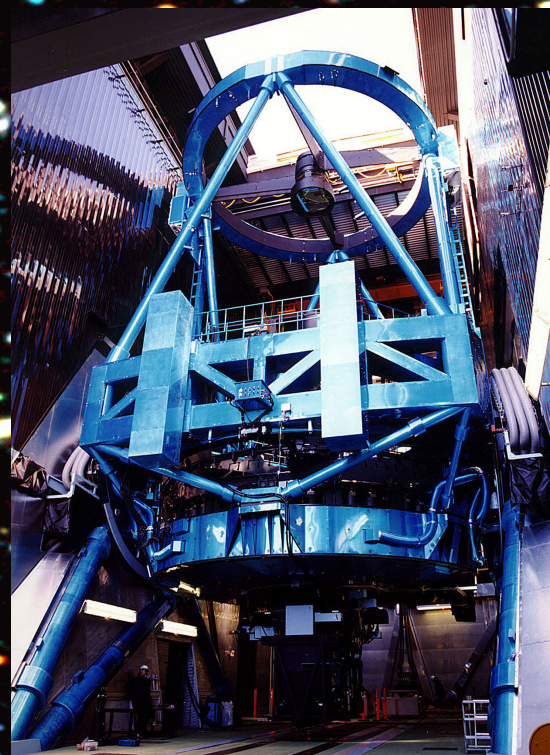
Reionization and Galaxy Evolution probed by z=7 Lyα Emitters

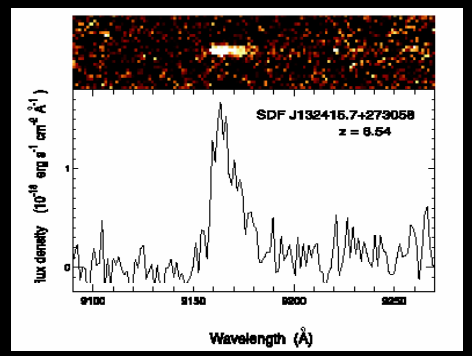
Kazuaki Ota
Univ. Tokyo



Introduction

How far back in the past can we still find objects ?

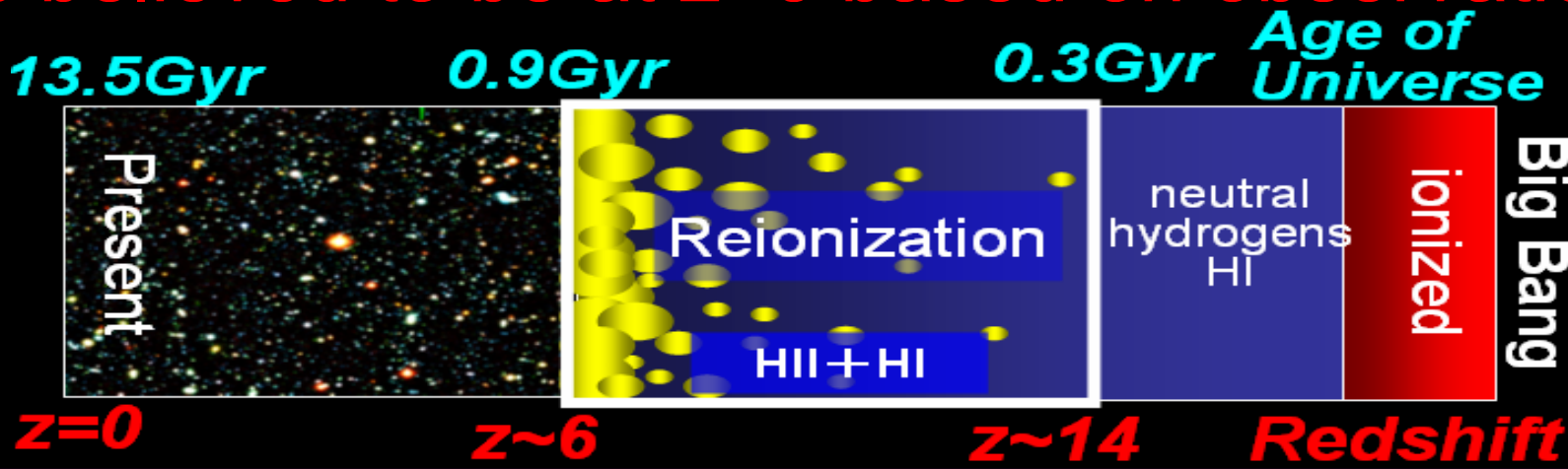
Previously most distant one:
z=6.6 Ly α emitting galaxies.
But, were there any at z>6.6, also?

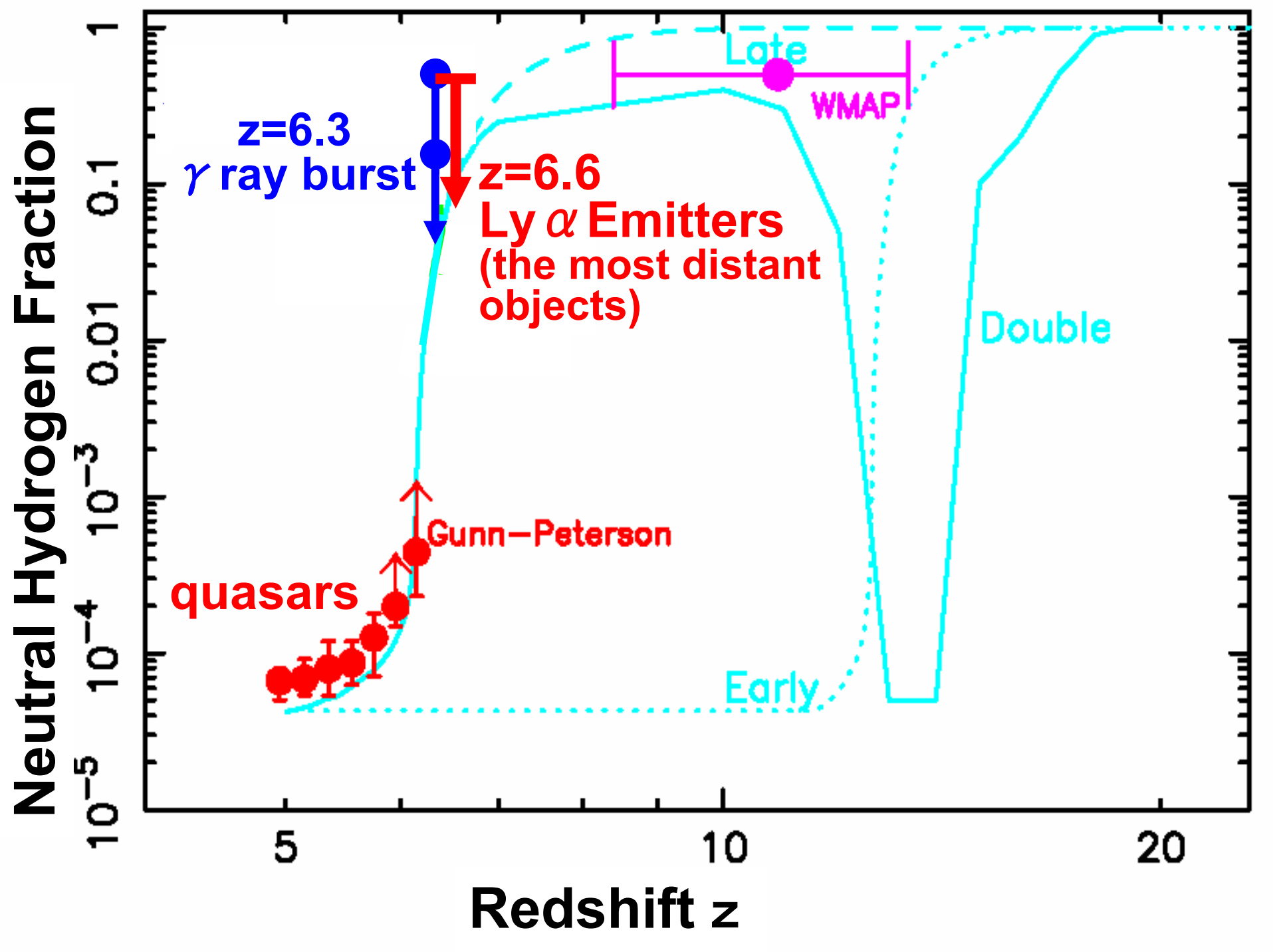


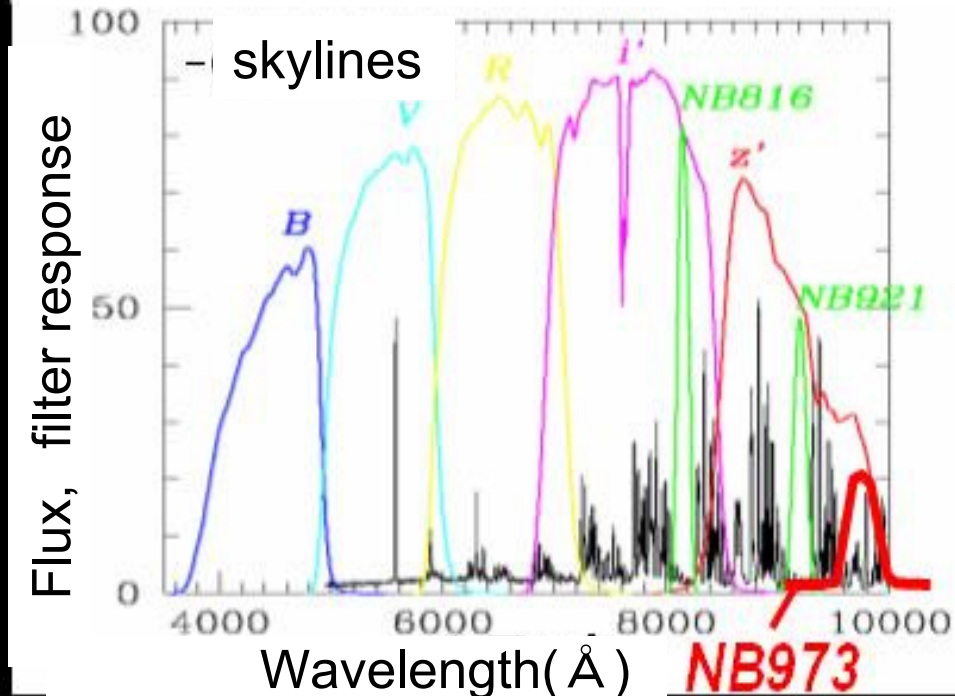
Taniguchi et al.2005

When did the reionization complete?

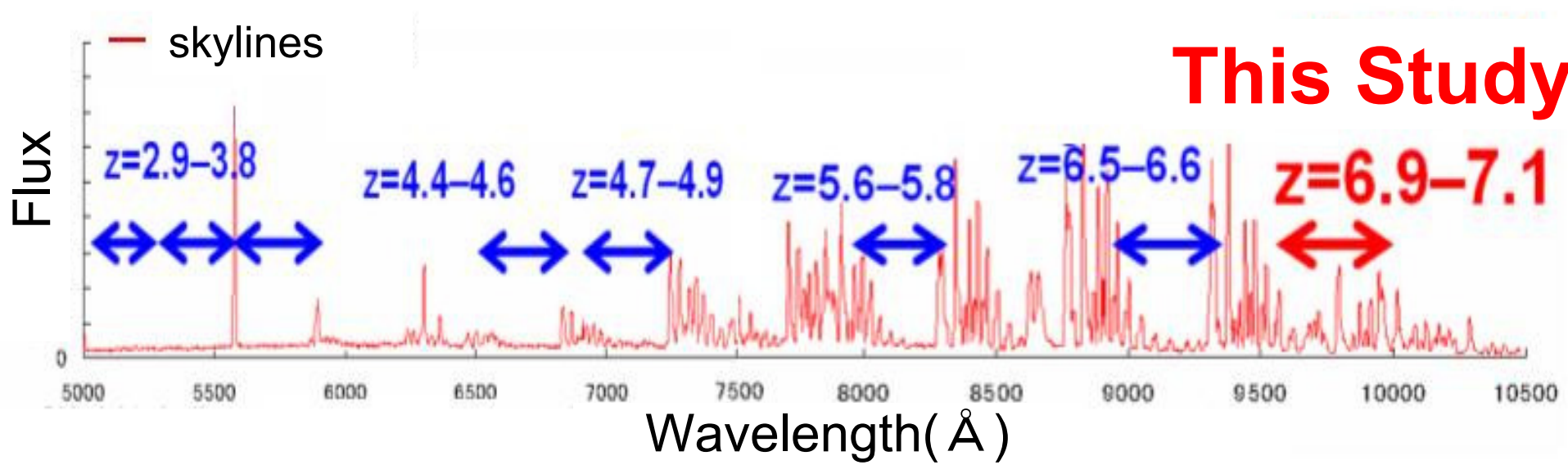
It is believed to be at z~6 based on observations.

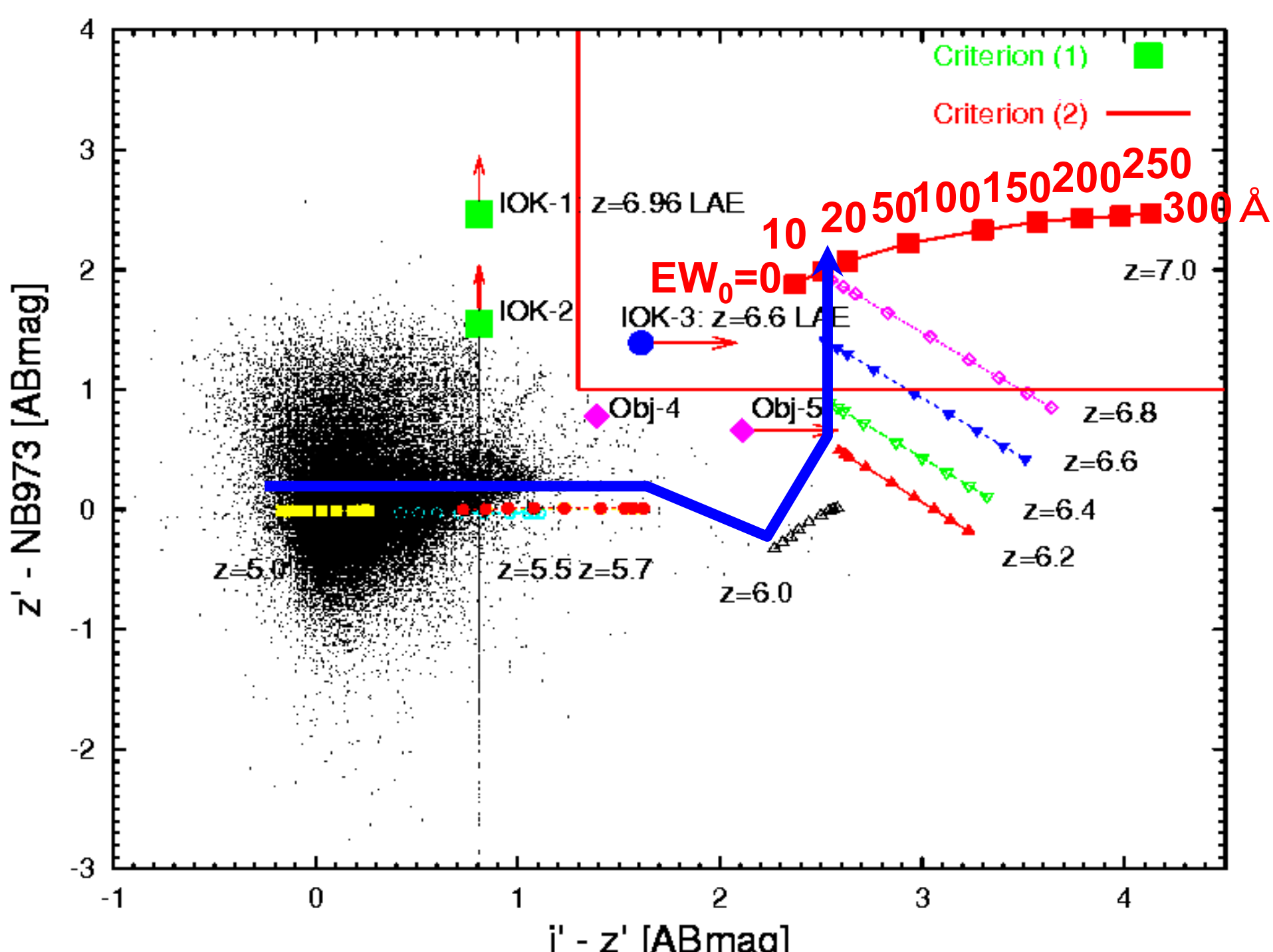



Neutral Hydrogen Fraction
1
0.1
0.01
10^{-3}
10^{-4}
10^{-5}
5
10
20
Redshift z
Late
WMAP
Double
Early
z=6.3
γ ray burst
z=6.6
Ly α Emitters
(the most distant objects)
Gunn−Peterson
quasars

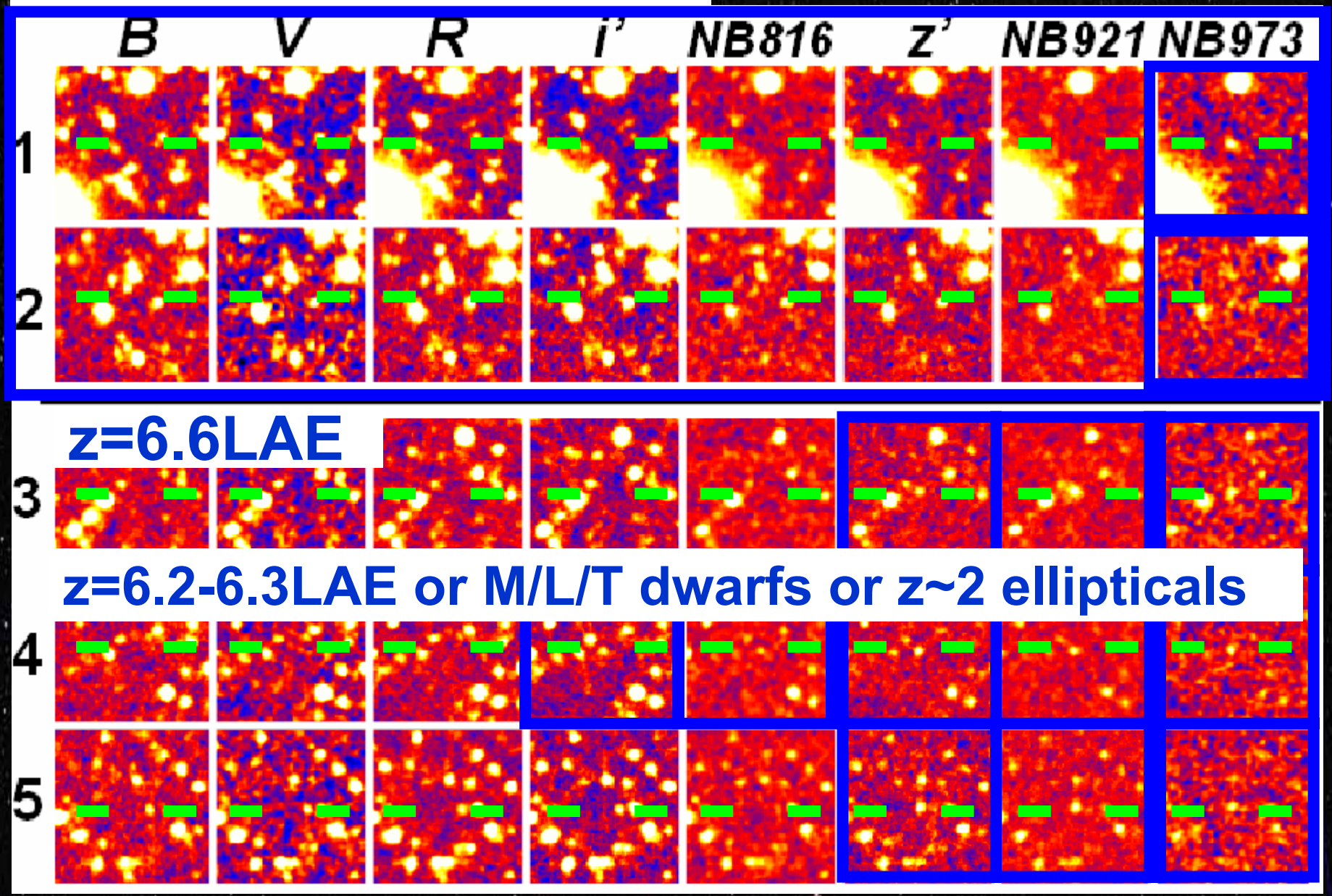


Subaru Deep Field Suprime-Cam **NB973** (λ c=9755 Å , $\Delta\lambda$ =200 Å)




Criterion (1)
Criterion (2)
IOK-1: z=6.96 LAE
IOK-2
IOK-3: z=6.6 LAE
Obj-4
Obj-5
10
20
50
100
150
200
250
300 Å
EW0=0
z=7.0
z=6.8
z=6.6
z=6.4
z=6.2
z=6.0
z=5.0
z=5.5
z=5.7
z' - NB973 [ABmag]
i' - z' [ABmag]

z=7LAE Candidates



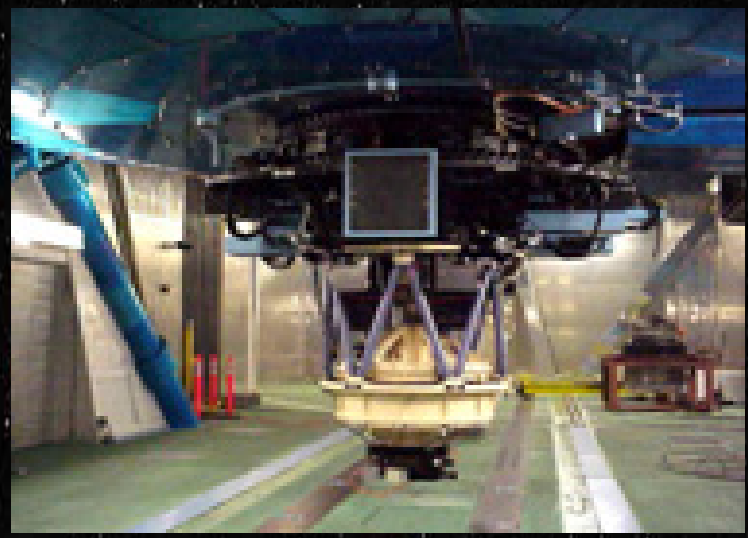
Follow-up Spectroscopy
May, June 2005, April 2006

10000 Å

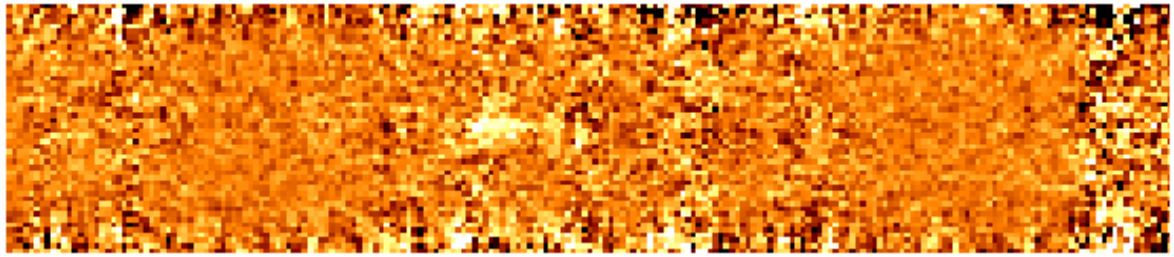
slit
W : 0.″ 8
L : 8 -15″

8300 Å

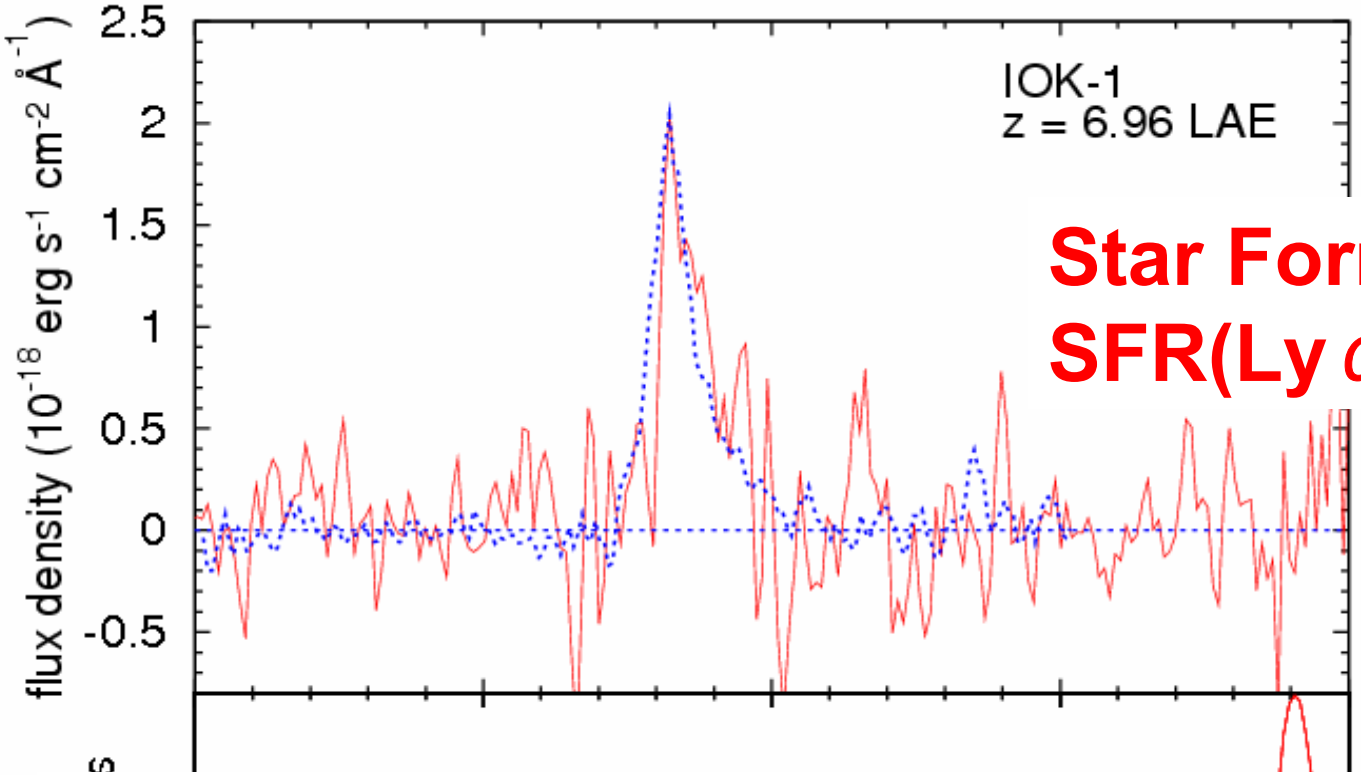
Subaru＋FOCAS



- **Echelle grism + z’ filter**
  （175 lines／mm）
- **Resolution ~ 1600**
- Dispersion = 0.98 Å /pixel



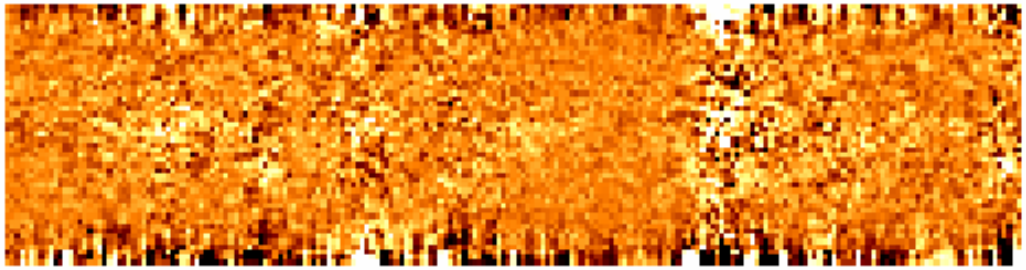
IOK-1 z=6.96 LAE

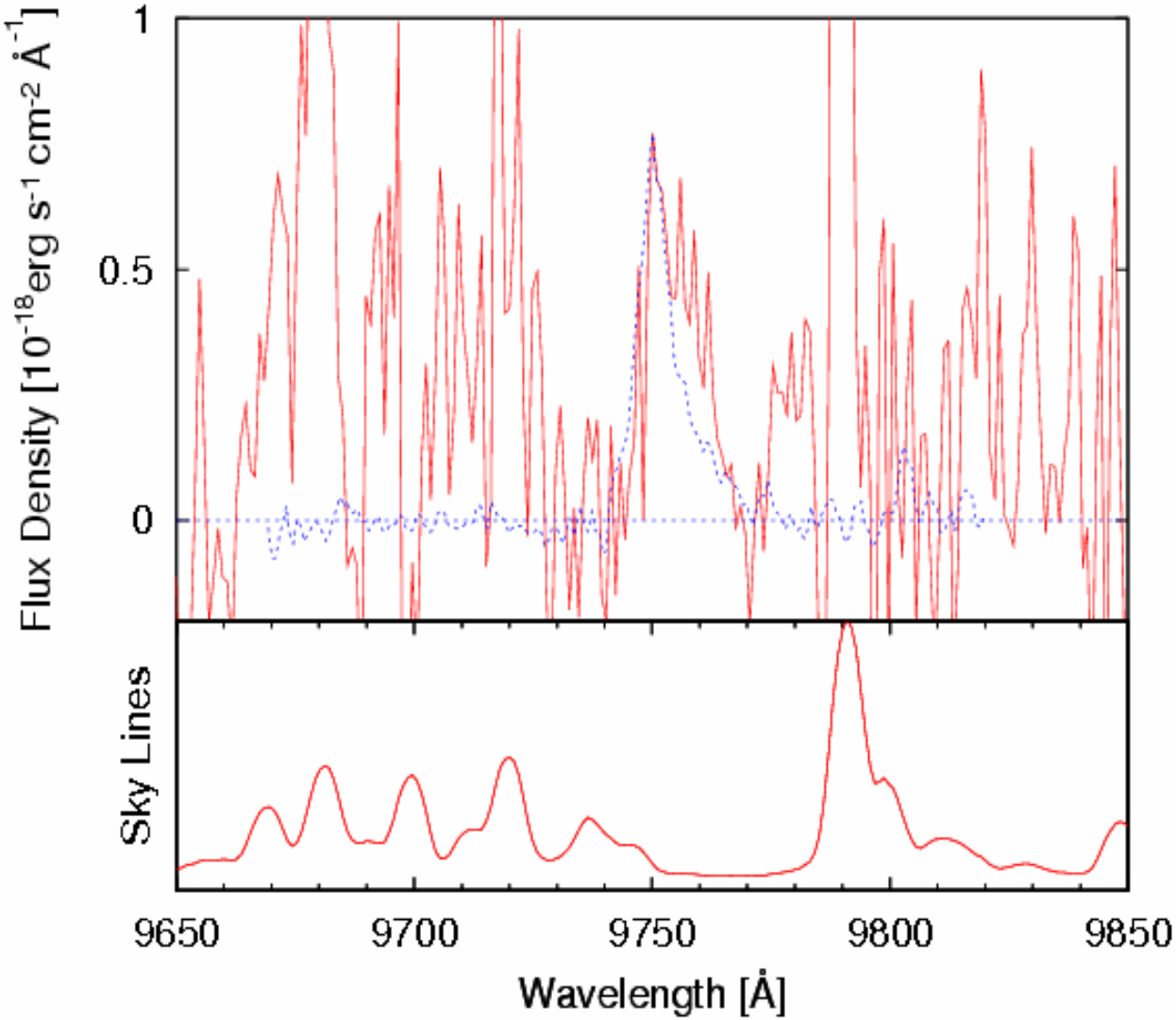


Star Formation Rate
SFR(Ly α)～10M$\odot$yr^{-1}

5.5hr exp.
S/N=5.5

Galaxy formation was already under way just 750Myr after the Big Bang（only ~6% of the present age of the Universe）!





IOK-2

z=7.02

LAE ?

3hr exp.

S/N~2

Need additional spectroscopy for confirmation.

Did the reionization really complete at z~6?

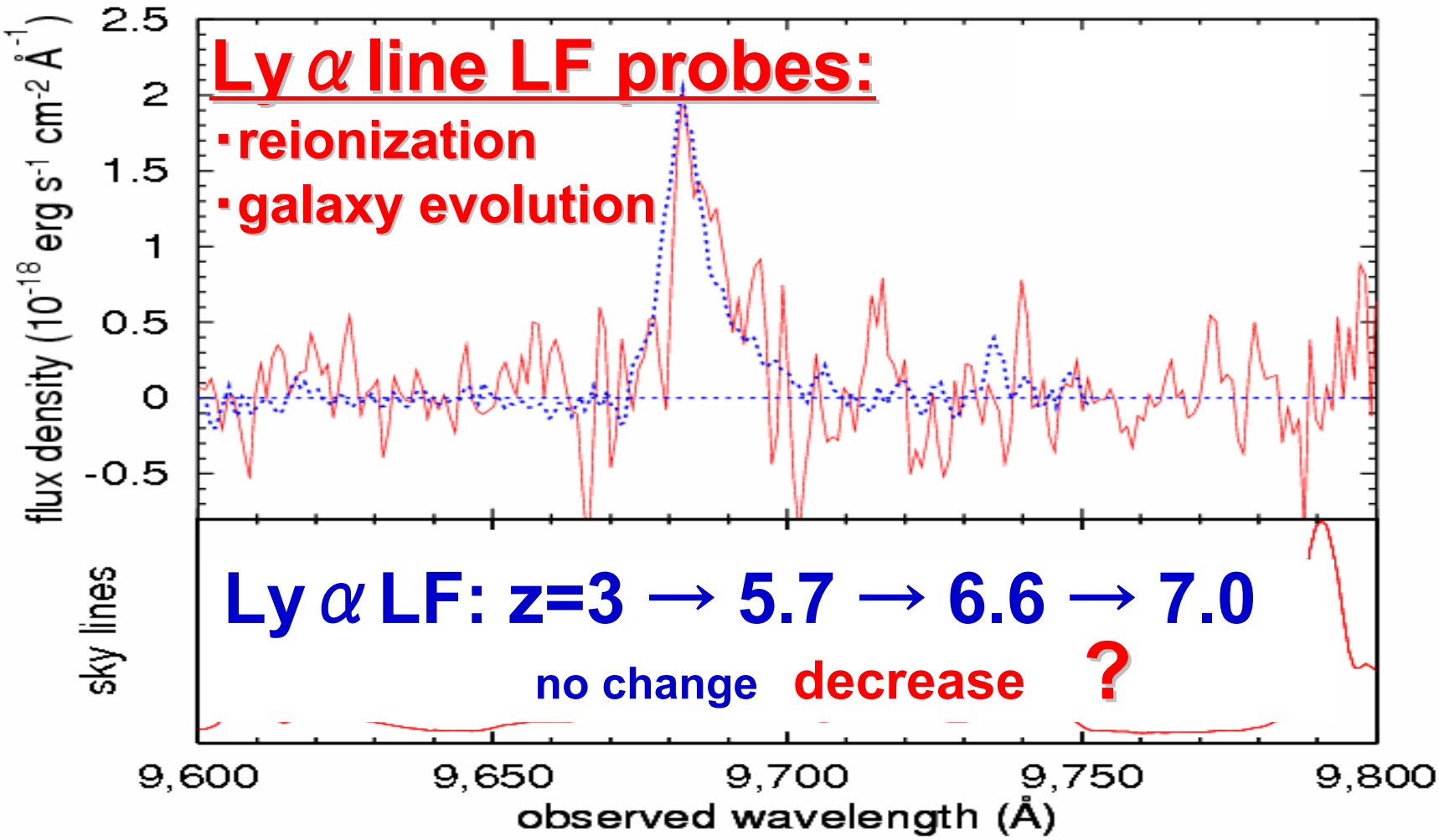
Now we compare the

- Lyα line LF (gal. evol. &/ reionization)
- UV LF (gal. evol.)

of z=7 LAE with those of z<6.6 LAEs

z=6.96 LAE: deriving Ly α line LF

At z>6, if the reionization was still in progress,
Ly α photons could be attenuated by HI
→observed number (luminosity) density could be smaller

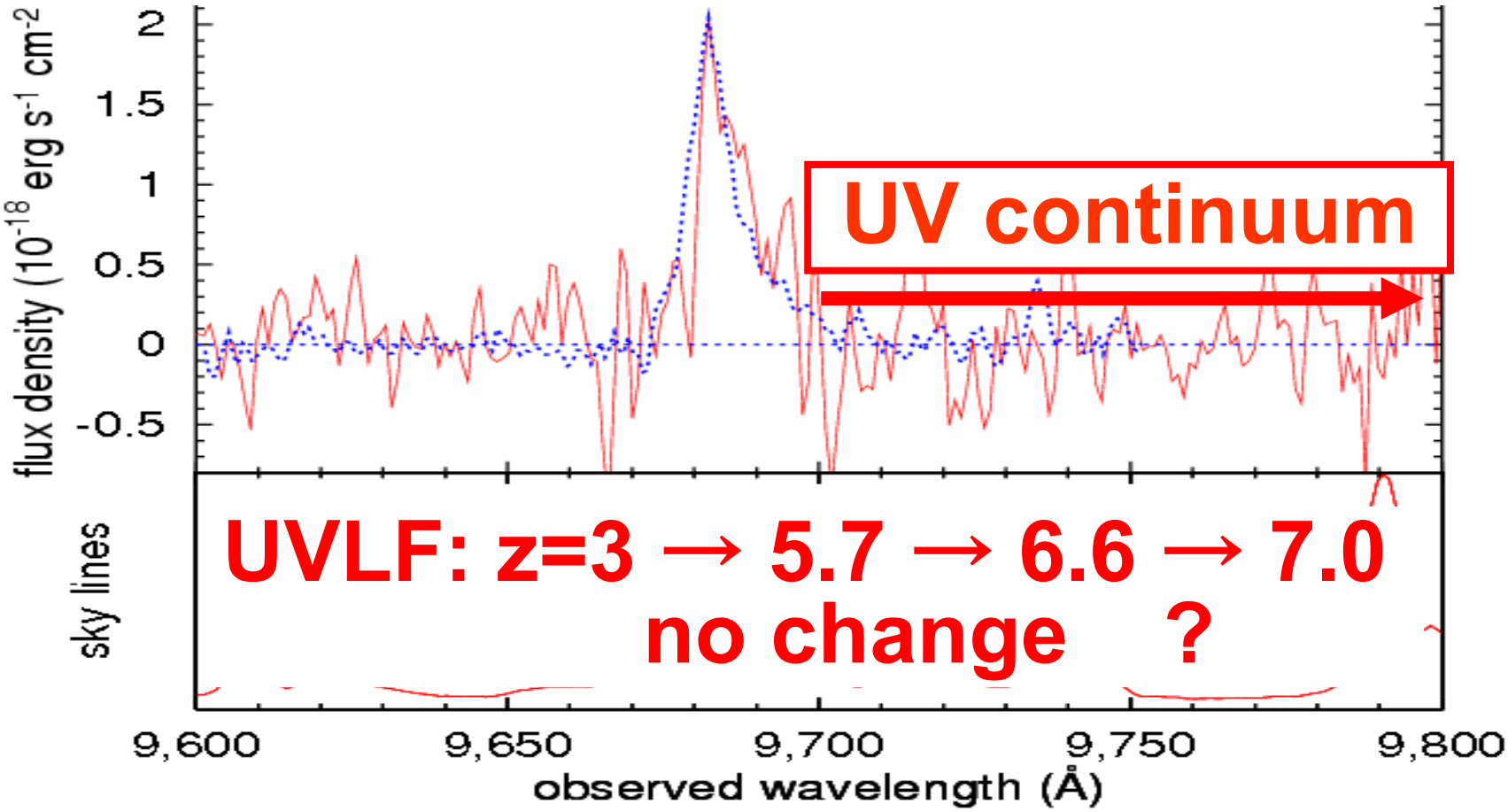


z=6.96 LAE: deriving UV LF

UV photons are NOT attenuated by HI.

LAEs are believed to have no/negligible dust.

→ Change in observed number (luminosity) density in UV LF could be due to galaxy evolution alon



How to derive LFs	Luminosity Functions(LFs)	
	Lyα line LF	UVLF
LAE obs.	Reionization LAE evolution	LAE evolution
model	LAE evolution	—
LBG obs.	—	LBG evolution

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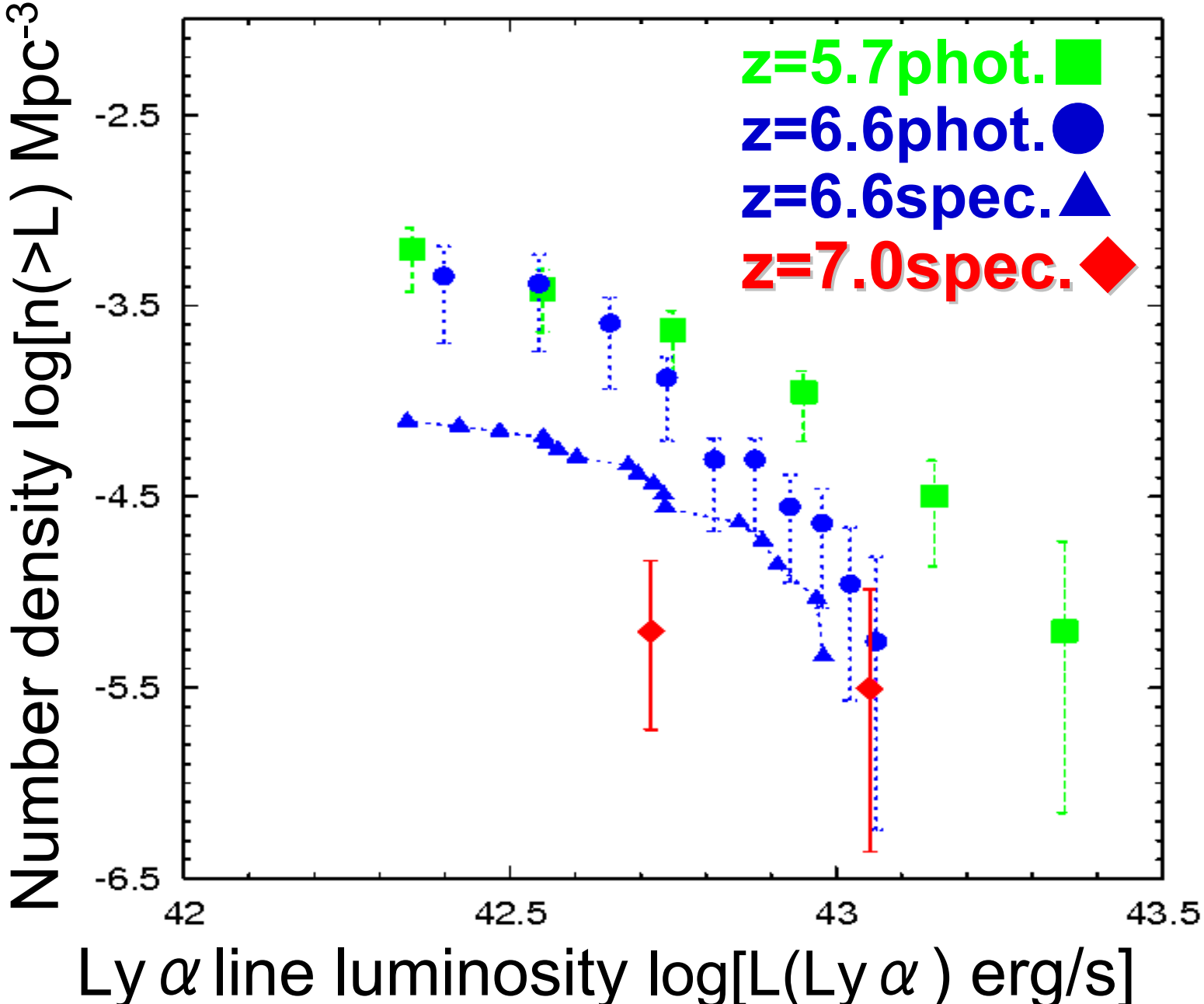
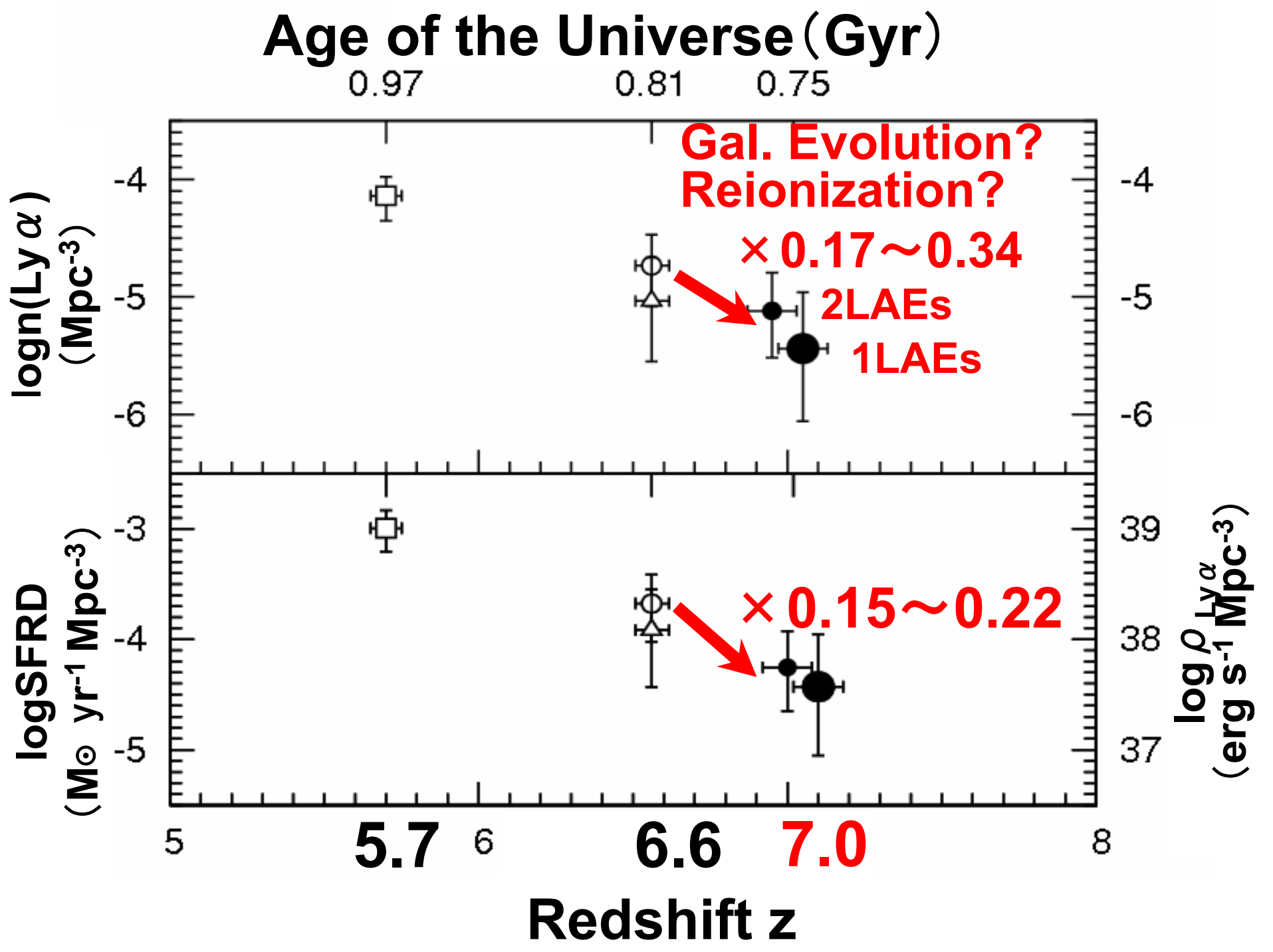
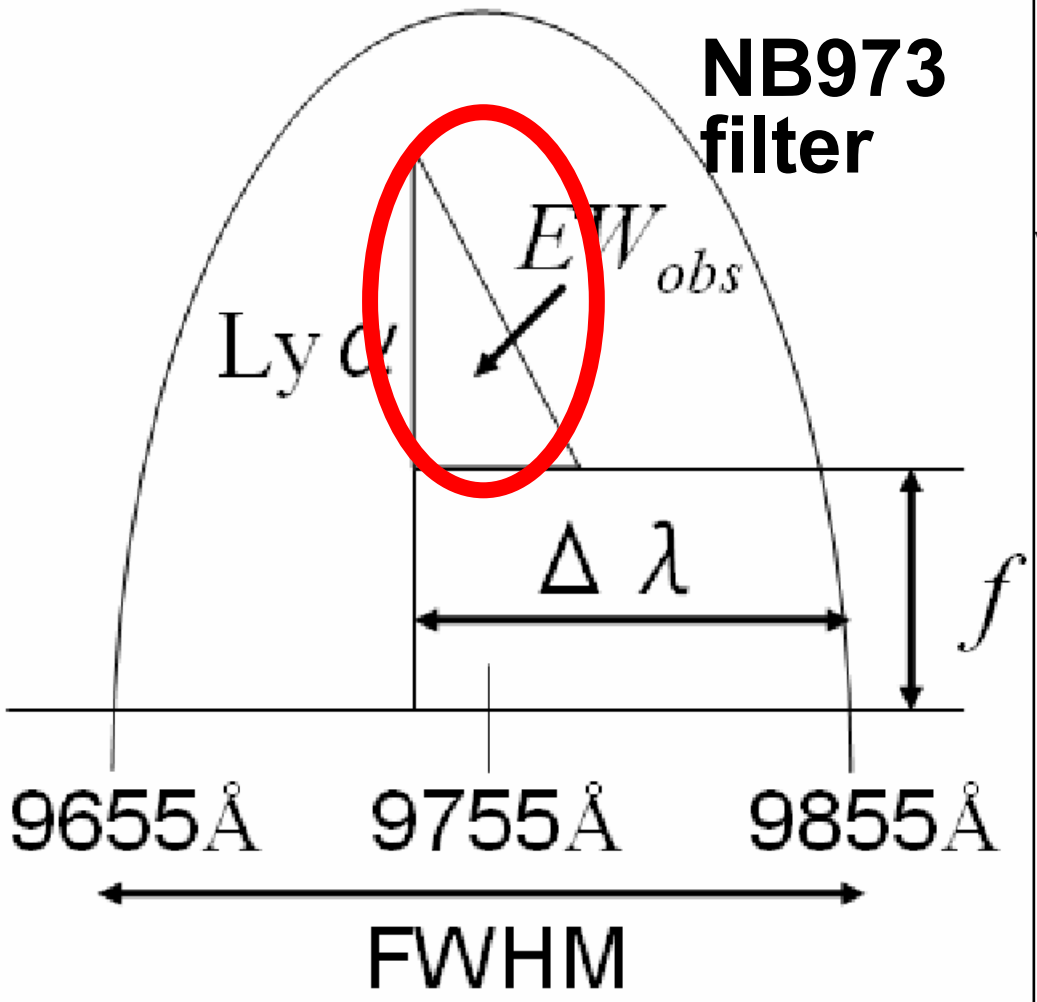
Ly α Line LF


z=5.7phot.
z=6.6phot.
z=6.6spec.
z=7.0spec.
Number density log[n(>L) Mpc^{-3}]
-2.5
-3.5
-4.5
-5.5
-6.5
42
42.5
43
43.5
Ly α line luminosity log[L(Ly α) erg/s]

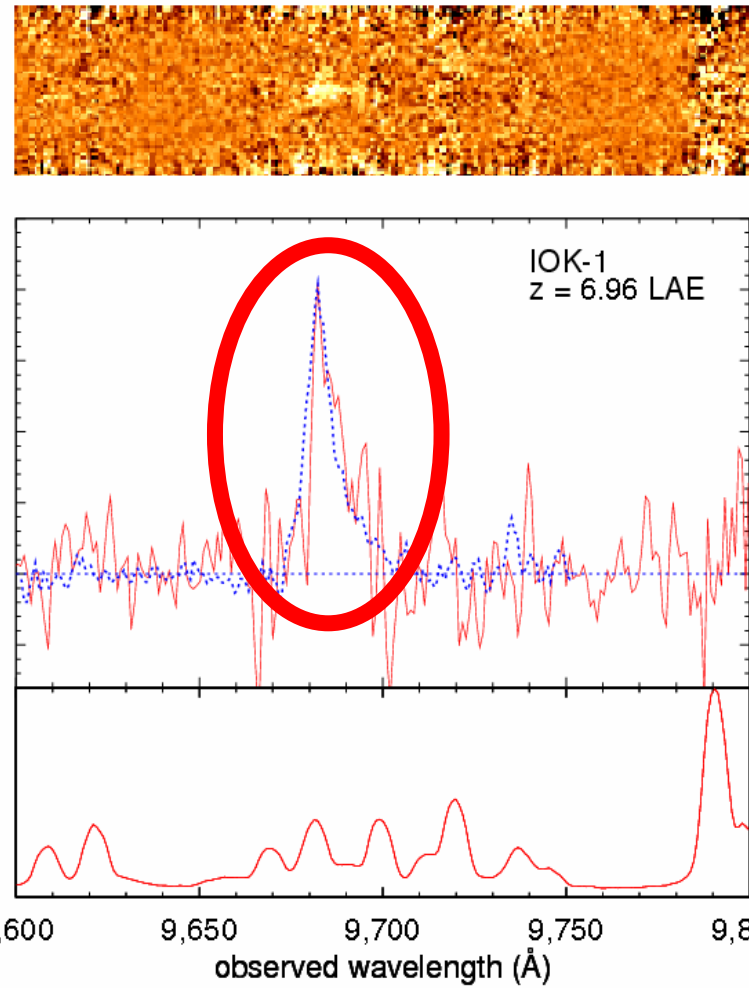

Age of the Universe（Gyr）
0.97
0.81
0.75
Gal. Evolution?
Reionization?
×0.17～0.34
2LAEs
1LAEs
×0.15～0.22
logn(Lyα)
（Mpc-3）
logSFRD
（M⊙ yr-1 Mpc-3）
log ρLyα
（erg s-1 Mpc-3）
-4
-5
-6
-3
-4
-5
39
38
37
5
6
8
5.7
6.6
7.0
Redshift z

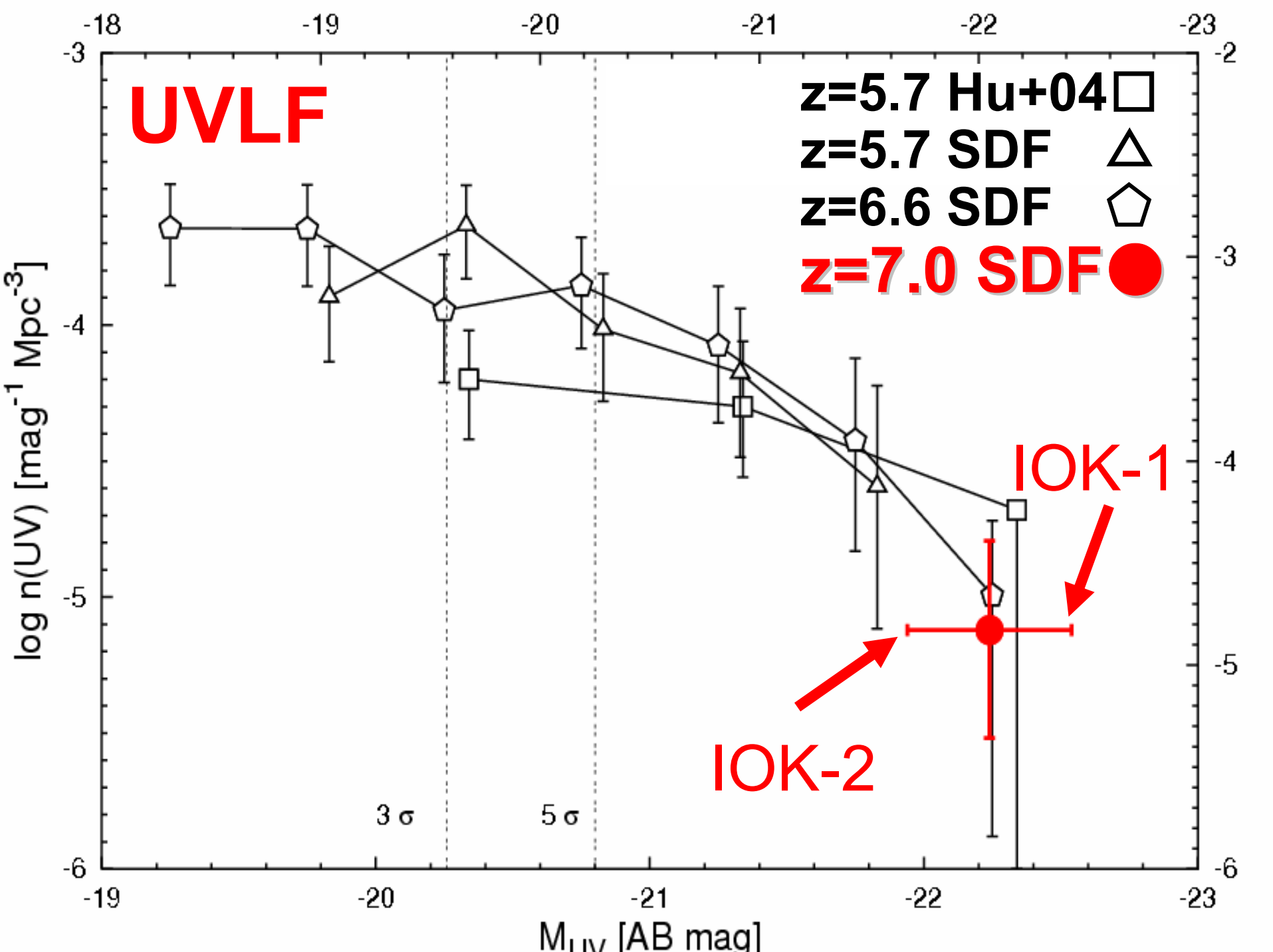
Calculating UV Luminosity

NB973 photometry



Spectrum




UVLF
z=5.7 Hu+04
z=5.7 SDF
z=6.6 SDF
z=7.0 SDF
IOK-1
IOK-2
3 σ
5 σ
log n(UV) [mag^{-1} Mpc^{-3}]
M_{UV} [AB mag]
-18
-19
-20
-21
-22
-23
-2
-3
-4
-5
-6

How to derive LFs	Luminosity Functions(LFs)	
	Lyα line LF	UVLF
LAE obs.	Reionization ~~LAE evolution~~	~~LAE evolution~~
model	LAE evolution	—
LBG obs.	—	LBG evolution

How to derive LFs	Luminosity Functions(LFs)	
	Lyα line LF	UVLF
LAE obs.	Reionization ~~LAE evolution~~	small statistics less reliable ~~LAE evolution~~
model	LAE evolution	—
LBG obs.	—	LBG evolution

Semi-analytic Galaxy Formation Model

Mitaka model

（Nagashima & Yoshii 2004）

↓ Hierarchical Clustering

OUTPUTs:

Physical properties of galaxies at each redshift

gas、magnitude、metallicity、star formation rate、etc.

↓

Intrinsic Ly α line luminosity

$$L(Ly\alpha)\ [\mathrm{erg\ s^{-1}}] = 1.366 \times 10^{42}\ \mathrm{SFR}\ [\mathrm{M_\odot yr^{-1}}]$$

× *Ly α photon escape fraction*

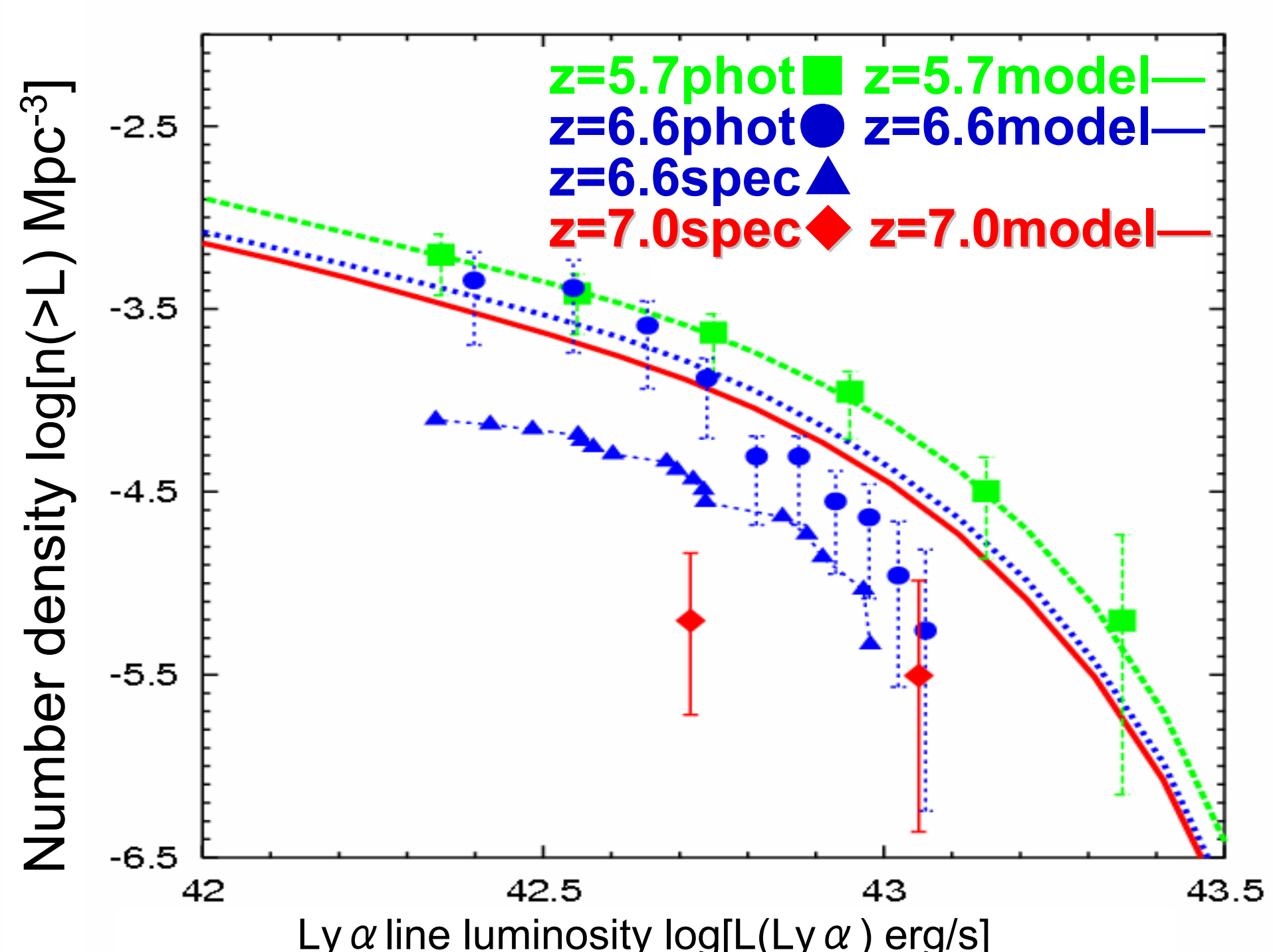
$$f_{esc} = f_{esc}^{0} \exp\left(-N_Z / N_Z^{0}\right)$$

N_z^0=metal column density

f_{esc}^0=0.3、N_z^0=4 ×10^{21}cm^{-2}

→ Observed Ly α line luminosity L(Ly α) not attenuated by IGM HI

Kobayashi et al. (2007, in prep.)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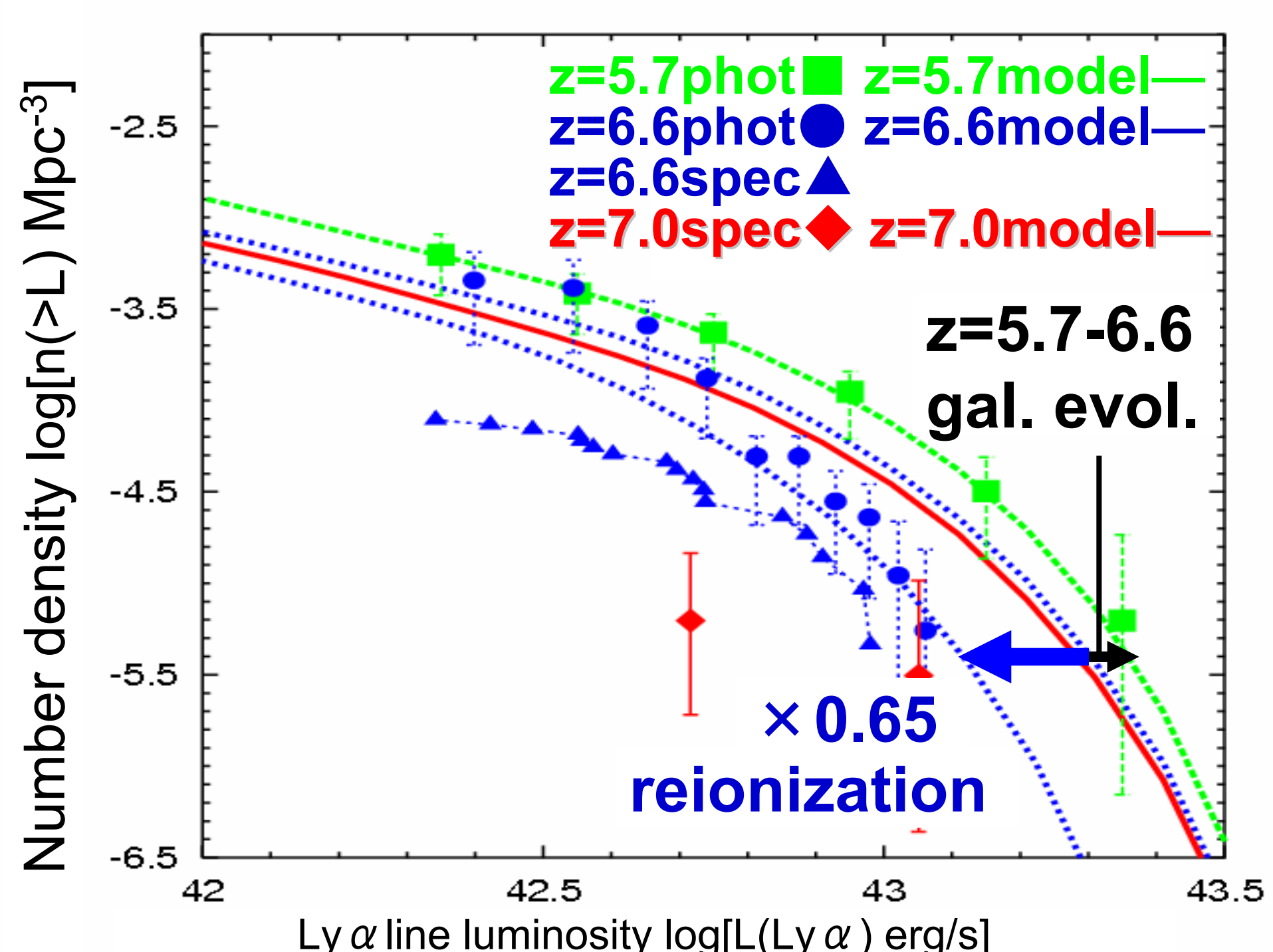
z=5.7phot
z=5.7model
z=6.6phot
z=6.6model
z=6.6spec
z=7.0spec
z=7.0model
z=5.7-6.6
gal. evol.
×0.65
reionization
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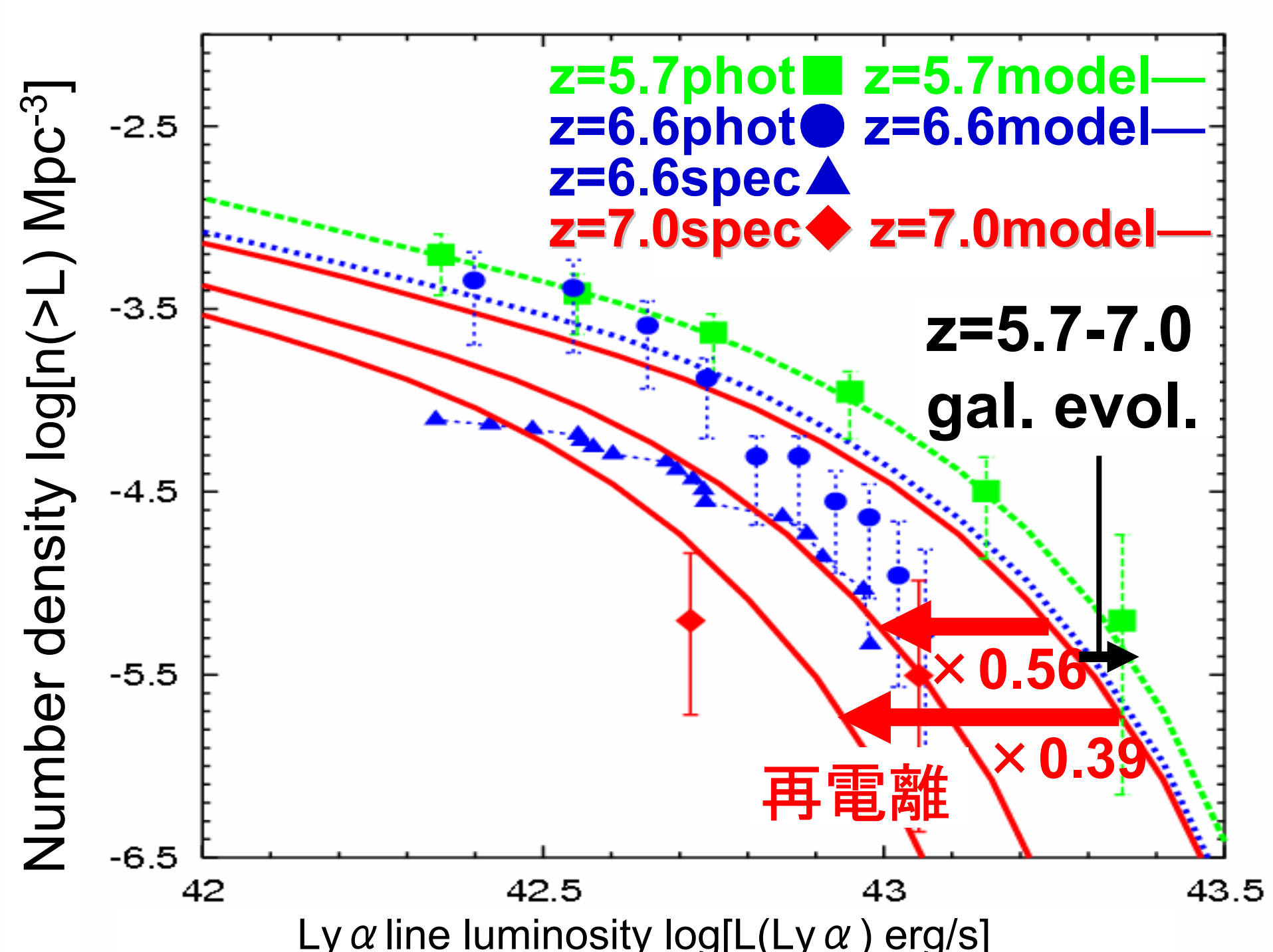
Ly α line luminosity log[L(Ly α) erg/s]


z=5.7phot■ z=5.7model—
z=6.6phot● z=6.6model—
z=6.6spec▲
z=7.0spec◆ z=7.0model—
z=5.7-7.0
gal. evol.
×0.56
×0.39
再電離
Number density log[n(>L) Mpc^{-3}]
-2.5
-3.5
-4.5
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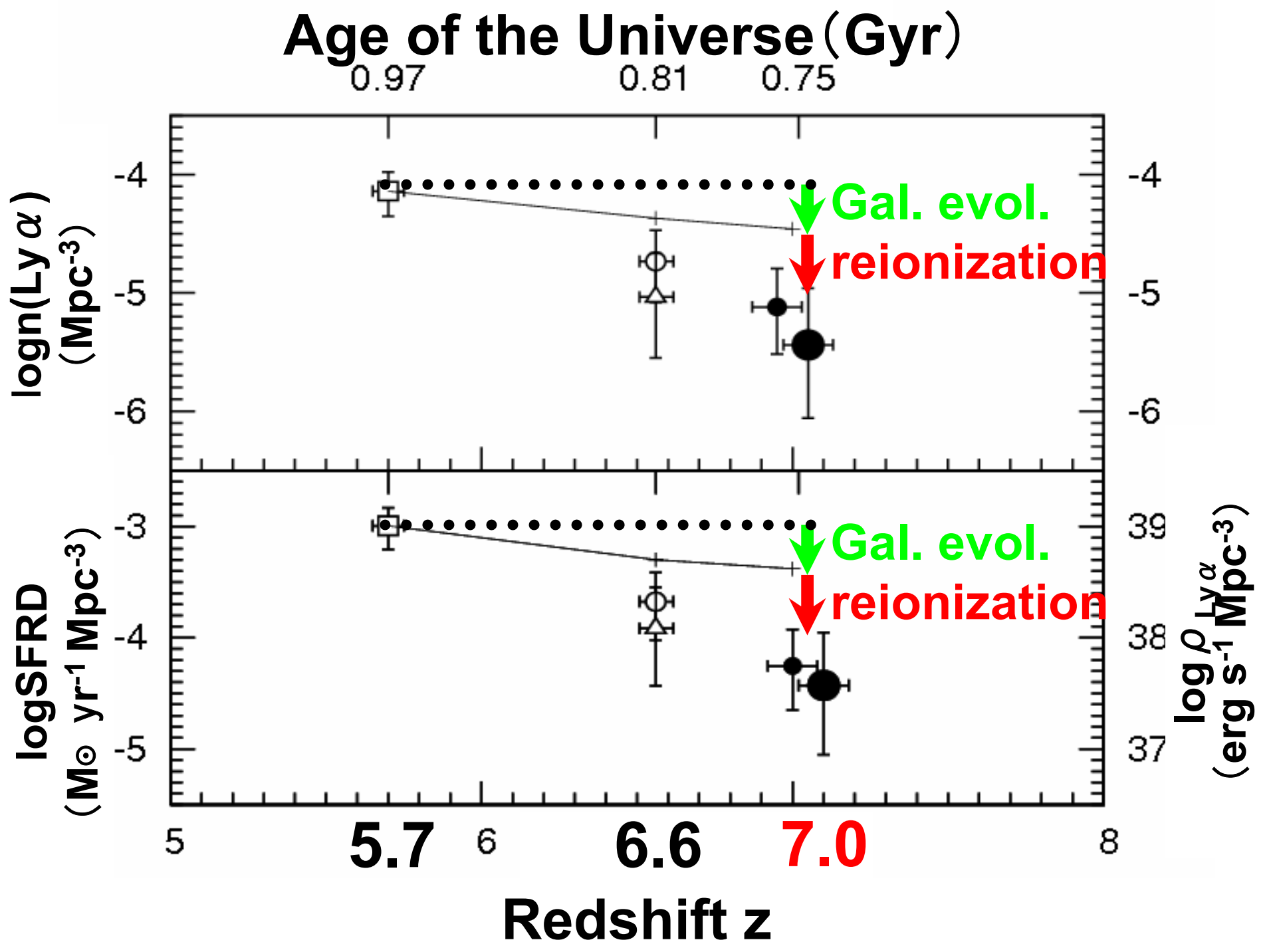
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logn(Ly α) (Mpc-3)
-4
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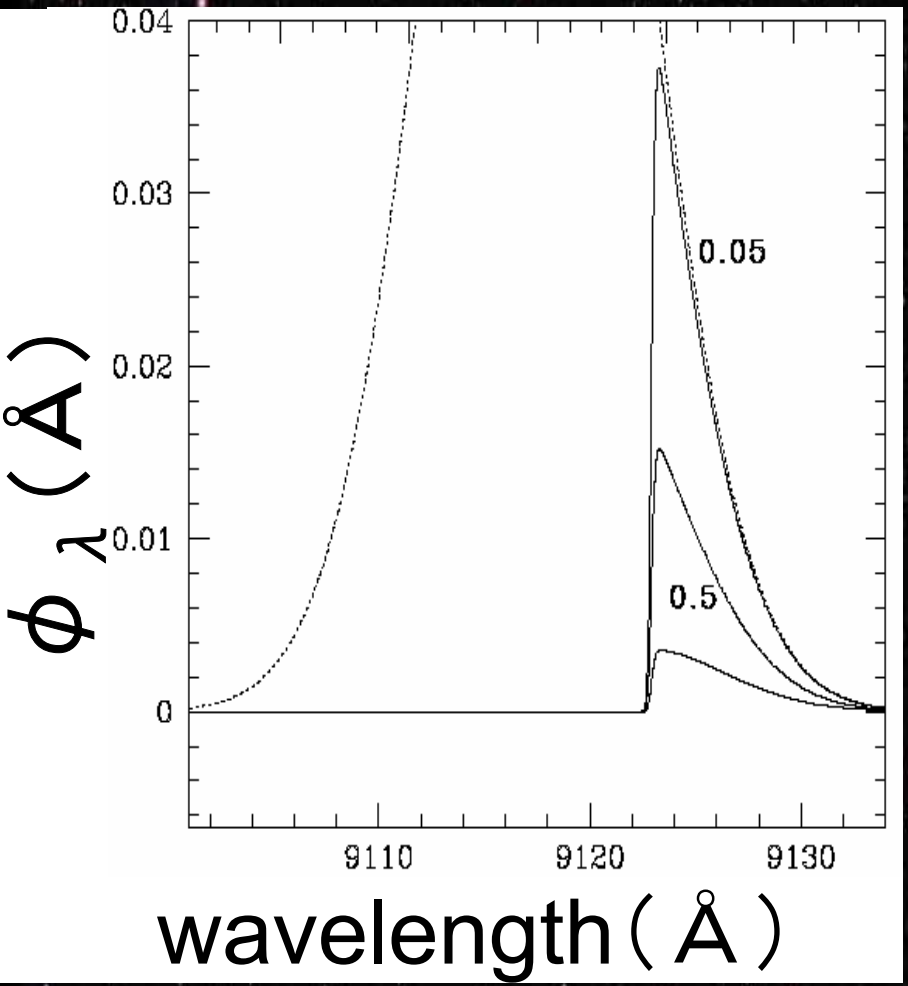
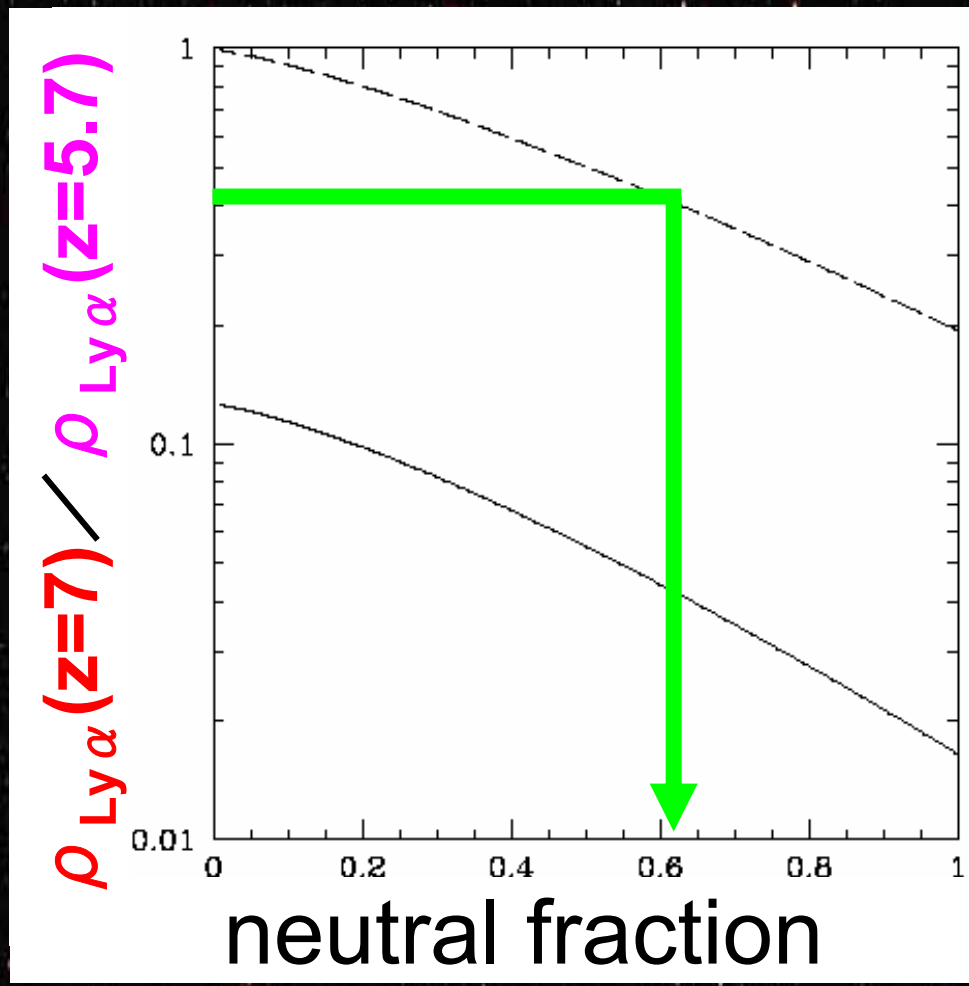
-6
Gal. evol.
reionization
logSFRD (M⊙ yr-1 Mpc-3)
-3
-4
-5
log ρ Ly α (erg s-1 Mpc-3)
39
38
37
5
5.7
6
6.6
7.0
8
Redshift z

attenuated L(Lyα) ÷ intrinsic L(Lyα)

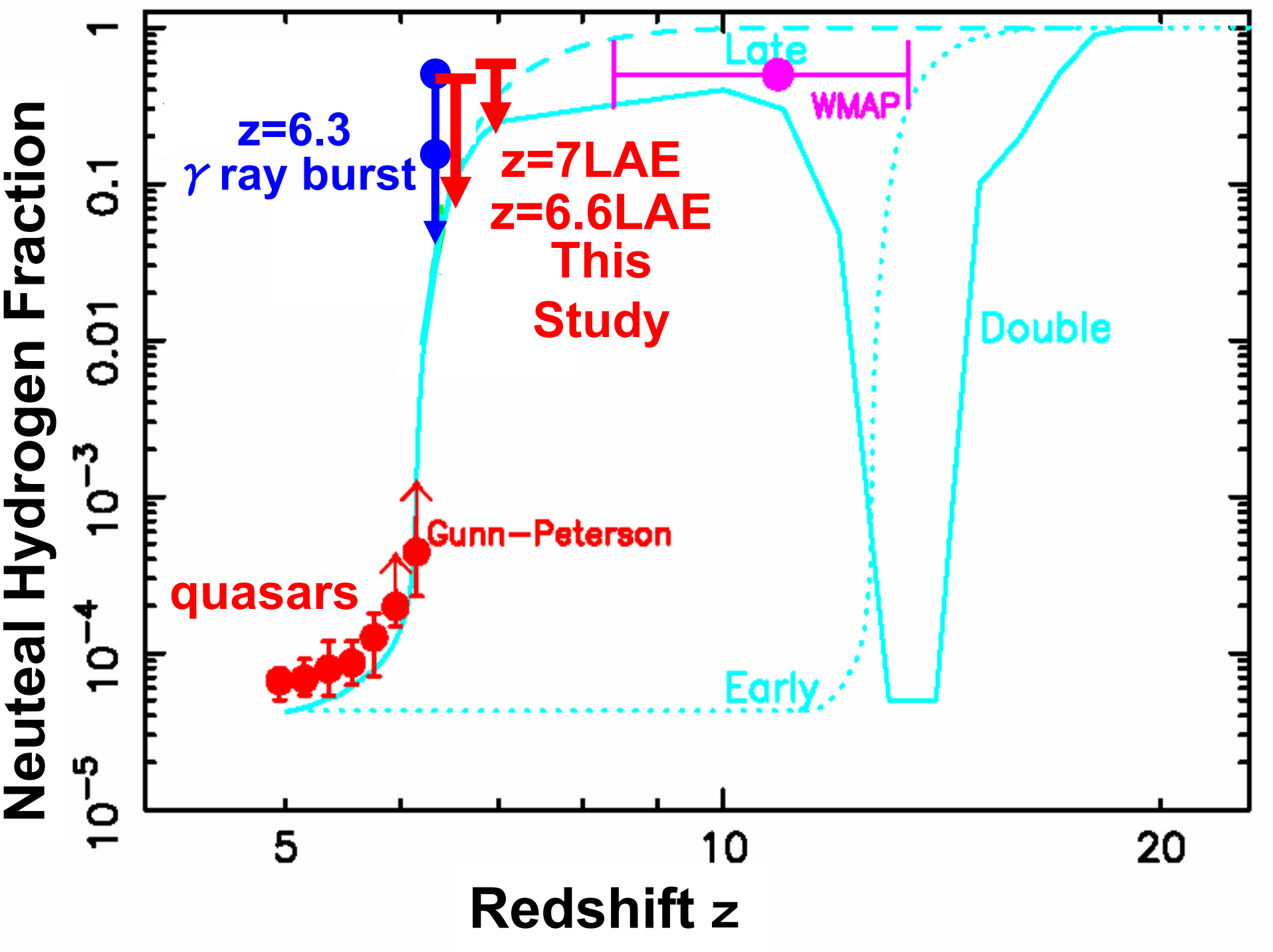
→ neutral fraction @z=7.0: 42-62%

@z=6.6: ~33%





Santos（2004）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Late
WMAP
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quasars


The End