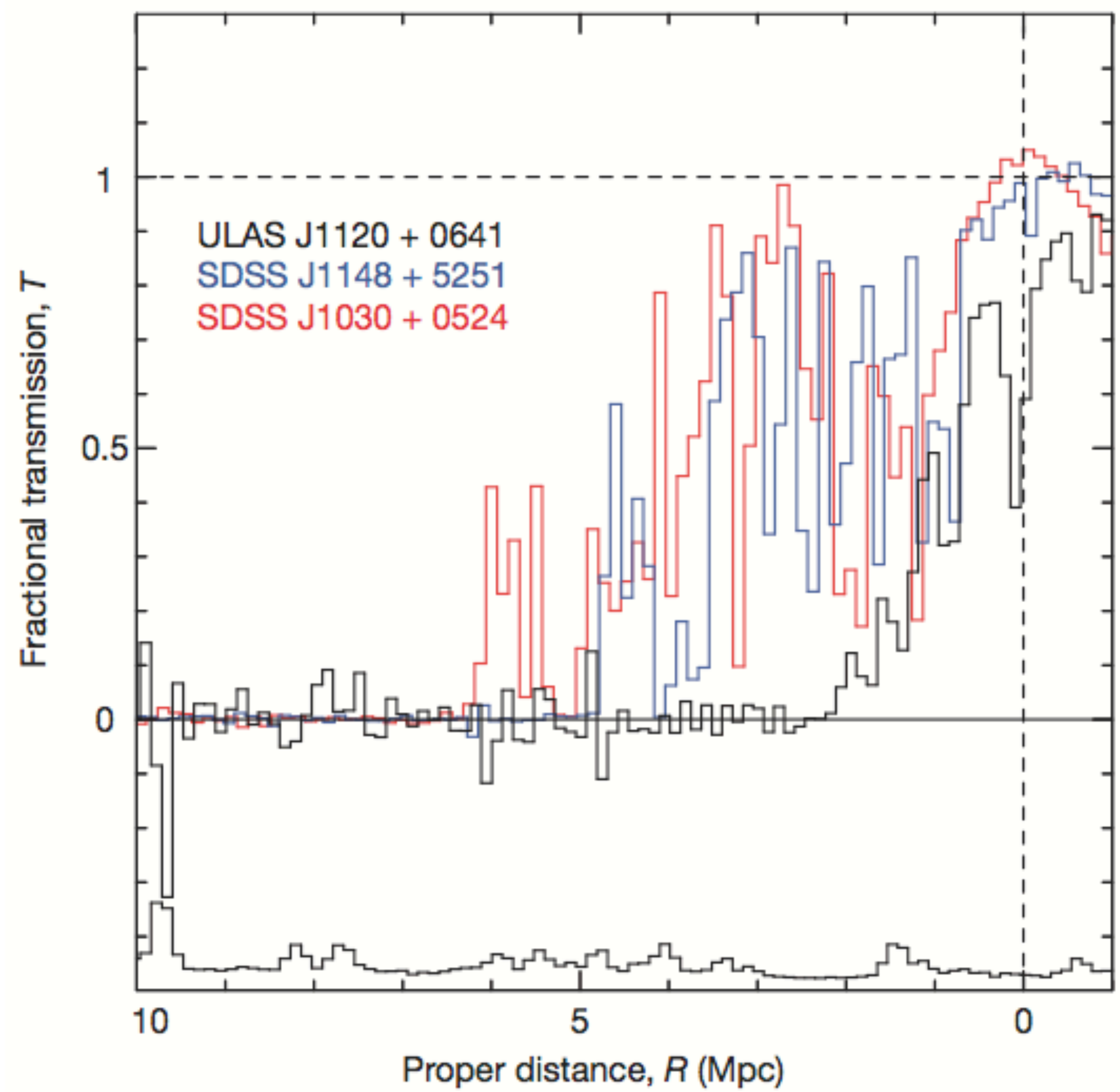


(Gemini Observatory/AURA by Lynette Cook)

Near zone sizes

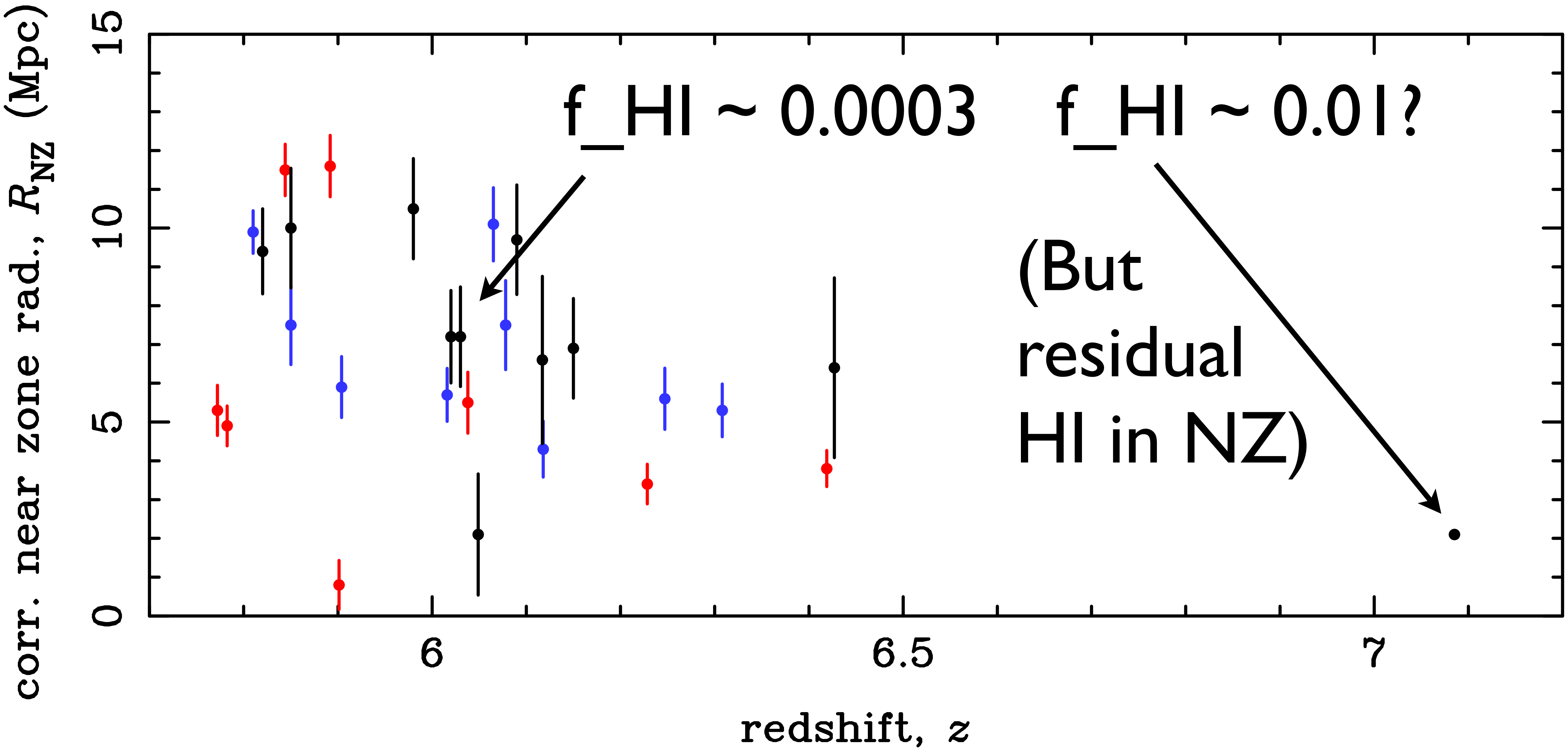


(Fan et al. 2006)



(Mortlock et al. 2011)

Near zone size evolution



(after Carilli et al. 2010)

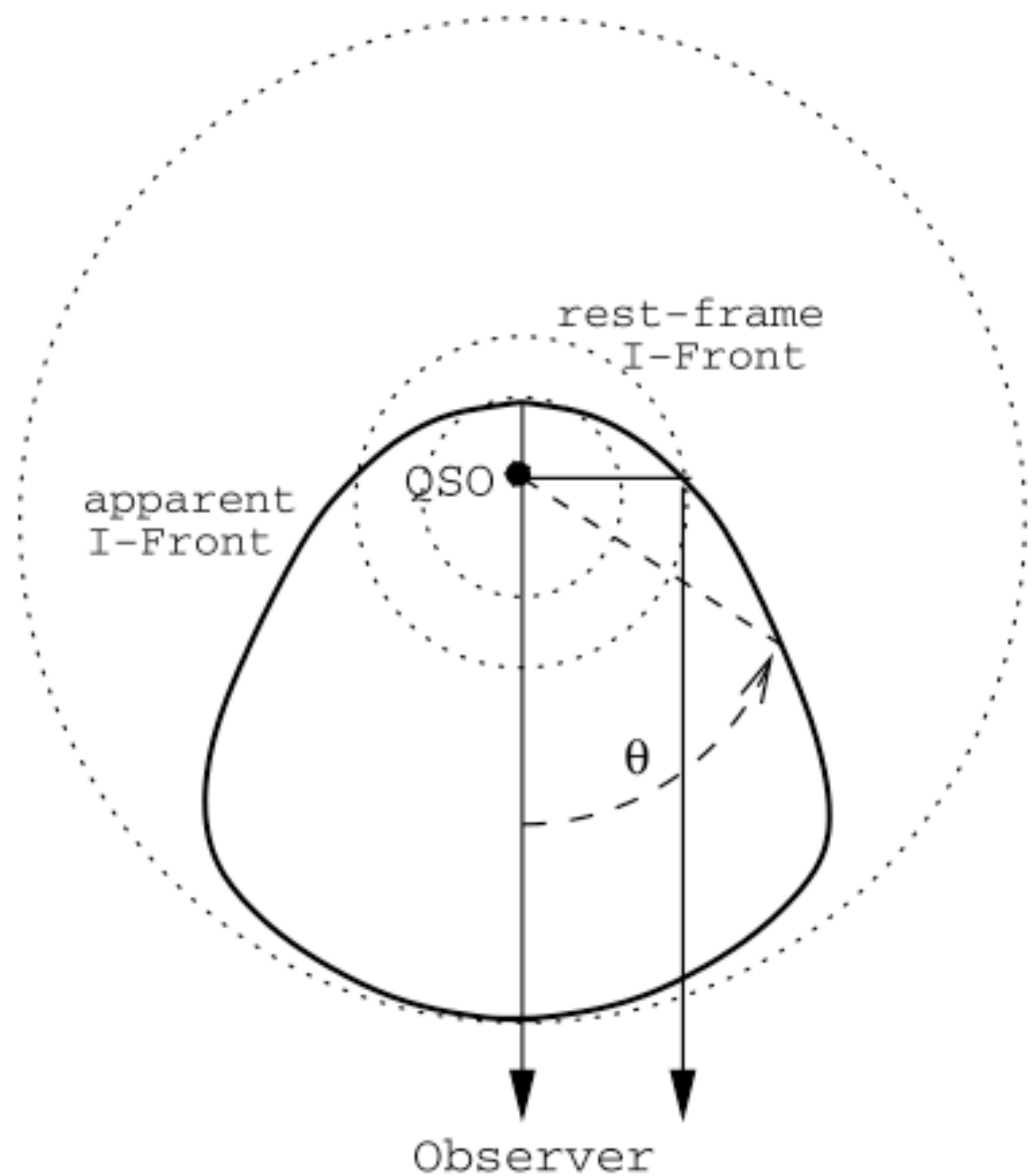
$$R_s = 8.0 f_{\mathrm{H\,I}}^{-1/3} \left(\dot{N}_Q / 6.5 \times 10^{57}\ \mathrm{s}^{-1}\right)^{1/3} \left(t_Q / 2 \times 10^7\ \mathrm{yr}\right)^{1/3} \left[(1 + z_Q)/7\right]^{-1}\ \text{proper Mpc.}$$

Direct observation

Collisionally-excited Ly alpha emission at ionization front.

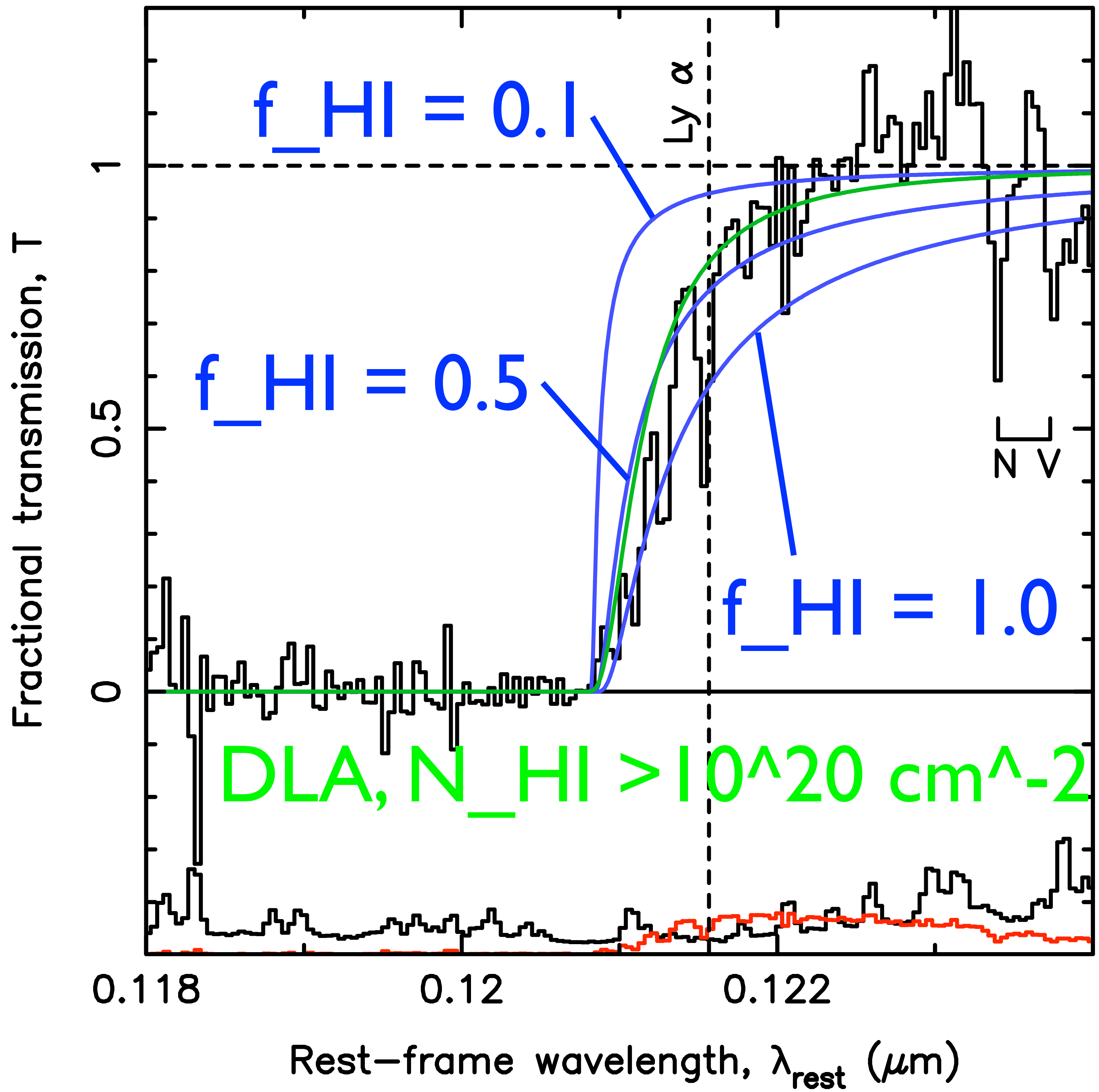
Stronger effect in smaller NZs around more distant quasars. (Cantaulpo et al. 2011)

HAWK-I observations of ULAS J1120+0641 underway.



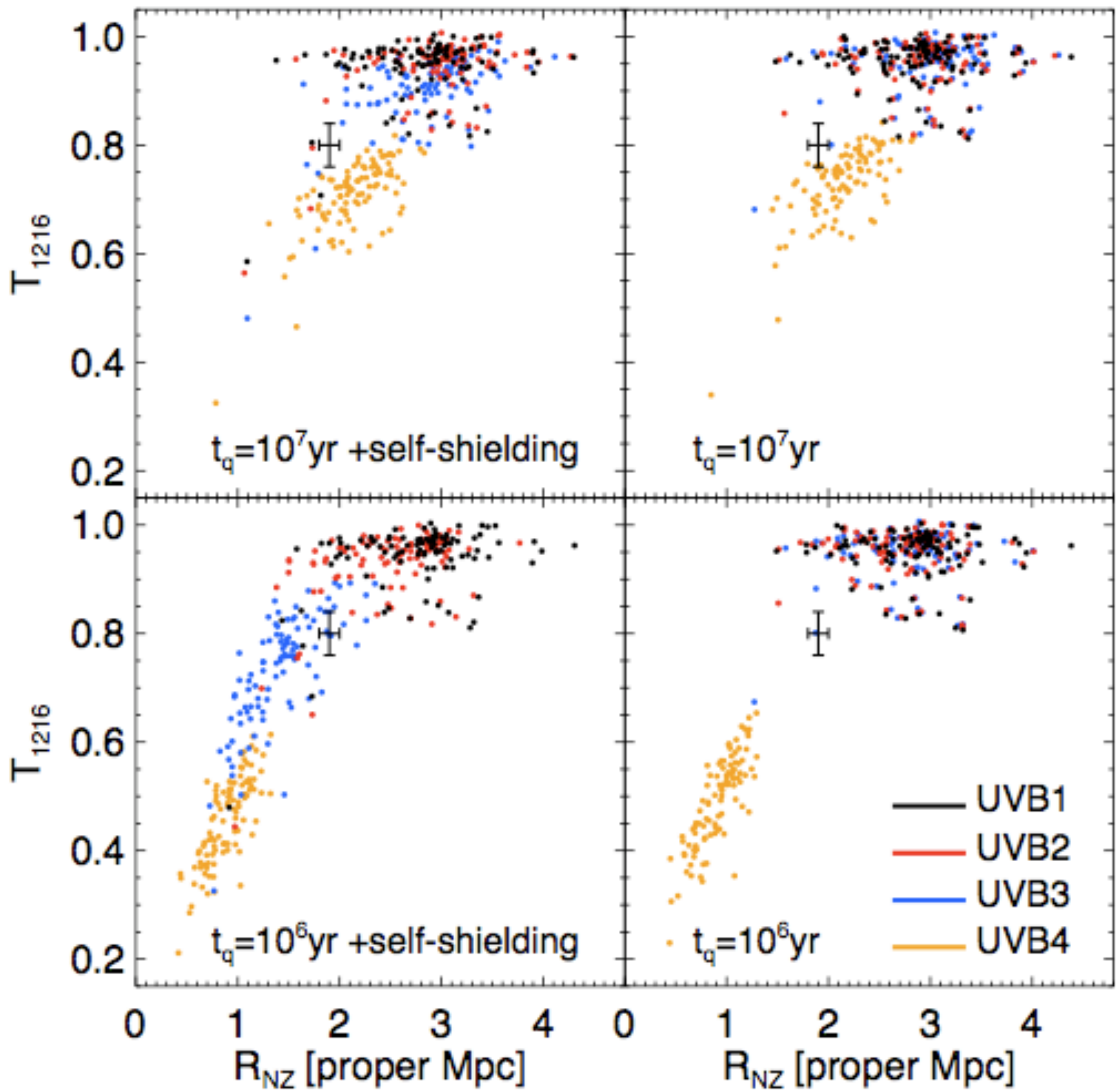
(Yu 2005; Cantalupo et al. 2011)

Ly alpha IGM damping wing?



(Mortlock et al. 2011)

Ly alpha IGM damping wing?



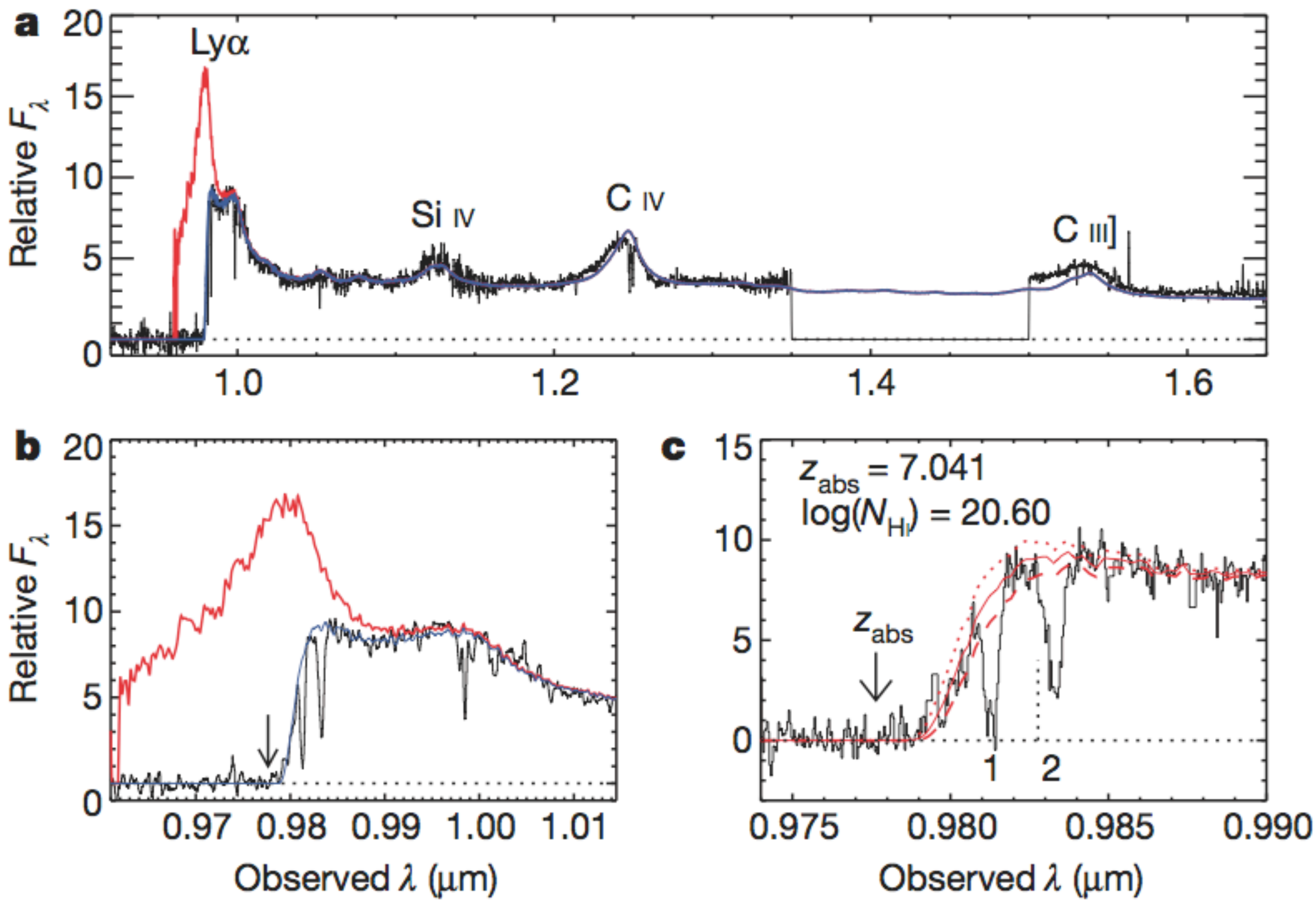
Confirmation f_HI > 0.1; but quasar young?

(DLA unlikely a priori; P=0.05)

Possible young age make BH problem worse

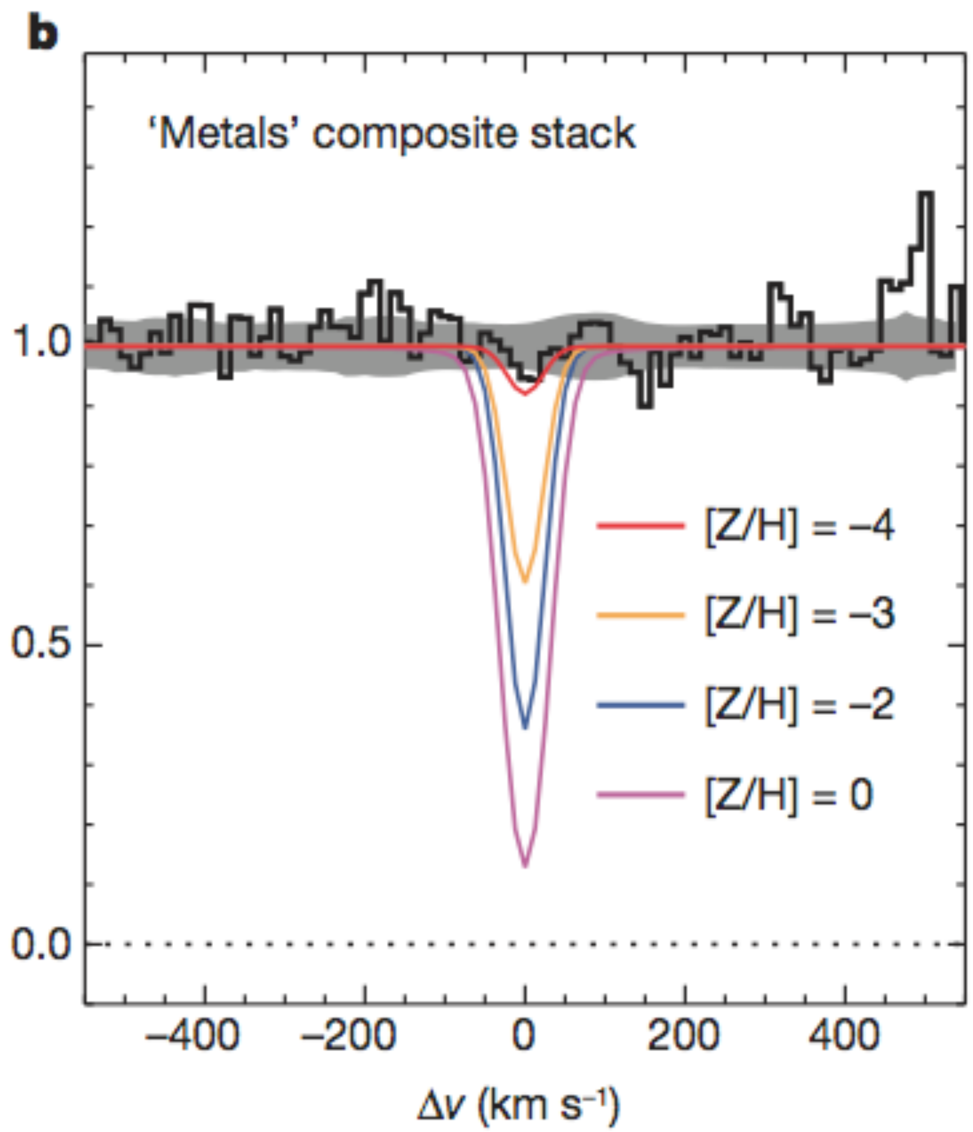
Bolton et al. (2011)

Ly alpha IGM damping wing?

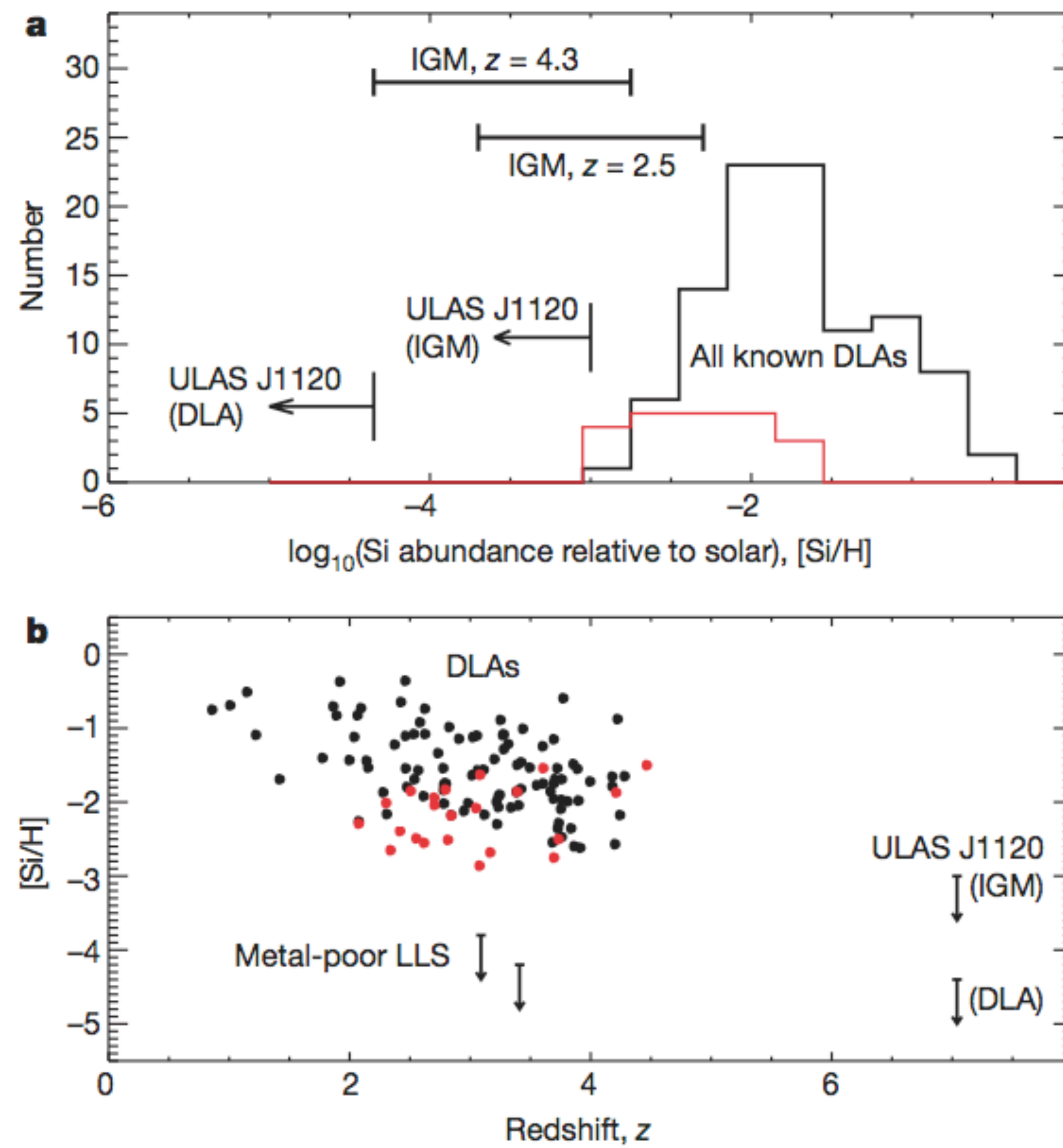


FIRE spectrum of ULAS J1120+0641 (Simcoe et al. 2012)

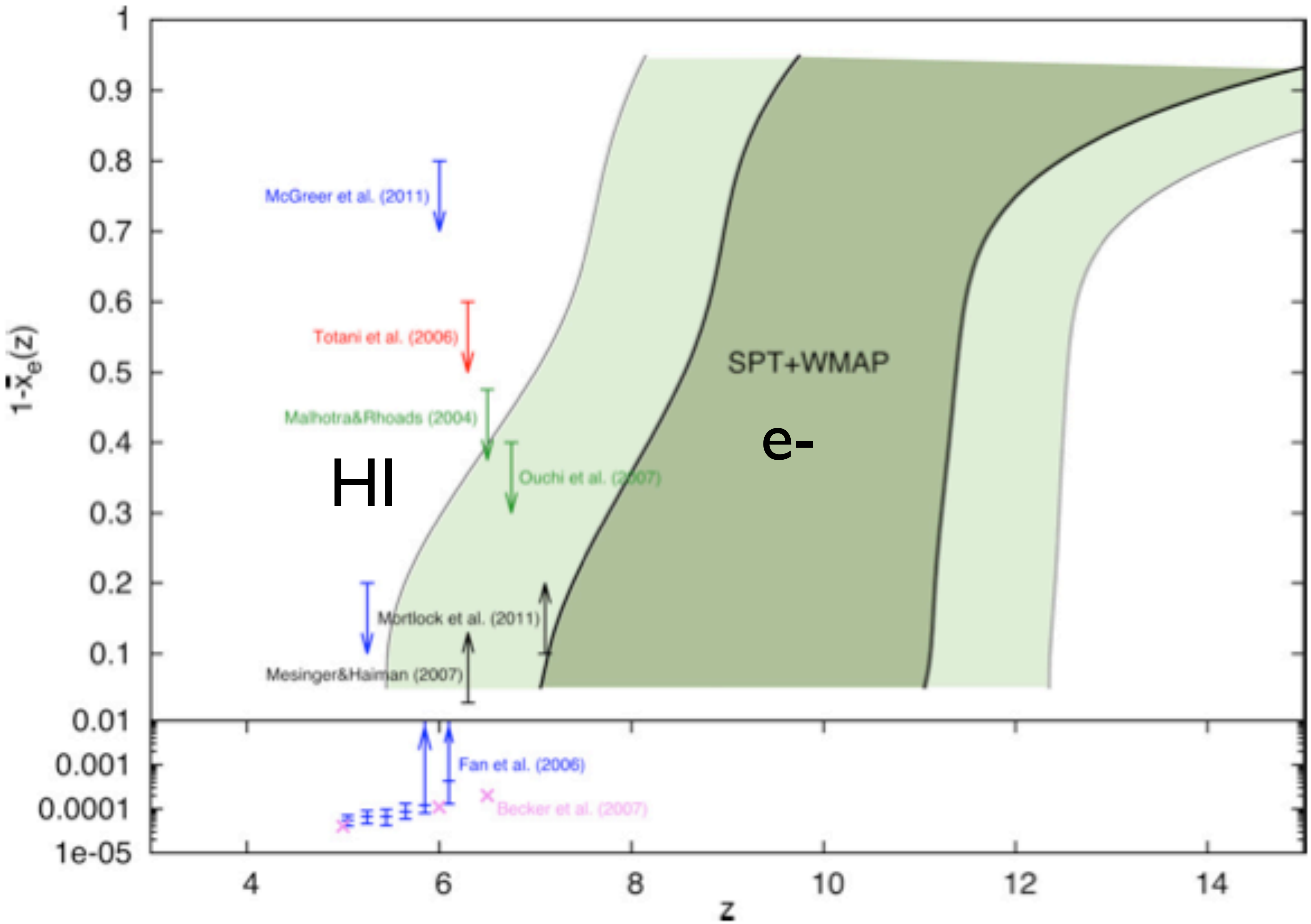
Ly alpha IGM damping wing?



(Simcoe et al. 2012)

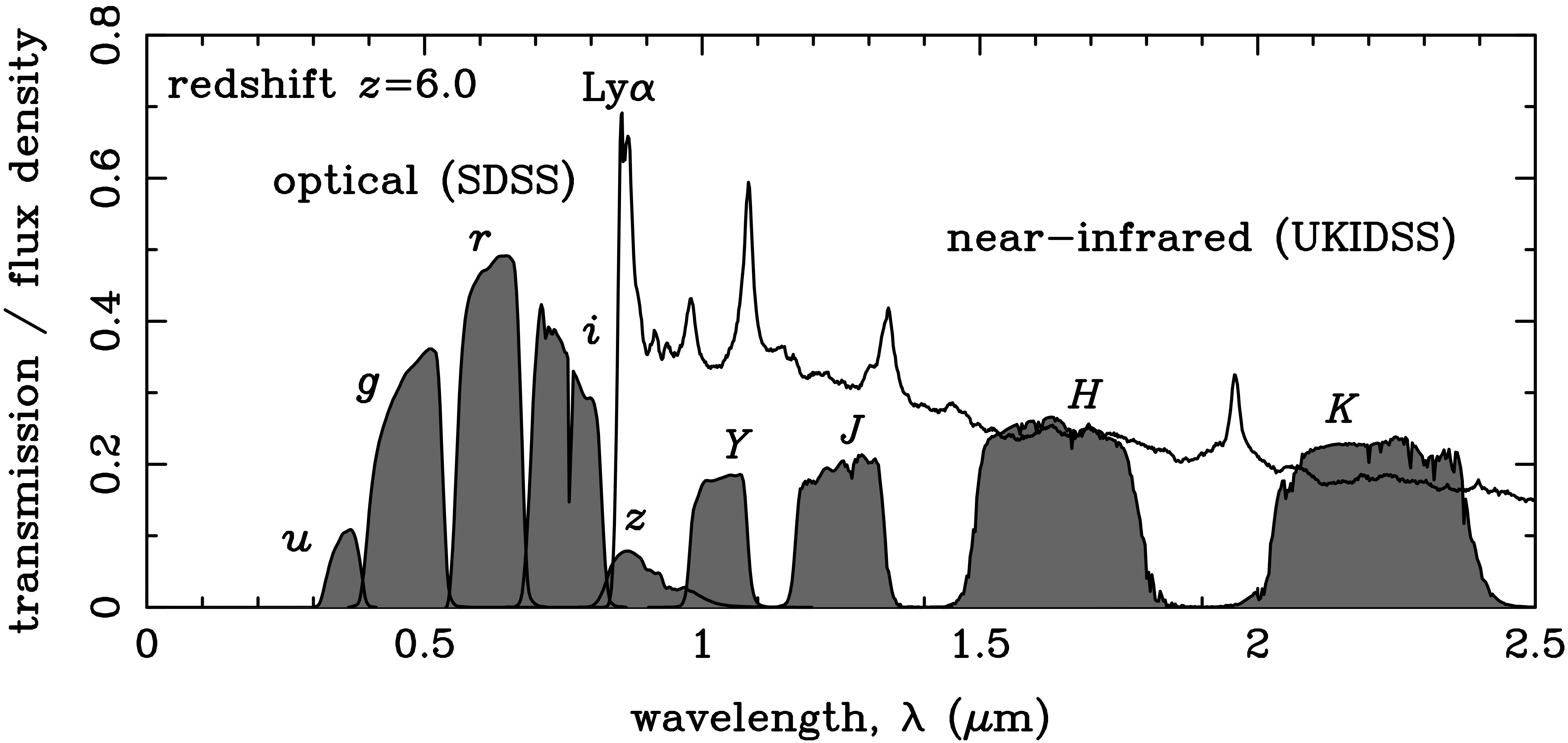


Neutral fraction evolution



(Zahn et al. 2012)

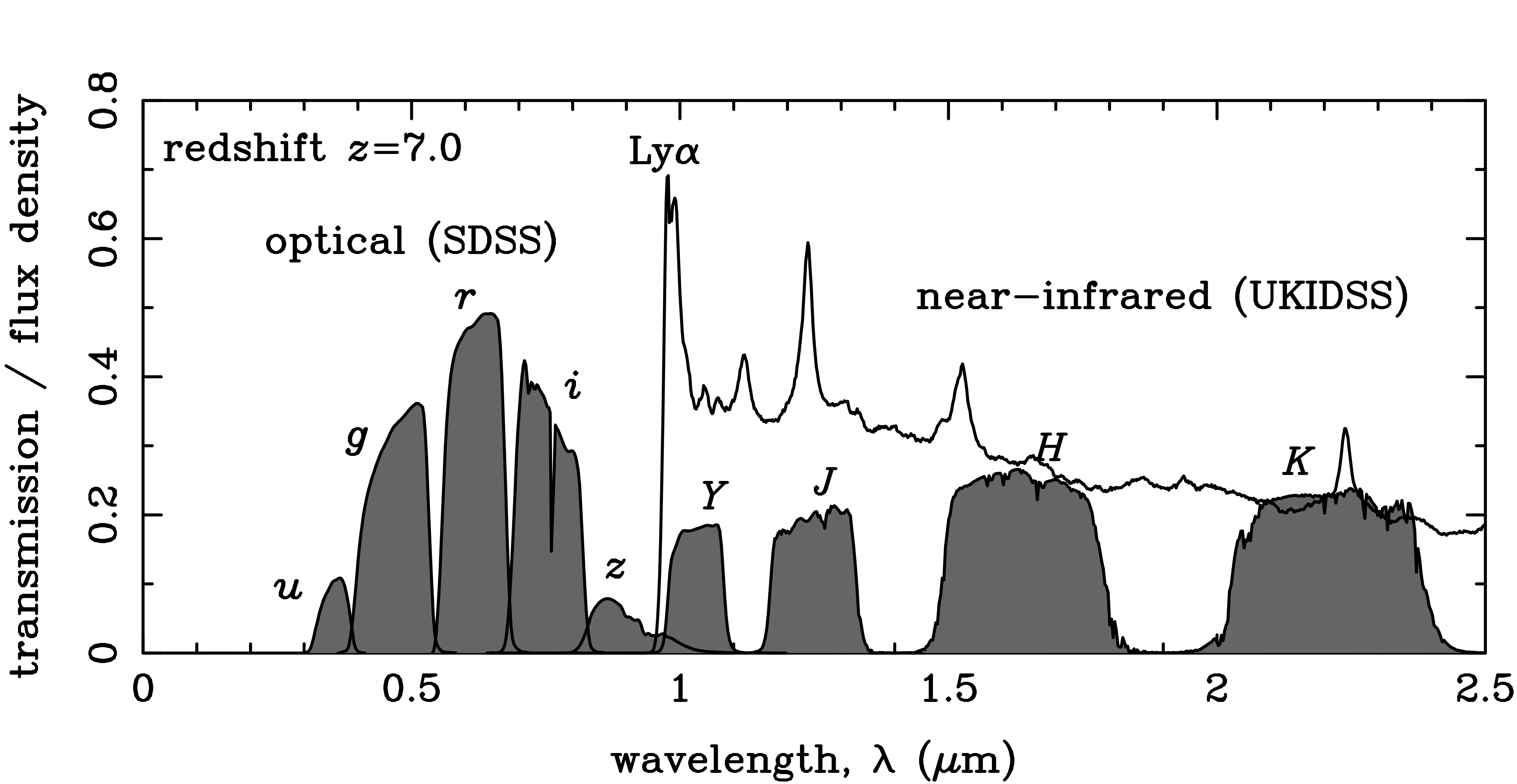
HZQ searches



optical
SDSS/Pan-STARRS

near-infrared
2MASS/UKIDSS/VISTA

HZQ searches



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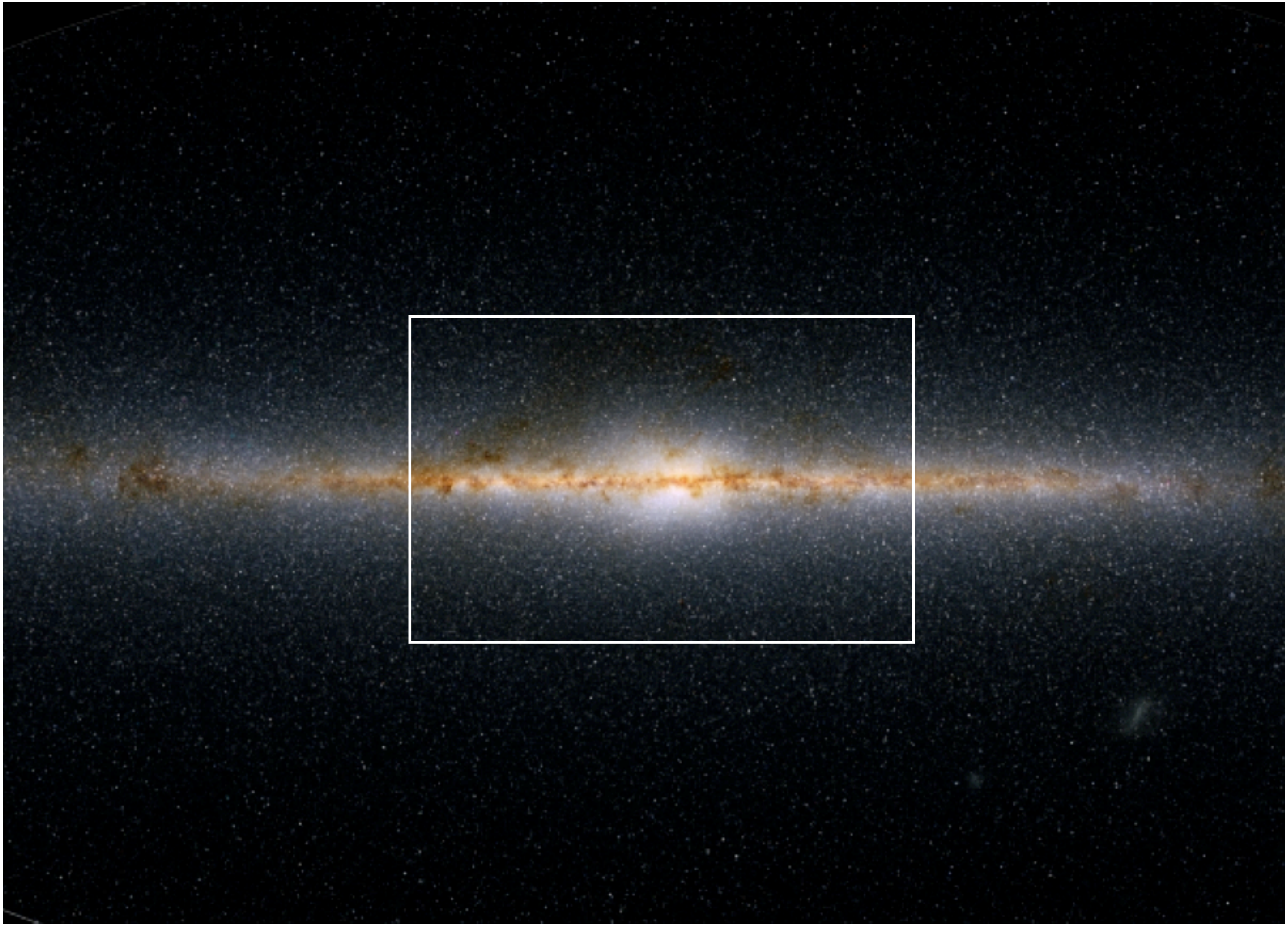
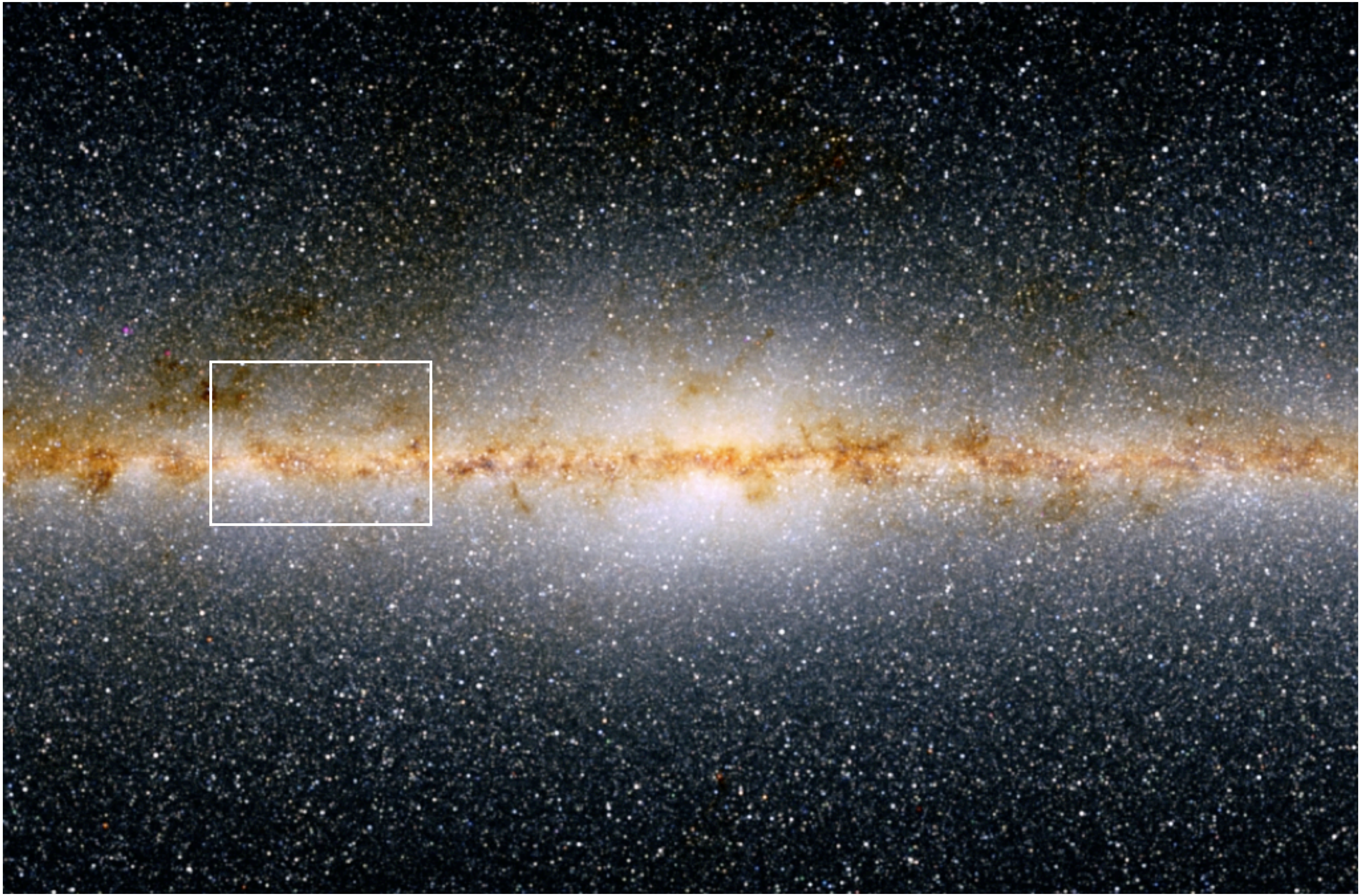
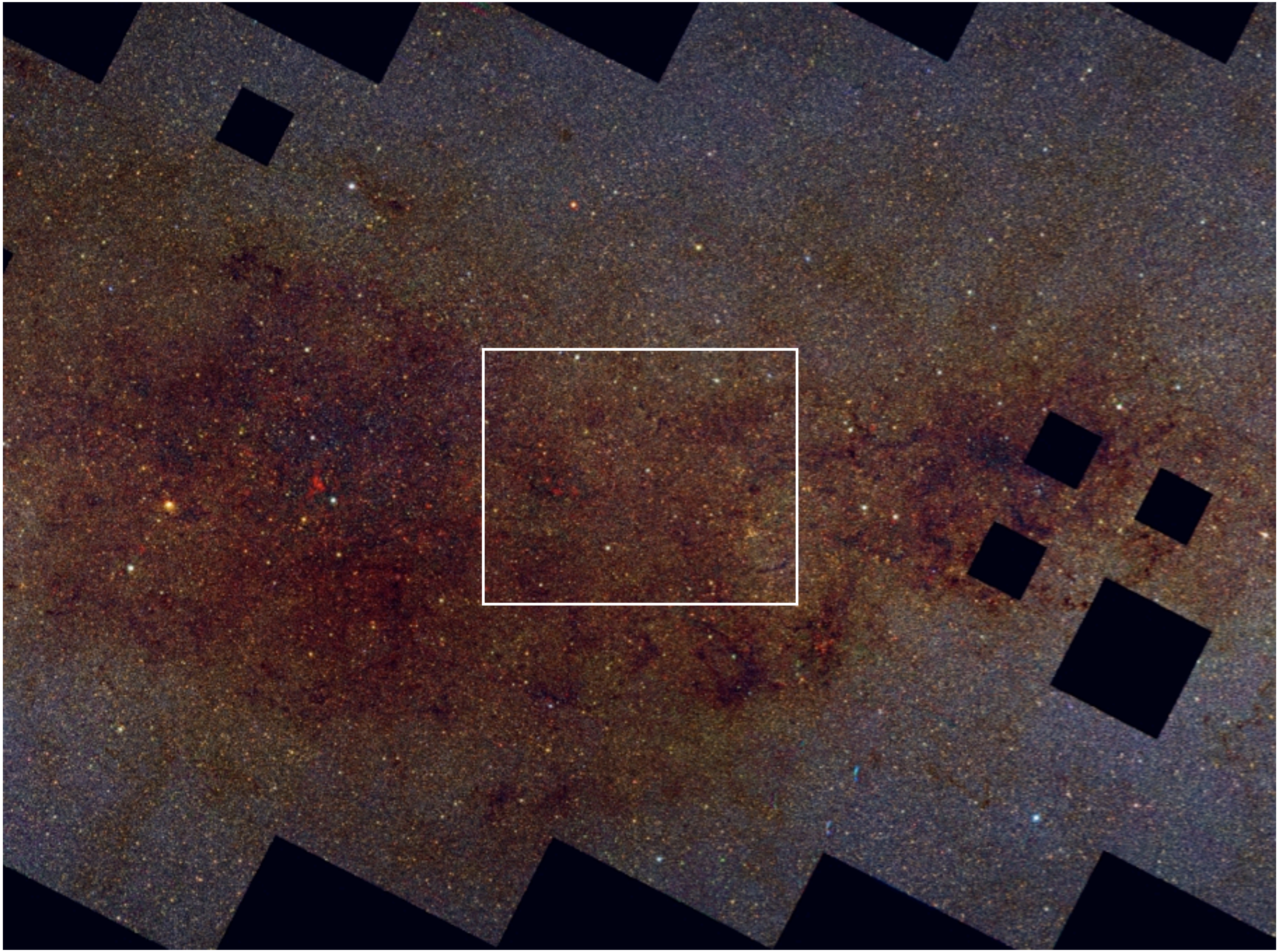


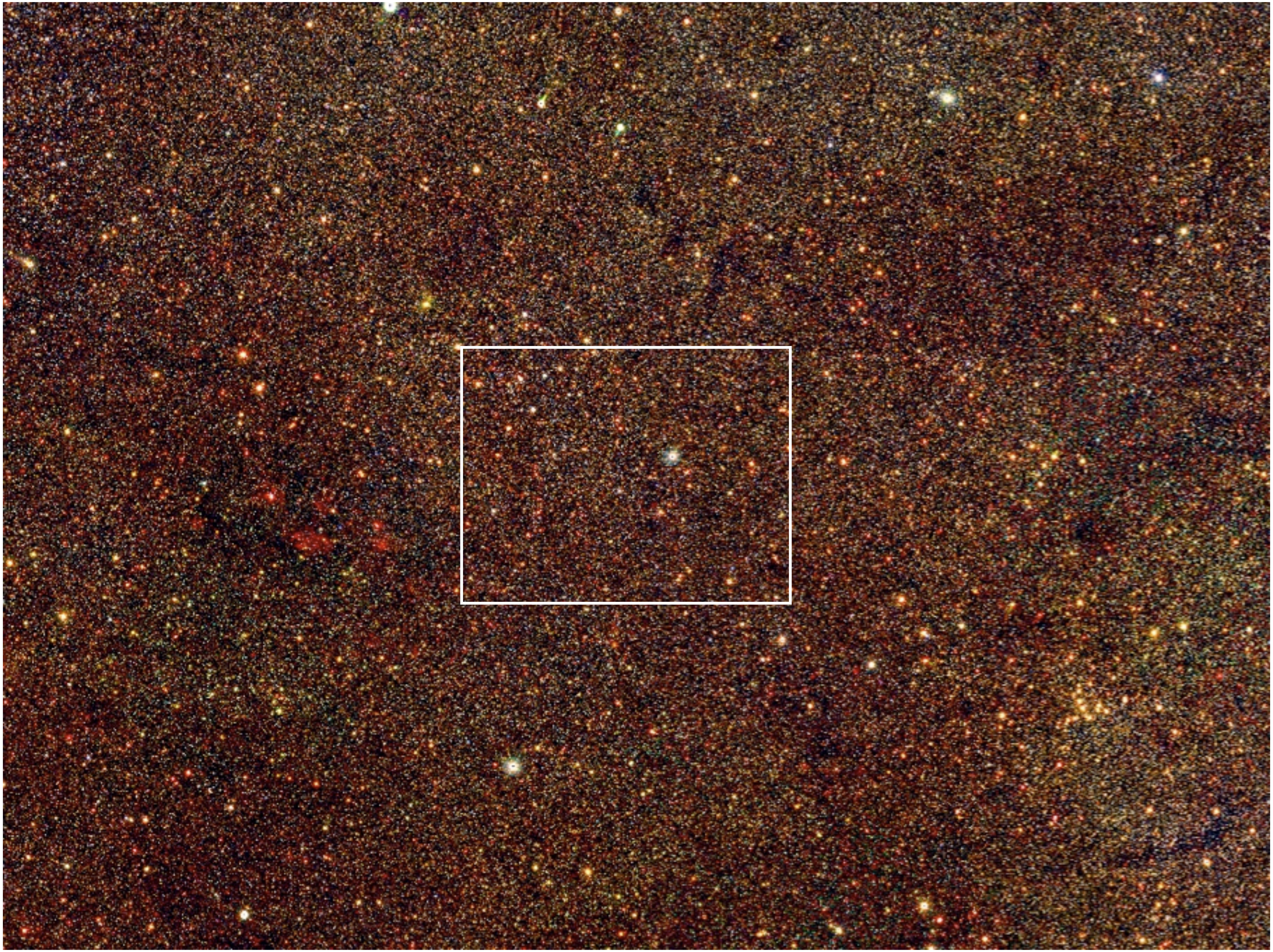
2MASS

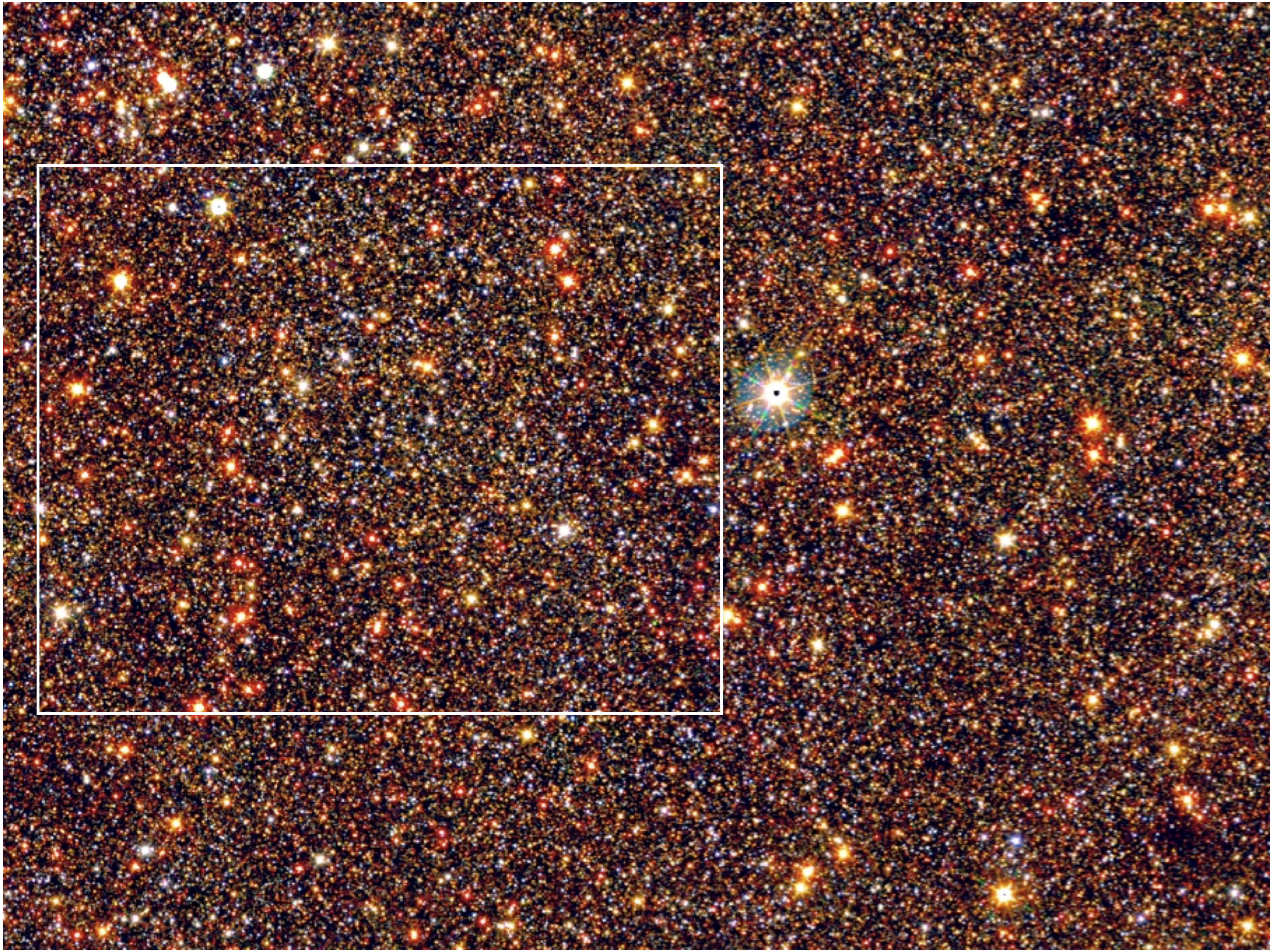


2MASS



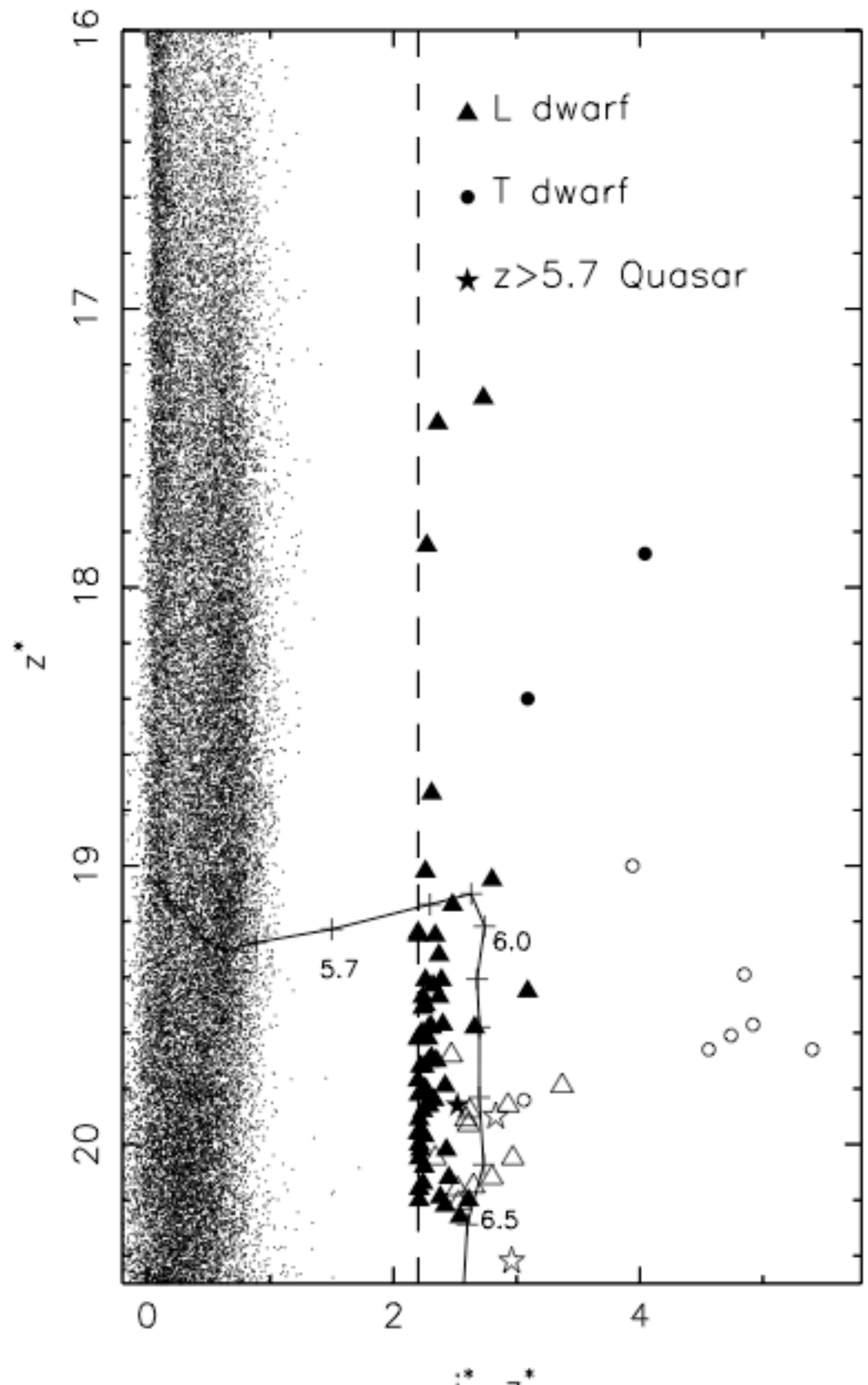
UKIDSS

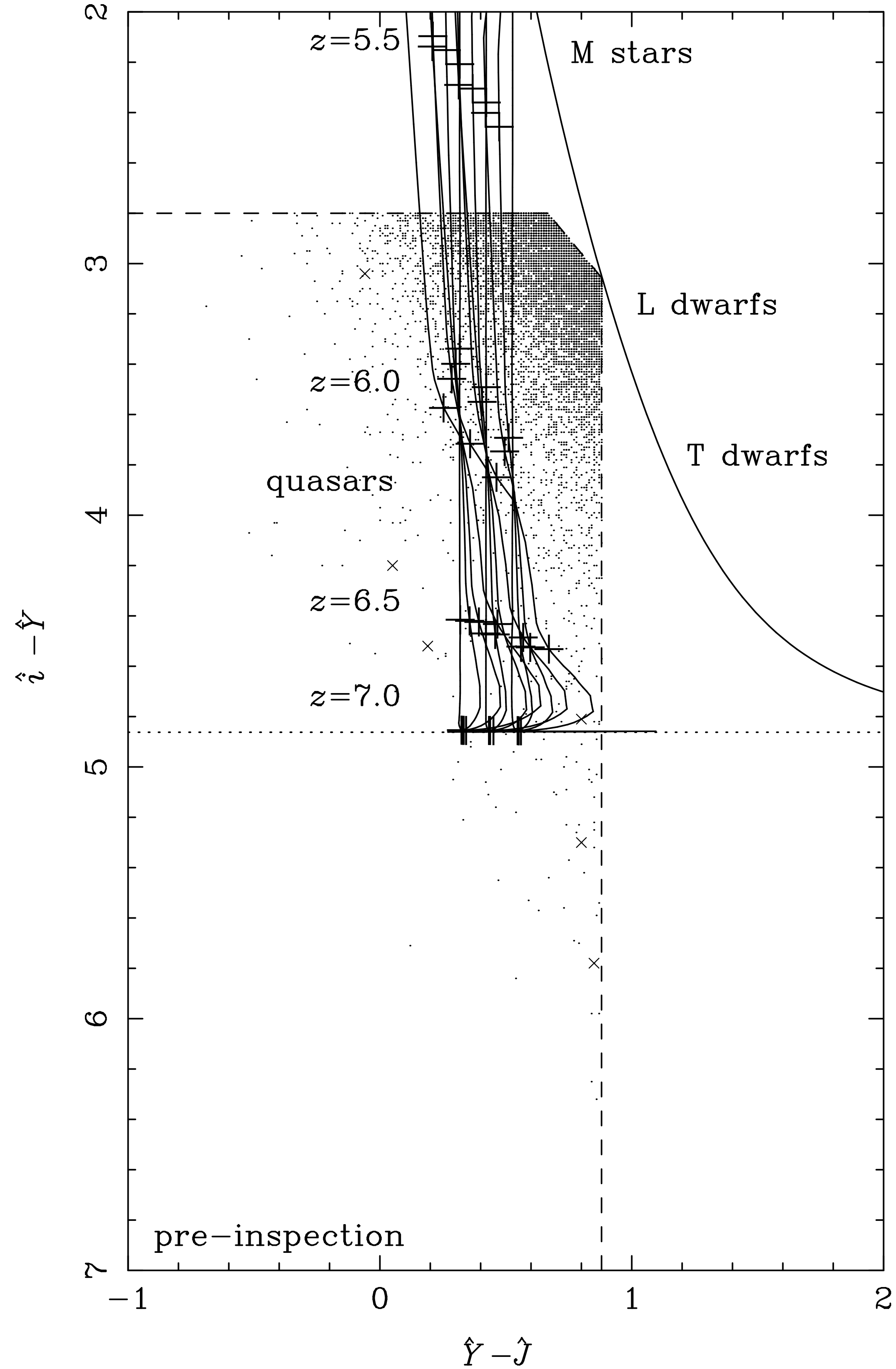




UKIDSS

UKIDSS



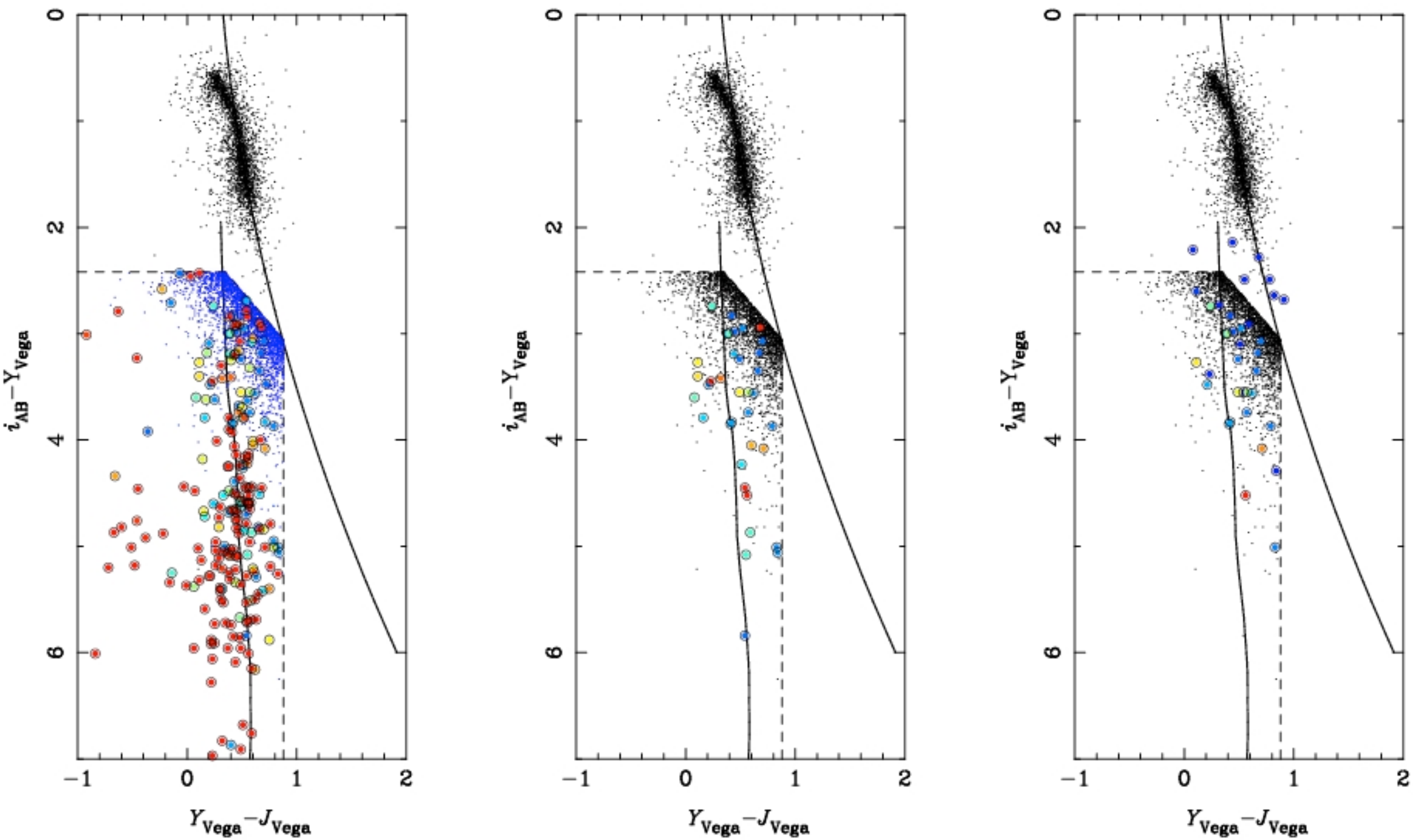


(Fan et al. 2006) (Mortlock et al. 2012)

Confuse dwarfs (D ~ 10 pc) and HZQs (D ~10 Gpc) . . .


Father Ted

UKIDSS HZQ survey

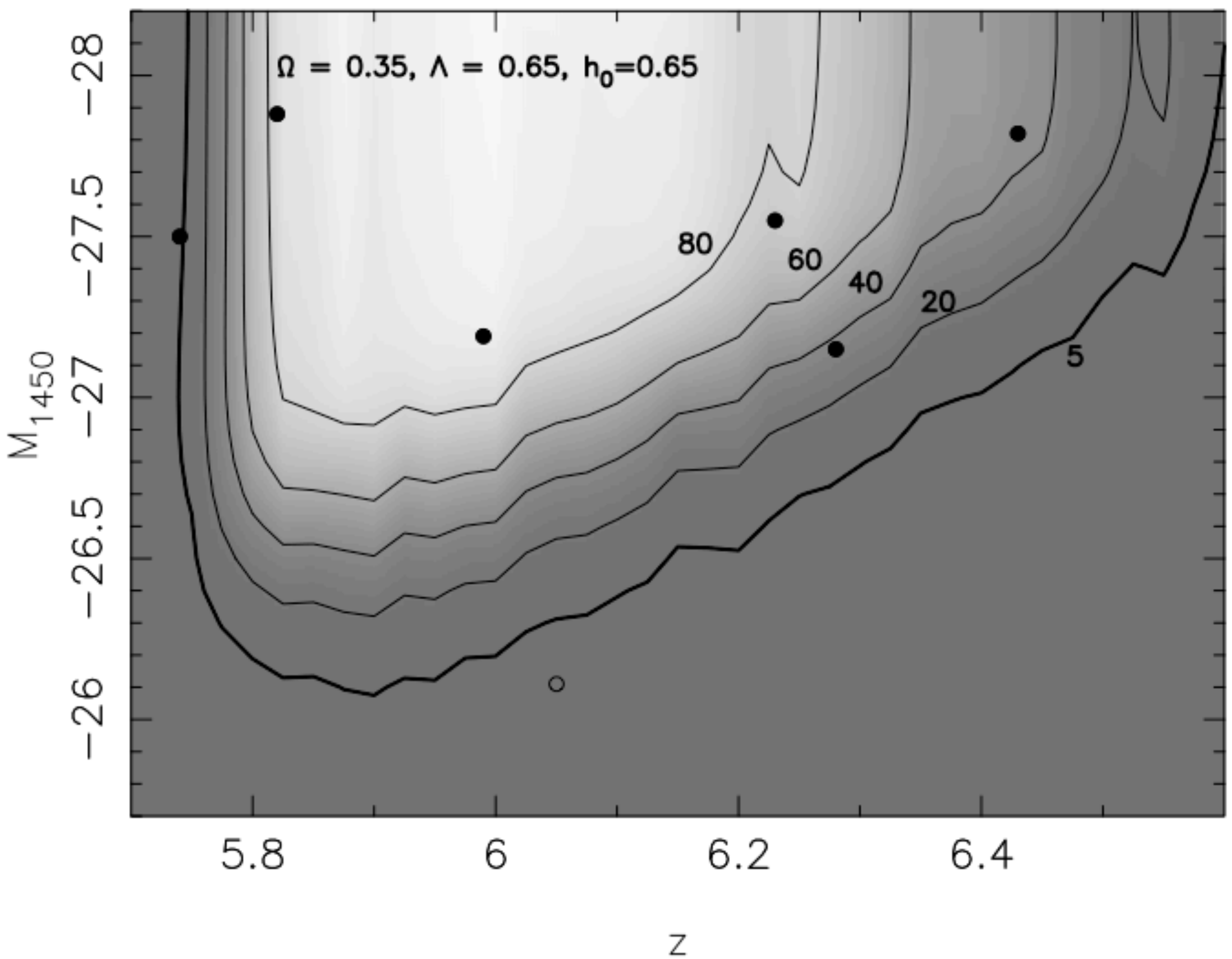


Probabilistic (Bayesian) candidate selection

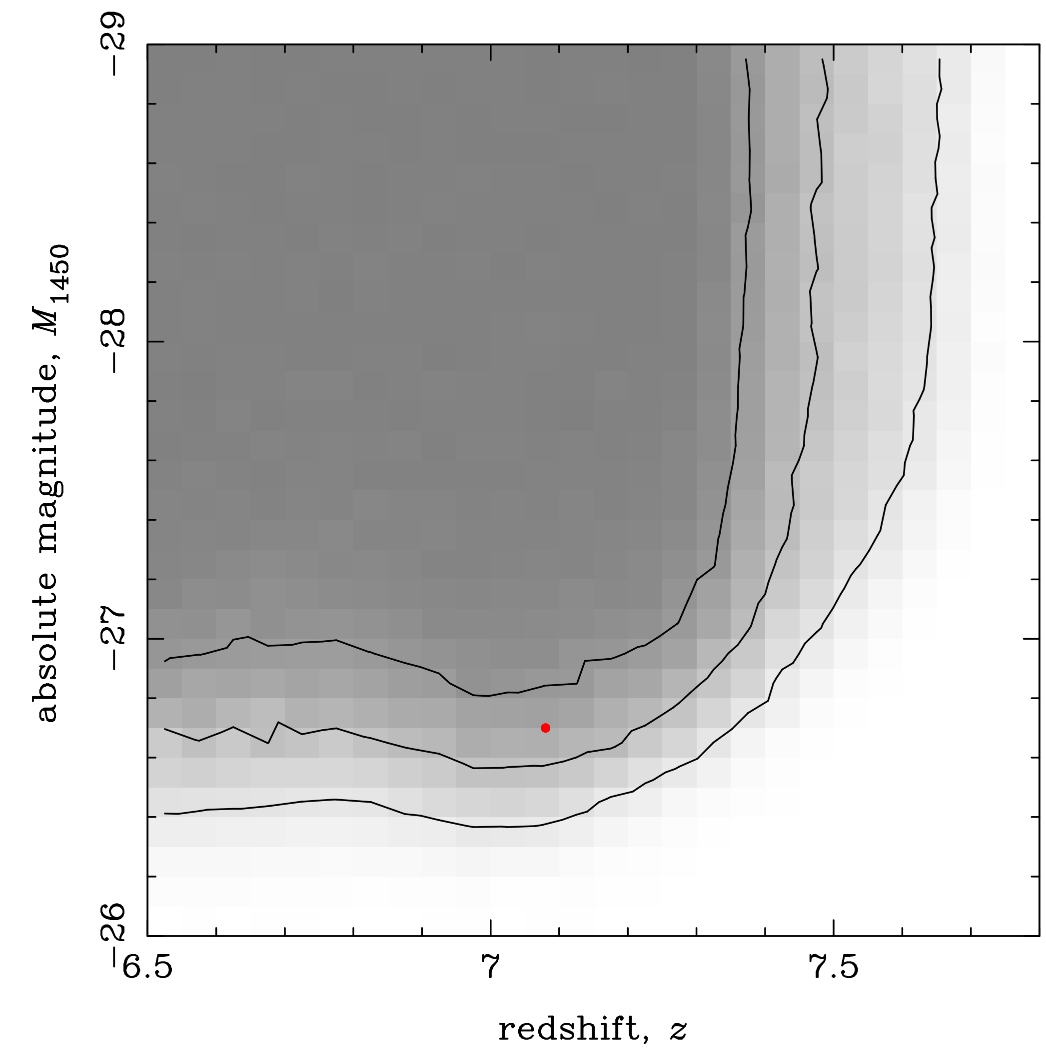
Current HZQ samples

survey	redshift range	number pub. (+unpub.)	AB mag. lim
SDSS	5.7 - 6.5	19 (+3)	z < 20.1
SDSS S82	5.7 - 6.5	11 (+1)	z < 21.8
CFHQS	5.7 - 6.5	19	z < 22.5
UKIDSS	5.7 - 7.4	3 (+6)	Y < 20.2
Pan-STARRs	5.7 - 6.5	1 (+2)	z <~ 21
VIKING	6.5 - 7.5	(+3)	Y <~ 21

Survey completeness



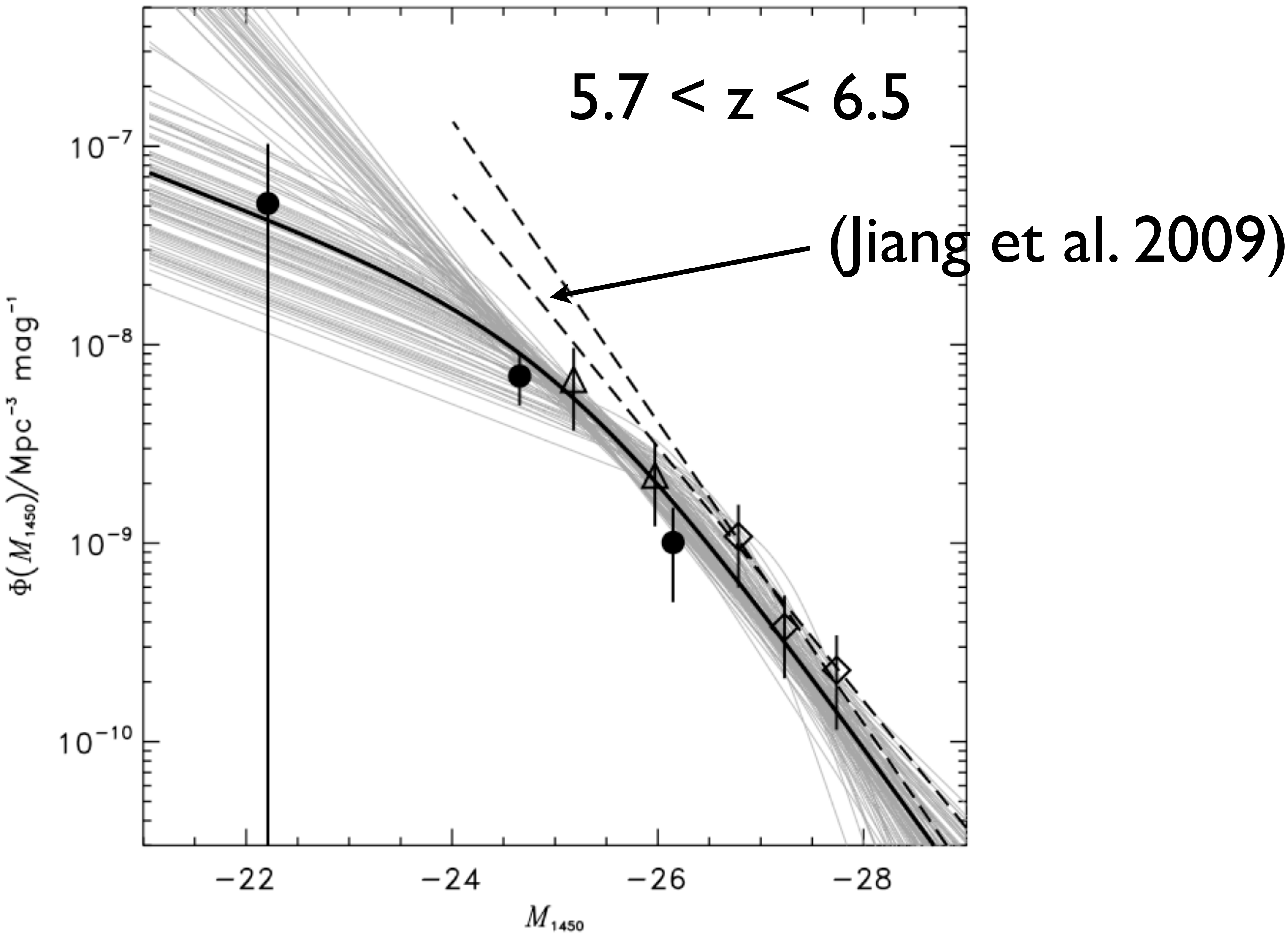
(Fan et al. 2003)



(Mortlock et al. 2013)

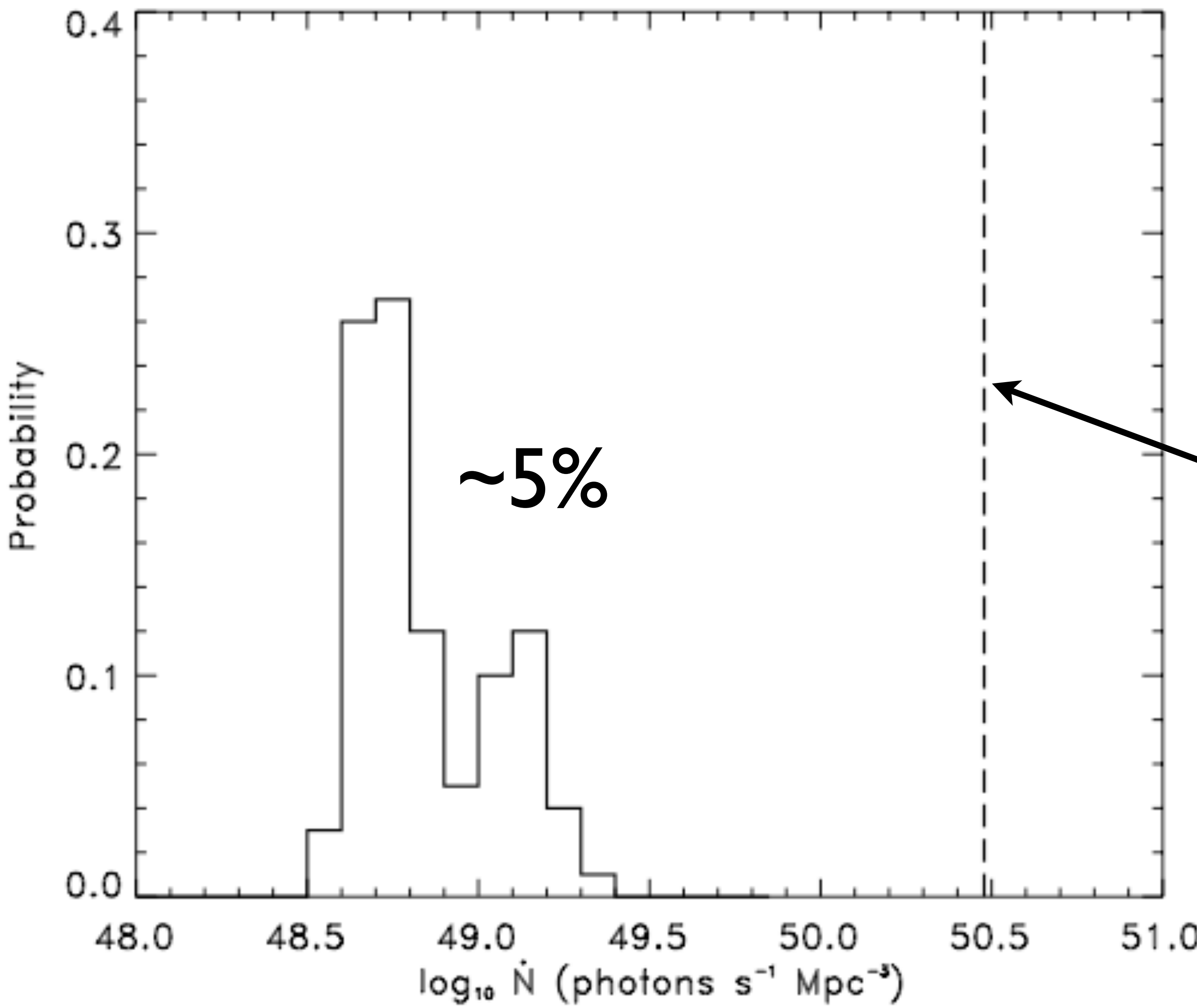
Completenss calculations require assumptions about distribution of HZQ intrinsic properties.

HZQ luminosity function



(Willott et al. 2010)

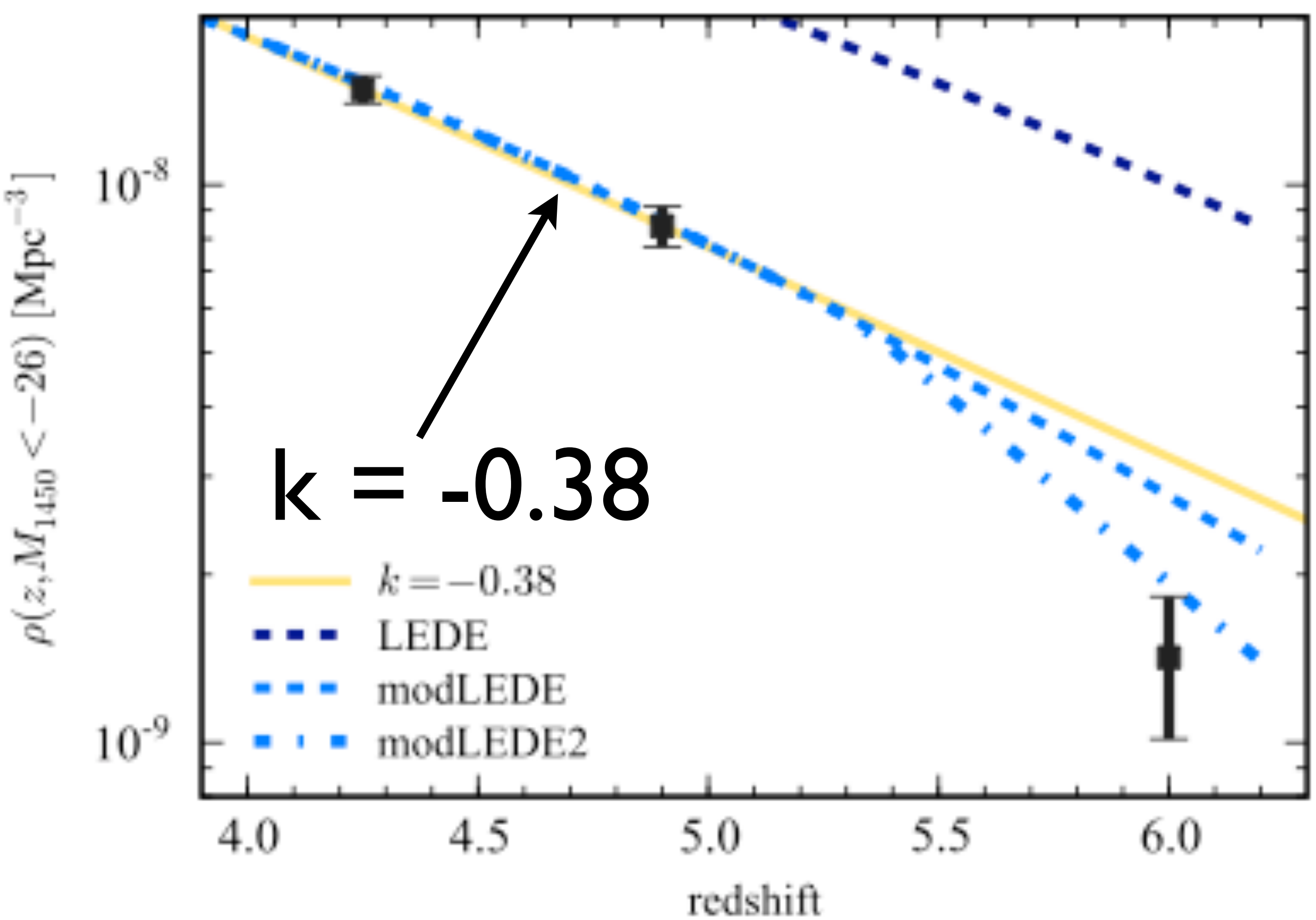
HZQ ionizing contribution



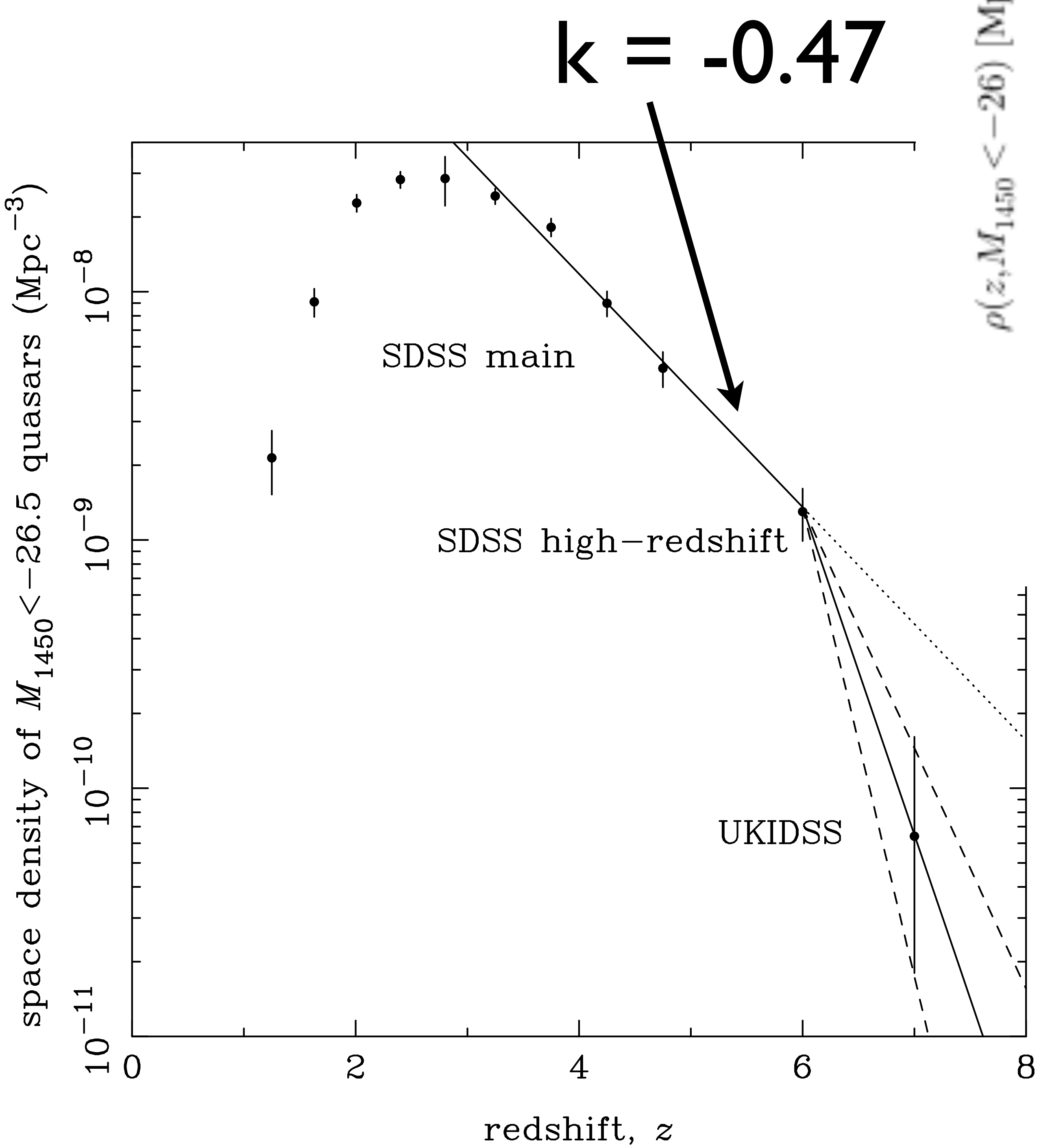
Rate required to keep the Universe ionized.

(Willott et al. 2010)

HZQ number evolution

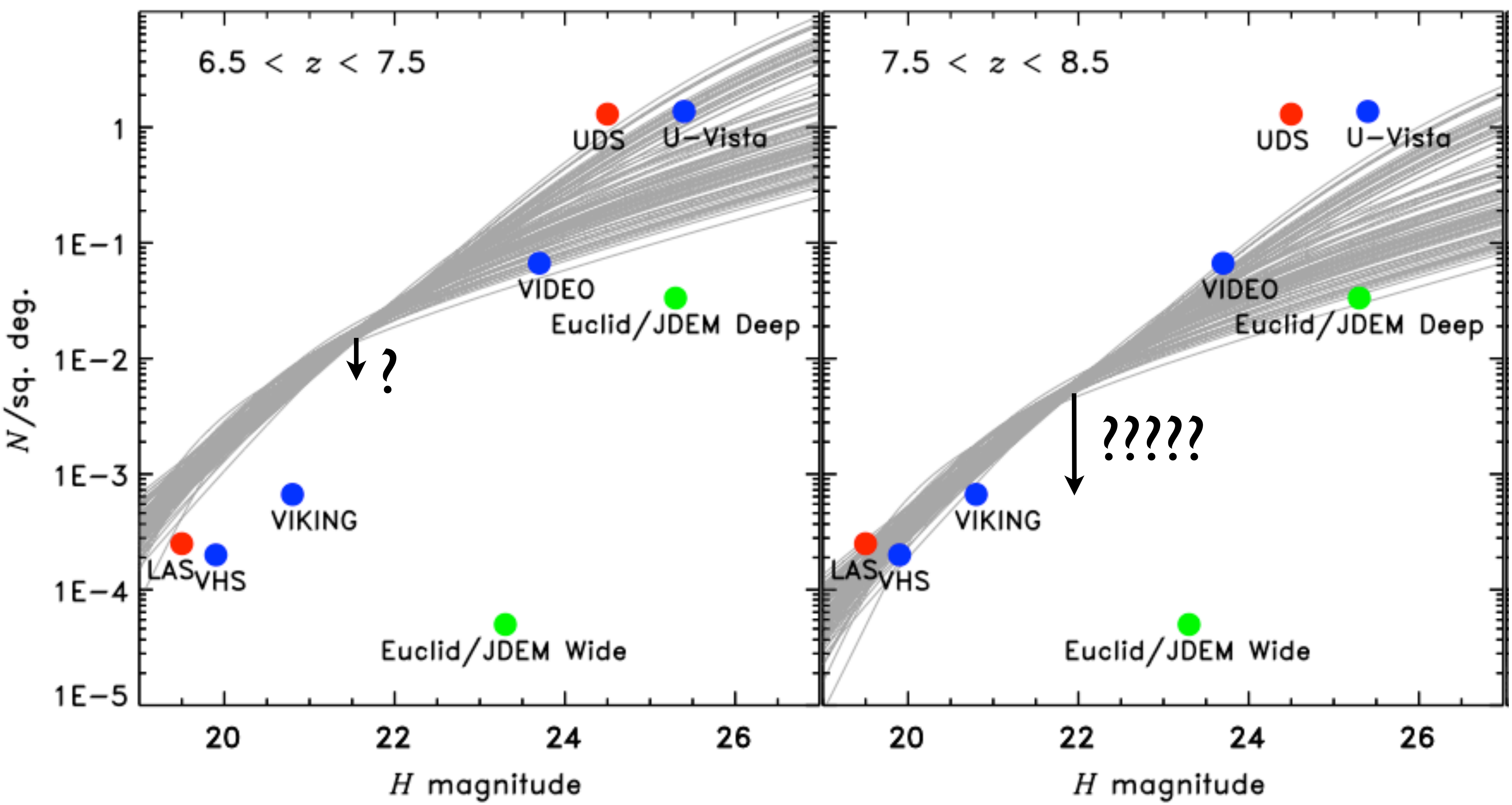


(McGreer et al. 2013)



(Mortlock et al. 2013)

Future HZQ searches



(Willott et al. 2010)

Short answer(s):

The first black holes and the first quasars:

- were rare (and much rarer at higher redshifts);
- are hard to find;
- are hard to form;
- contribute a little to (hydrogen) reionization;
- can be used to probe (hydrogen) reionization.