

*Deep Survey of $z=7$ Ly α Emitters in the
Subaru/XMM-Newton Deep Field:
Implications for Reionization*



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Joint Subaru/Gemini Science Conference, Kyoto, 2009

Outline

1. Background

- Study reionization epoch by observing Ly α emitter at $z > 6$
- But we had weaknesses in our previous $z = 7$ survey

2. New Deeper $z = 7$ Ly α Emitter Survey

- With upgraded Subaru/Suprime-Cam

3. Result:

- Deeper Ly α LF \rightarrow neutral fraction of the Universe at $z = 7$

4. Conclusion

5. My Experience at Gemini

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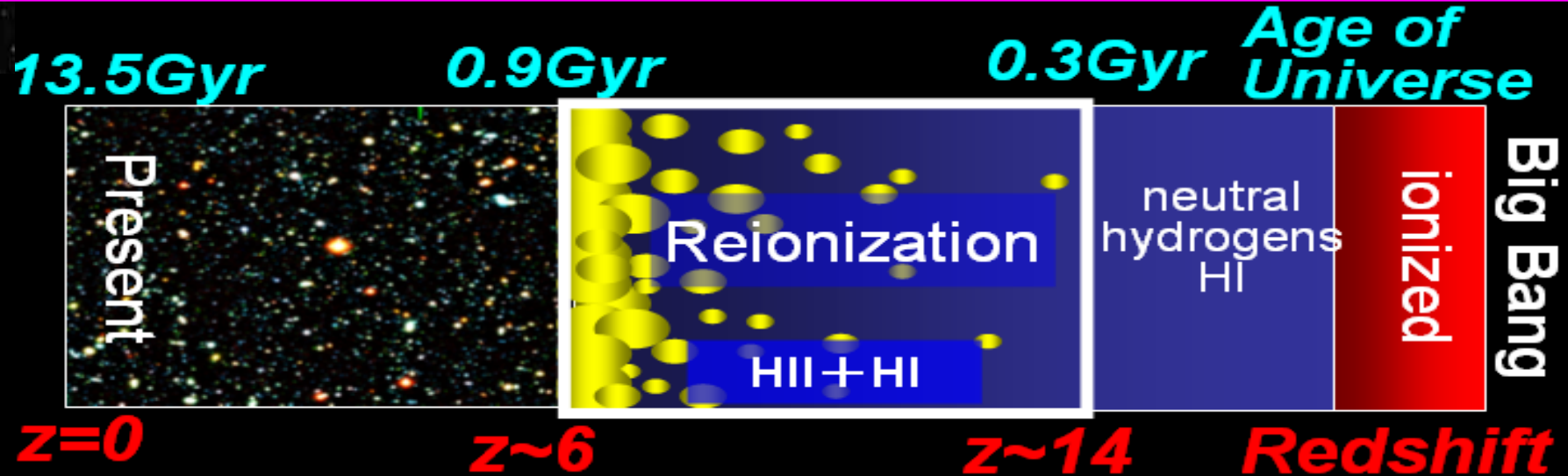
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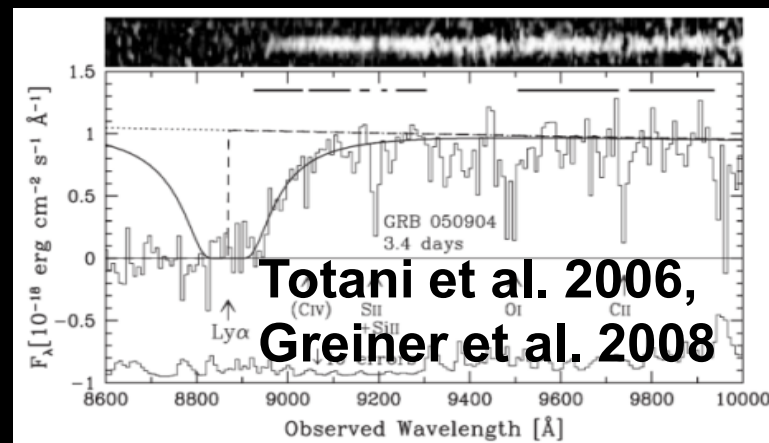
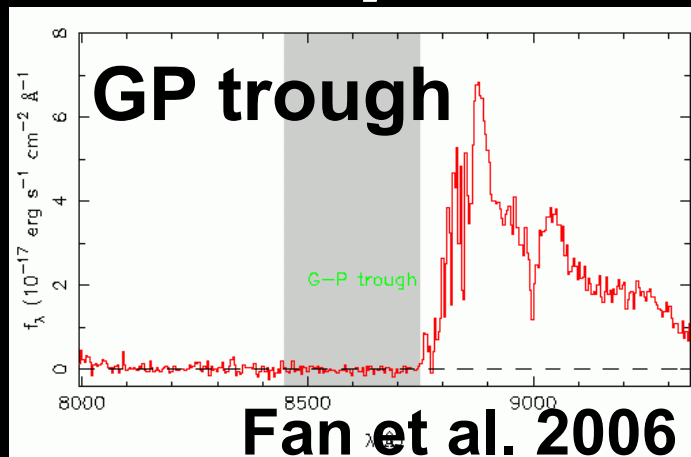
Reionization Probed by Independent Observations



Redshift 6.2 6.3 6.7

Neutral H fraction 1-4% <17% >35%

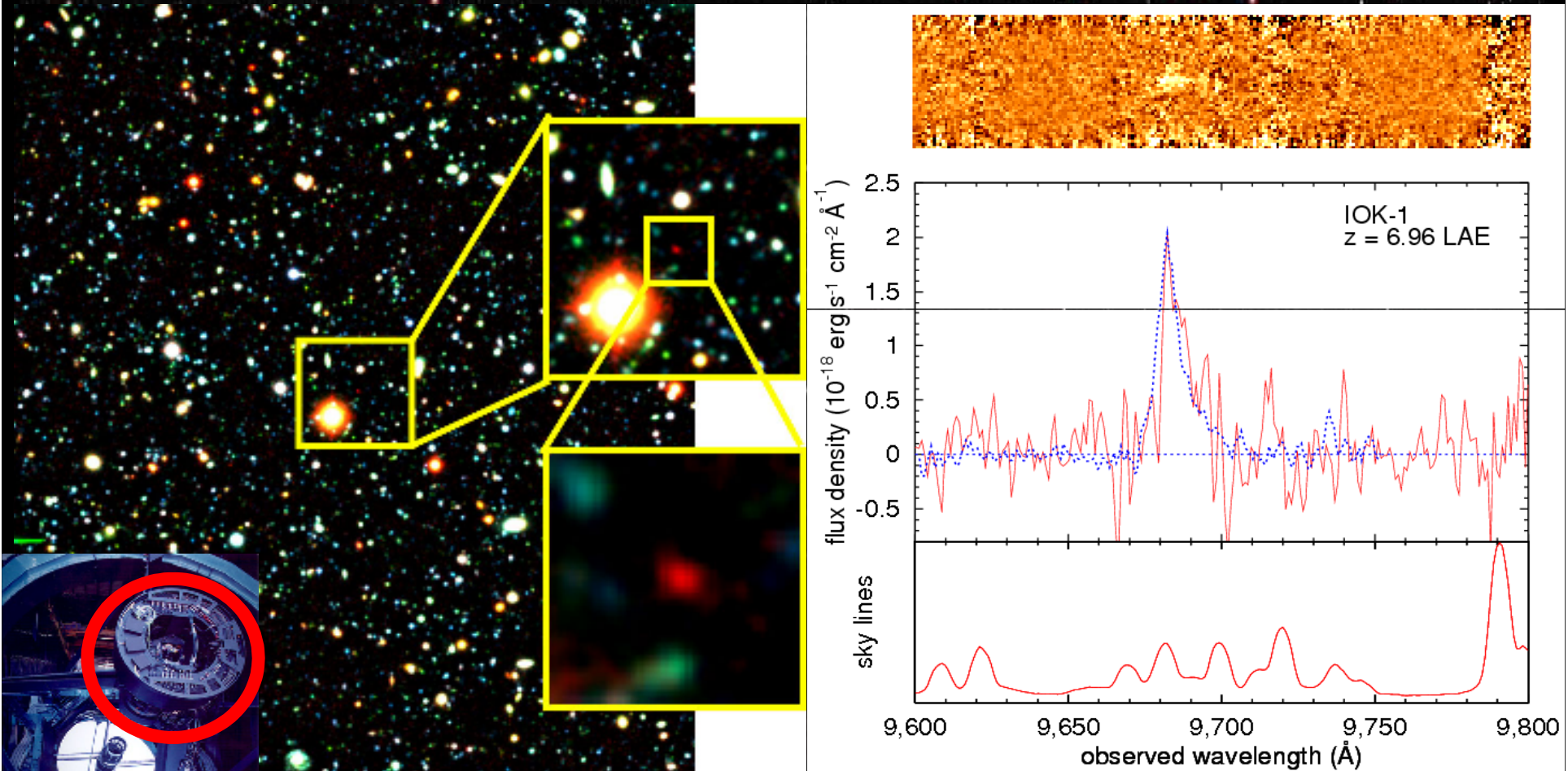
quasars *GRB*



Discovery of a $z=6.96$ Ly α emitter IOK-1

The most distant galaxy ever observed

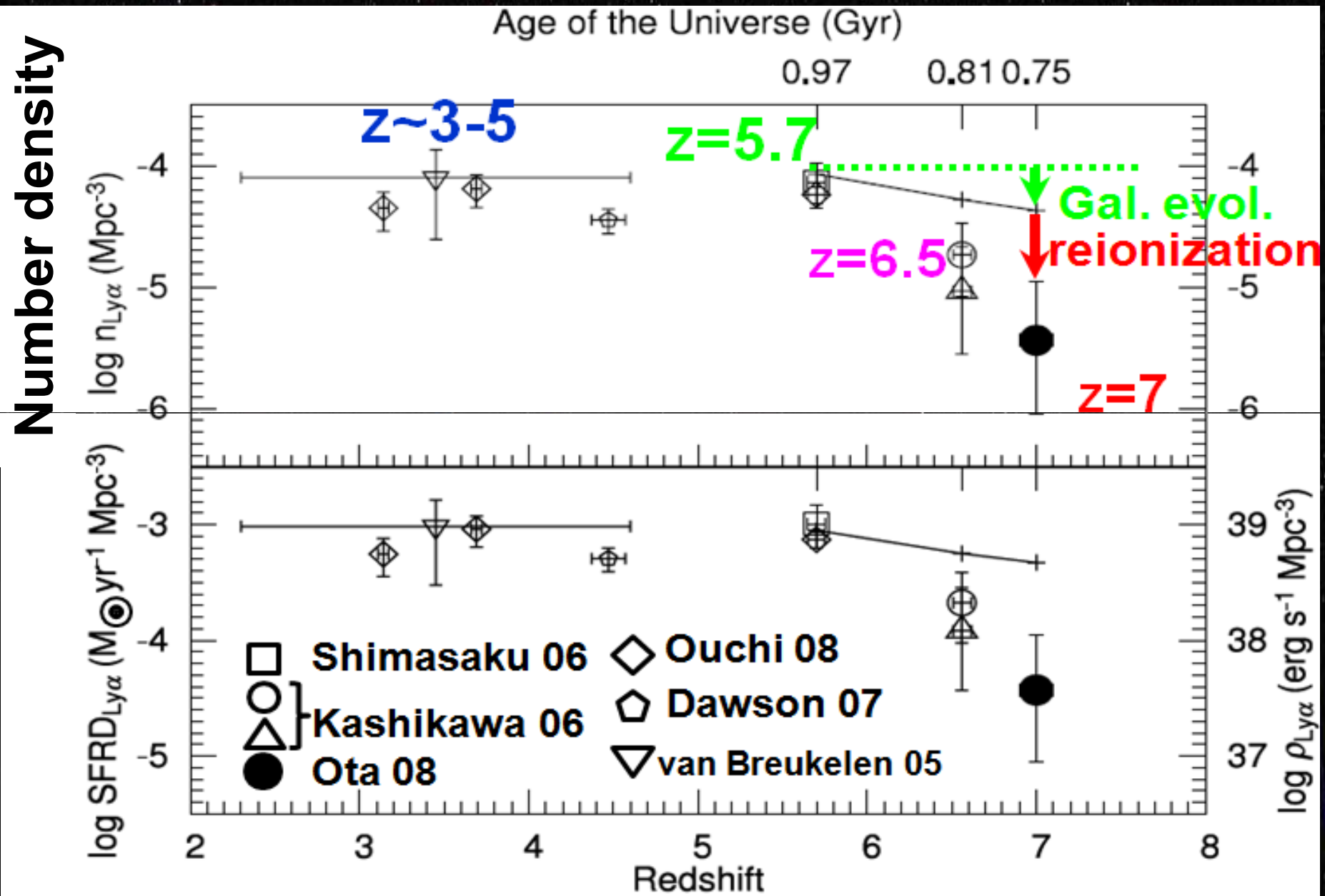
Evidence of galaxy formation only 750 Myr after Big Bang



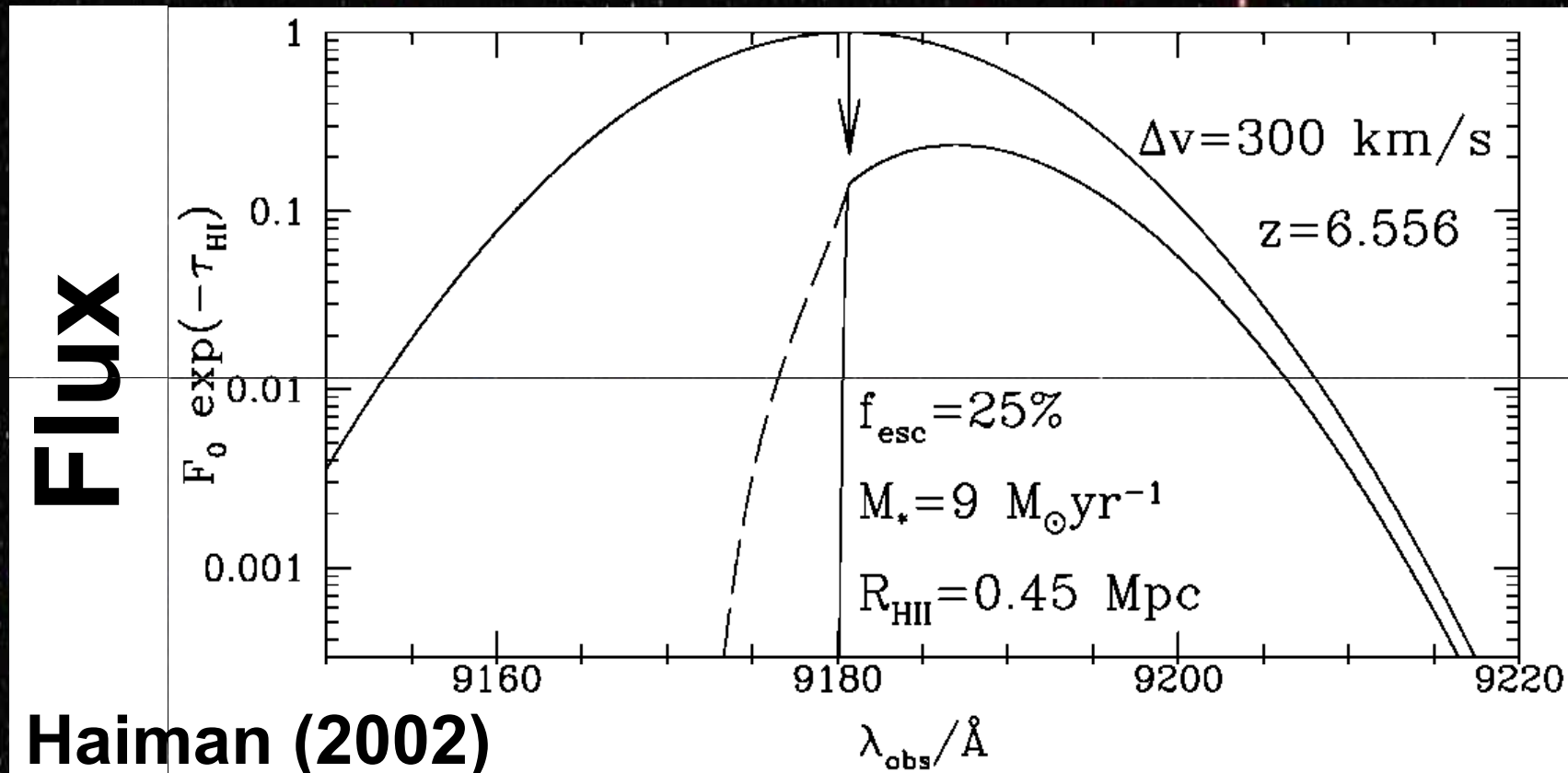
Subaru Deep Field Project

Suprime-Cam: Surveys of $z=5.7, 6.6, 7$ Ly α emitters

Galaxy number density decreases at $z > 6$

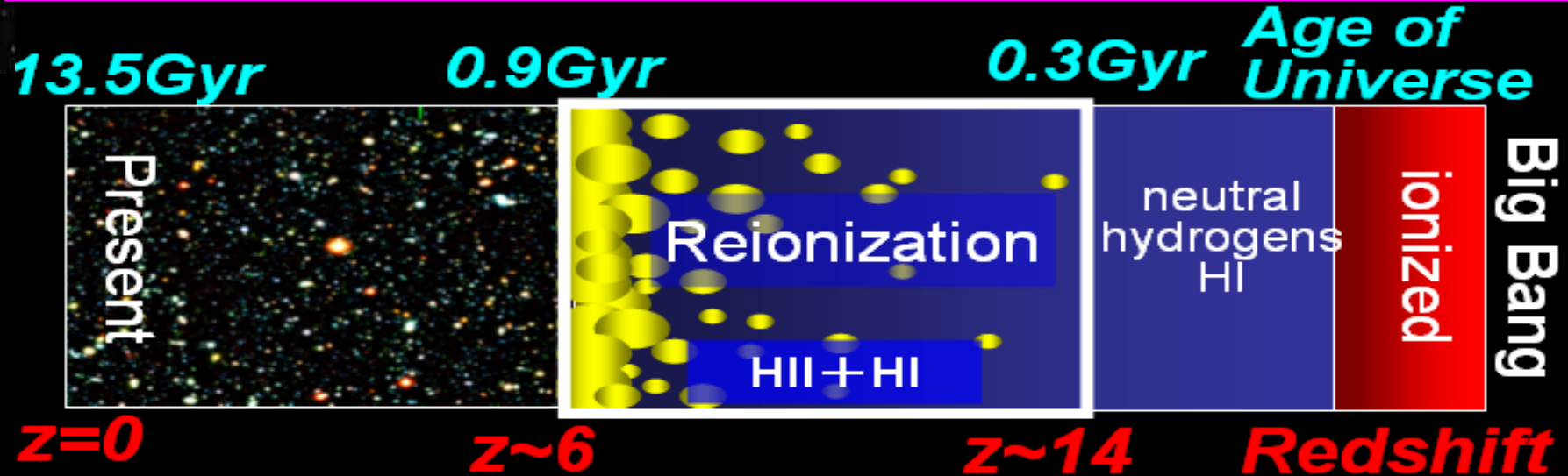


Ly α emission line is attenuated if neutral hydrogen exists



If neutral hydrogen fraction is large at $z > 6$,
we detect **smaller number** of Ly α emitters

Reionization Probed by Ly α emitters



Redshift

6.2 6.3 6.7

Neutral H fraction

1-4% <17% >35%

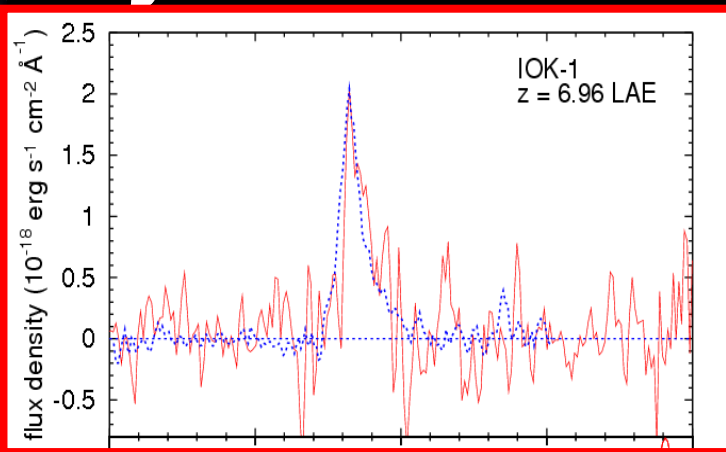
Ly α emitters

$z=6.6$

$z=7.0$

12-54%

32-64%



↑
Attenuation of Ly α flux

Decrease in number density

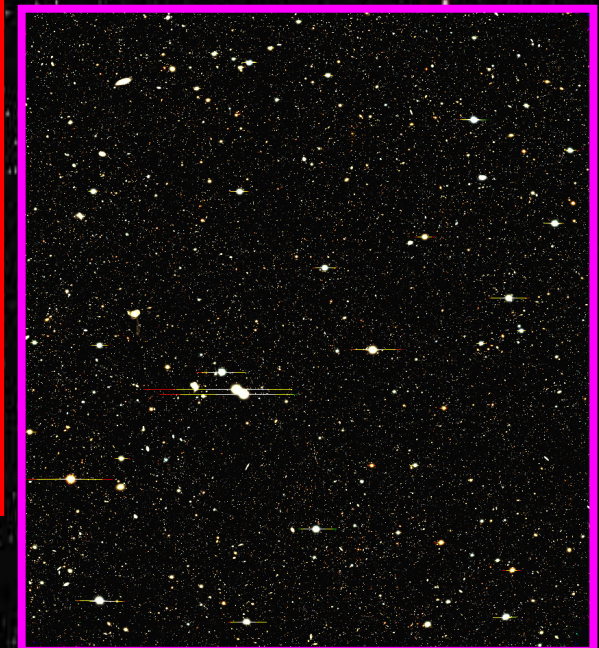
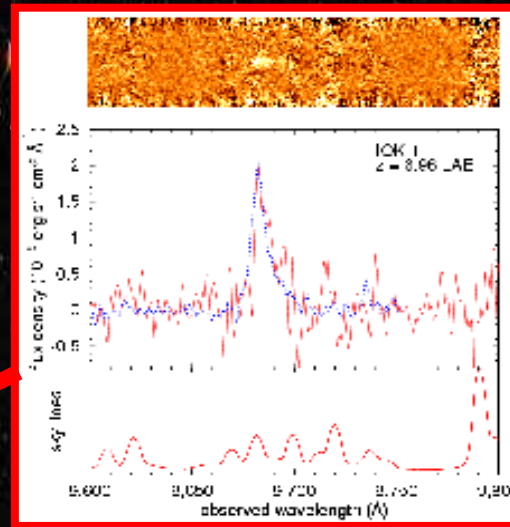
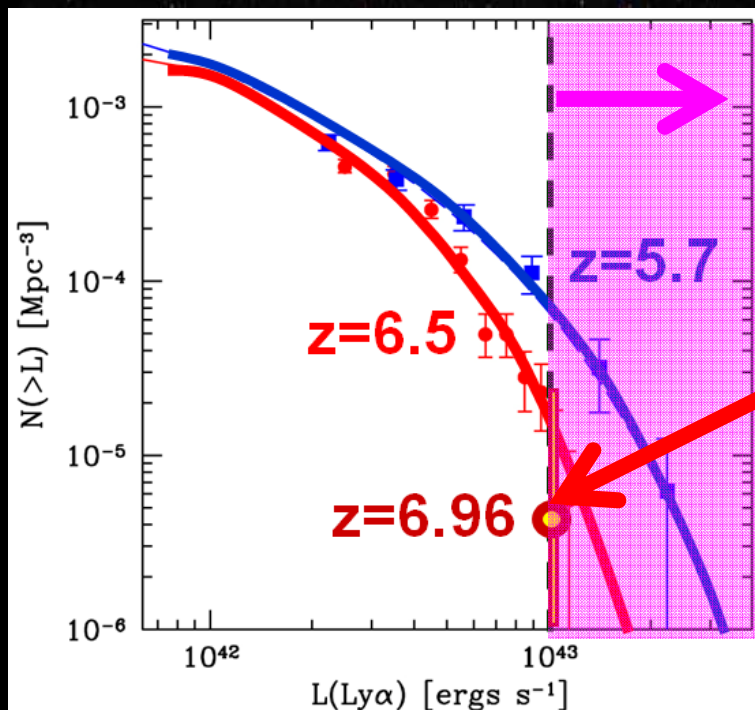
3 weaknesses in the previous $z=7$ survey

- (1) Depth was shallow.
- (2) Sample was small.
- (3) Only one sky field was surveyed.

$L(\text{Ly}\alpha) > 10^{43}$ erg/s

Only 1 Ly α emitter

Subaru Deep Field
876 arcmin²



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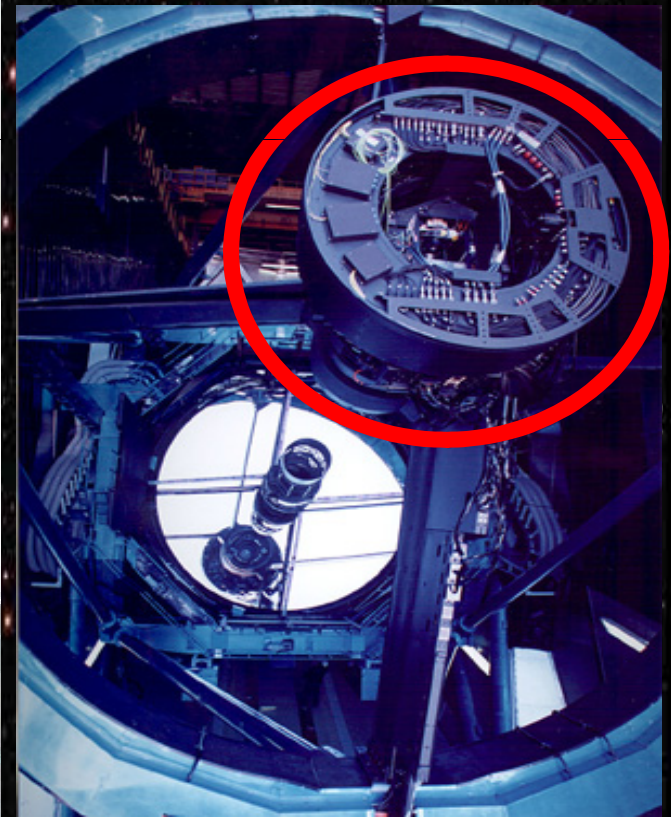
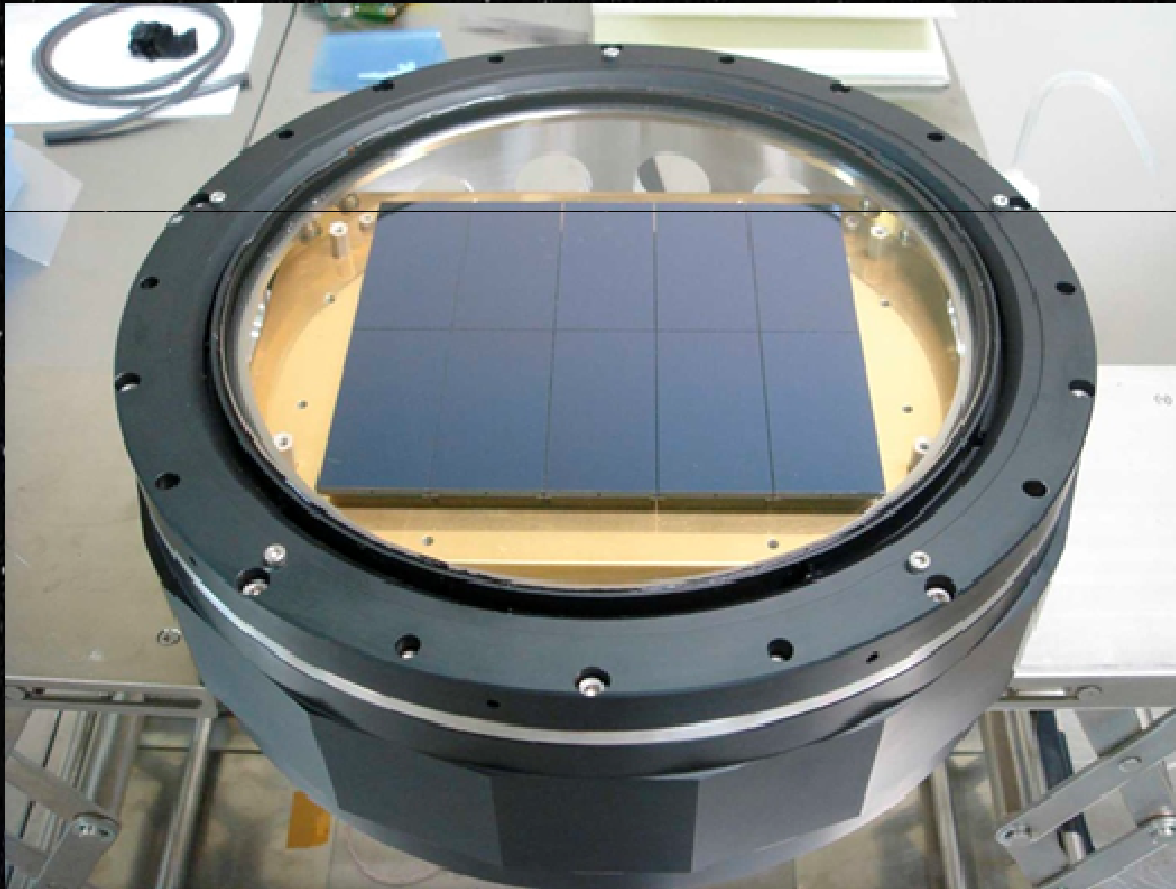
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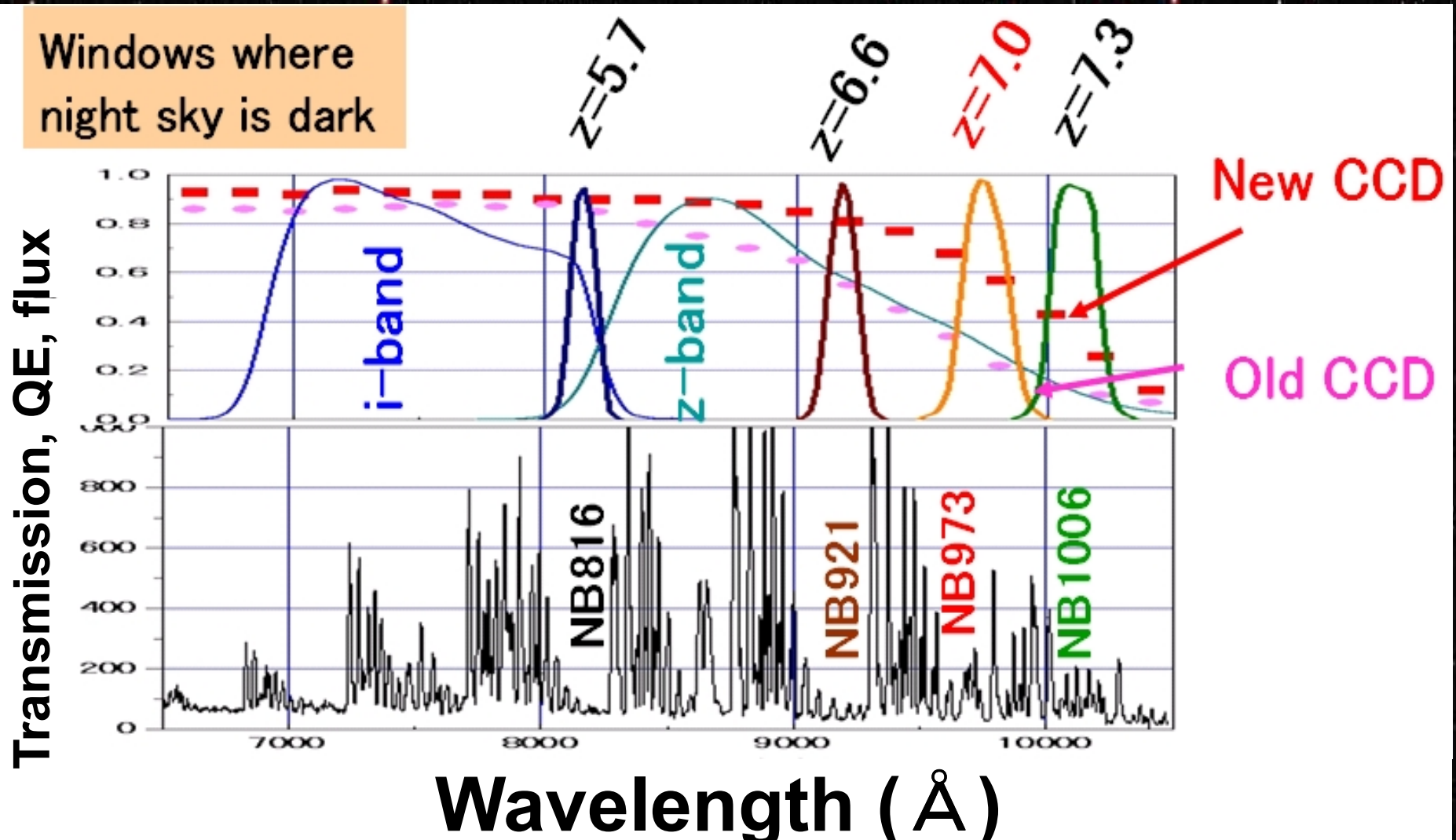
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New **Red-sensitive** CCD
installed on Suprime-Cam
in July 2008



2 x more sensitive to $z=7$ Ly α emission



Target Sky Region

Subaru/XMM-Newton Deep Survey Field (SXDS)

13 hours imaging
NB973 = 25.4 (5σ)
(previously, 24.9)

XMM-Newton GALEX Spitzer BLAST

X-rays UV Visible IR Sub mm Radio

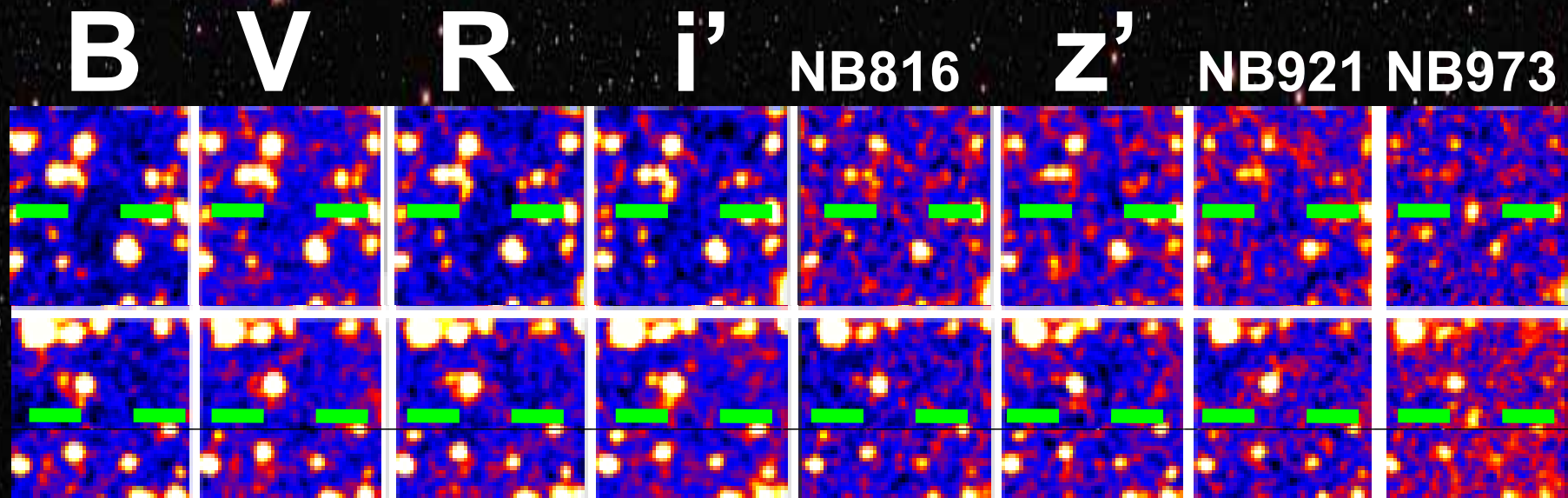
Spitzer

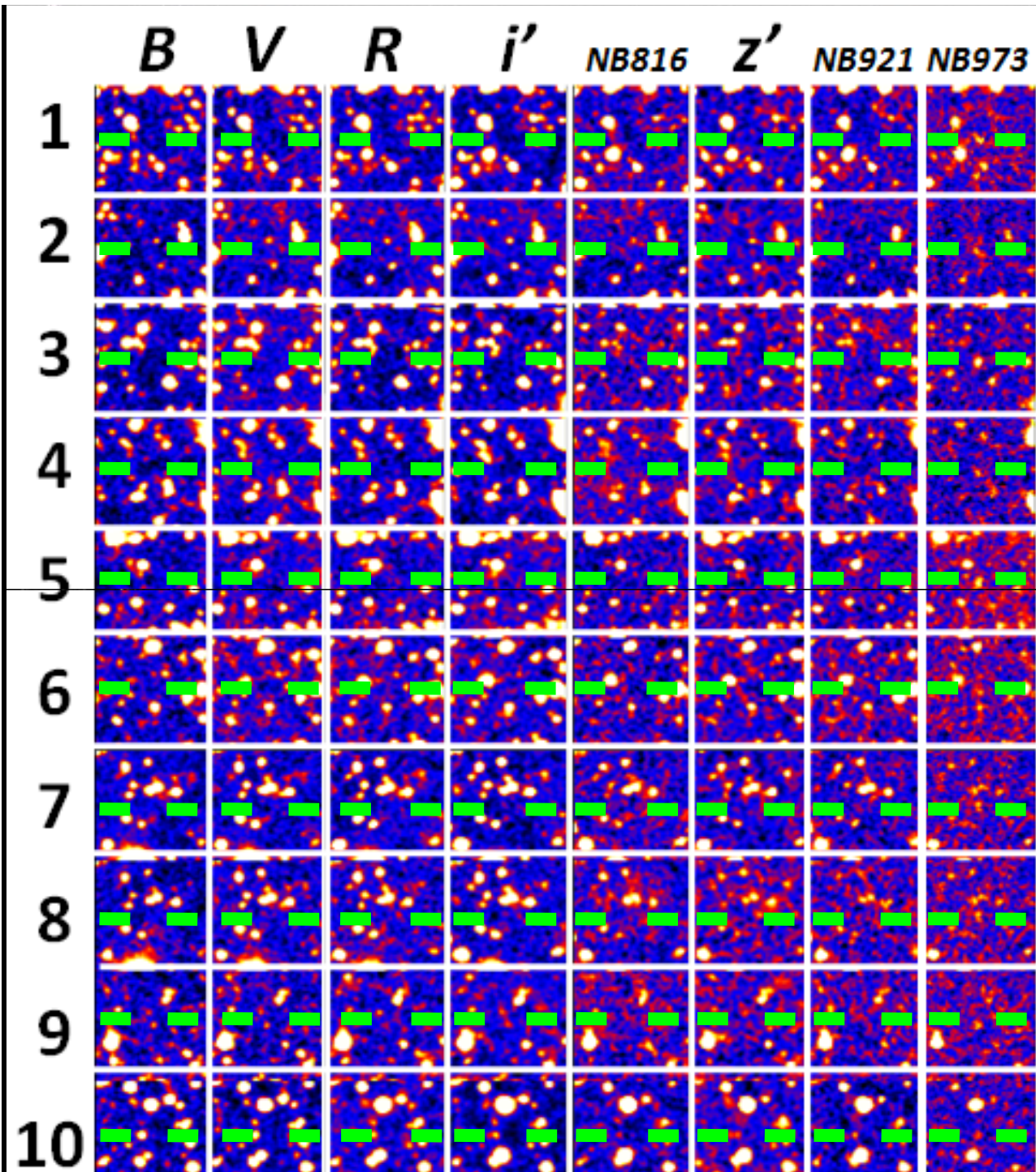
ALMA VLA

UKIDSS-UDS

Oct, Nov 2008
Subaru
This Work

New $z=7$ Ly α emitter candidates





Color Selection



Visual Inspection



10 $z=7$ Ly α emitter candidates

(tentative)



Remove spurious & transient objects using images taken in different months



#Candidates ≤ 10

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Ly α Luminosity Function

Assumption (1): $F(\text{Ly}\alpha) = F(\text{NB filter})$

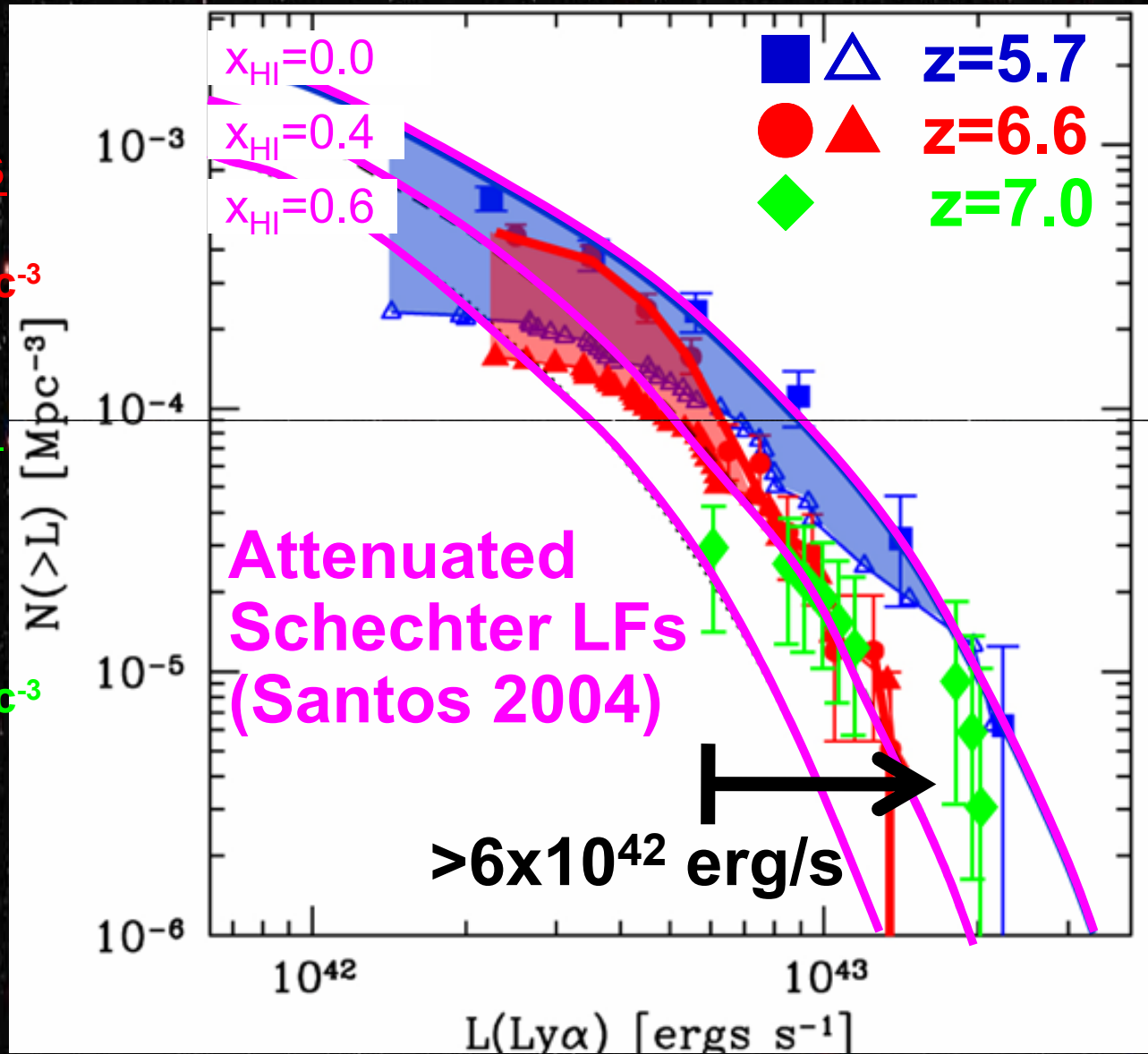
Observed Densities

$n_{\text{Ly}\alpha}: 3.9 \times 10^{-5} \text{ Mpc}^{-3}$
 $\rho_{\text{Ly}\alpha}: 4.7 \times 10^{38} \text{ erg/s/Mpc}^{-3}$

Predicted Densities when $x_{\text{HI}}=0$

(Kobayashi et al, 2007
 LAE evolution Model)
 $n_{\text{Ly}\alpha}: 1.1 \times 10^{-4} \text{ Mpc}^{-3}$
 $\rho_{\text{Ly}\alpha}: 9.5 \times 10^{38} \text{ erg/s/Mpc}^{-3}$

Neutral Fraction
 $z=7.0 \quad \sim 49\%$

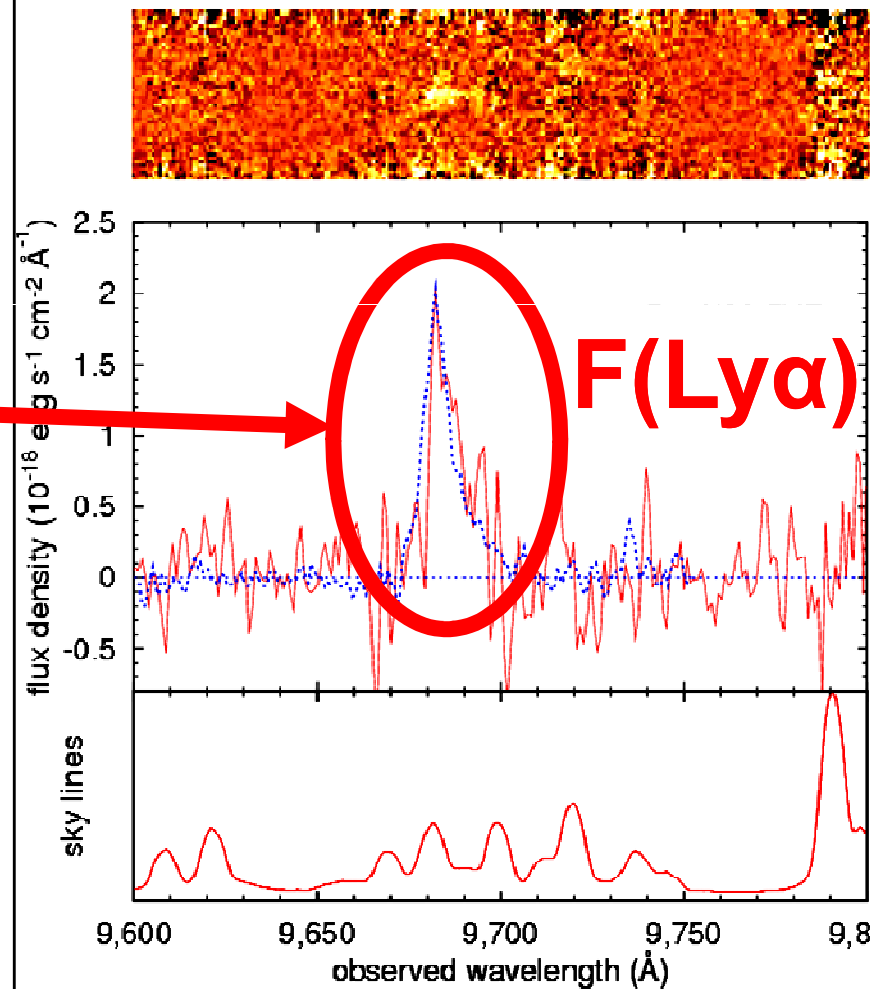
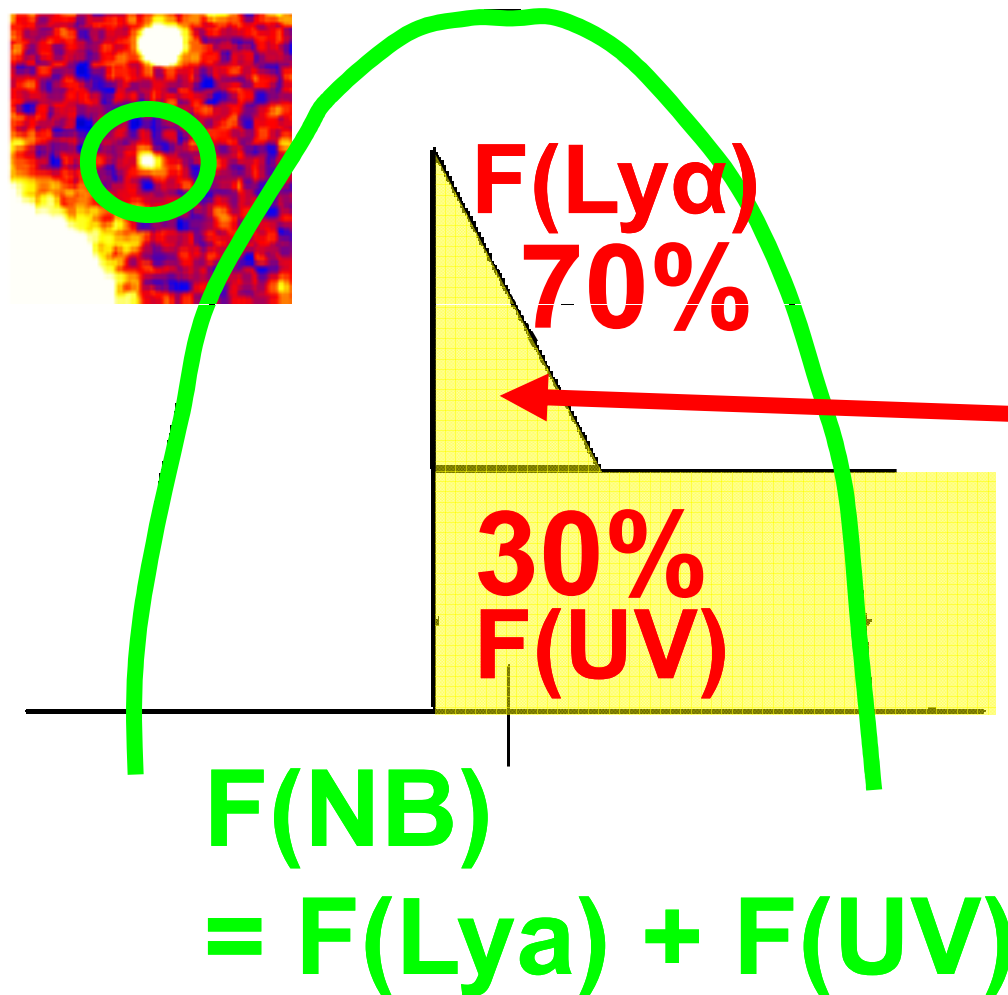


Fraction of Ly α flux in NB filter flux

$$F(\text{Ly}\alpha) \sim 0.7 \times F(\text{NB})$$

NB973 Filter Total Flux

Spectrum



Ly α Luminosity Function:

Assumption (2): $F(\text{Ly}\alpha) = 0.7 \times F(\text{NB973})$

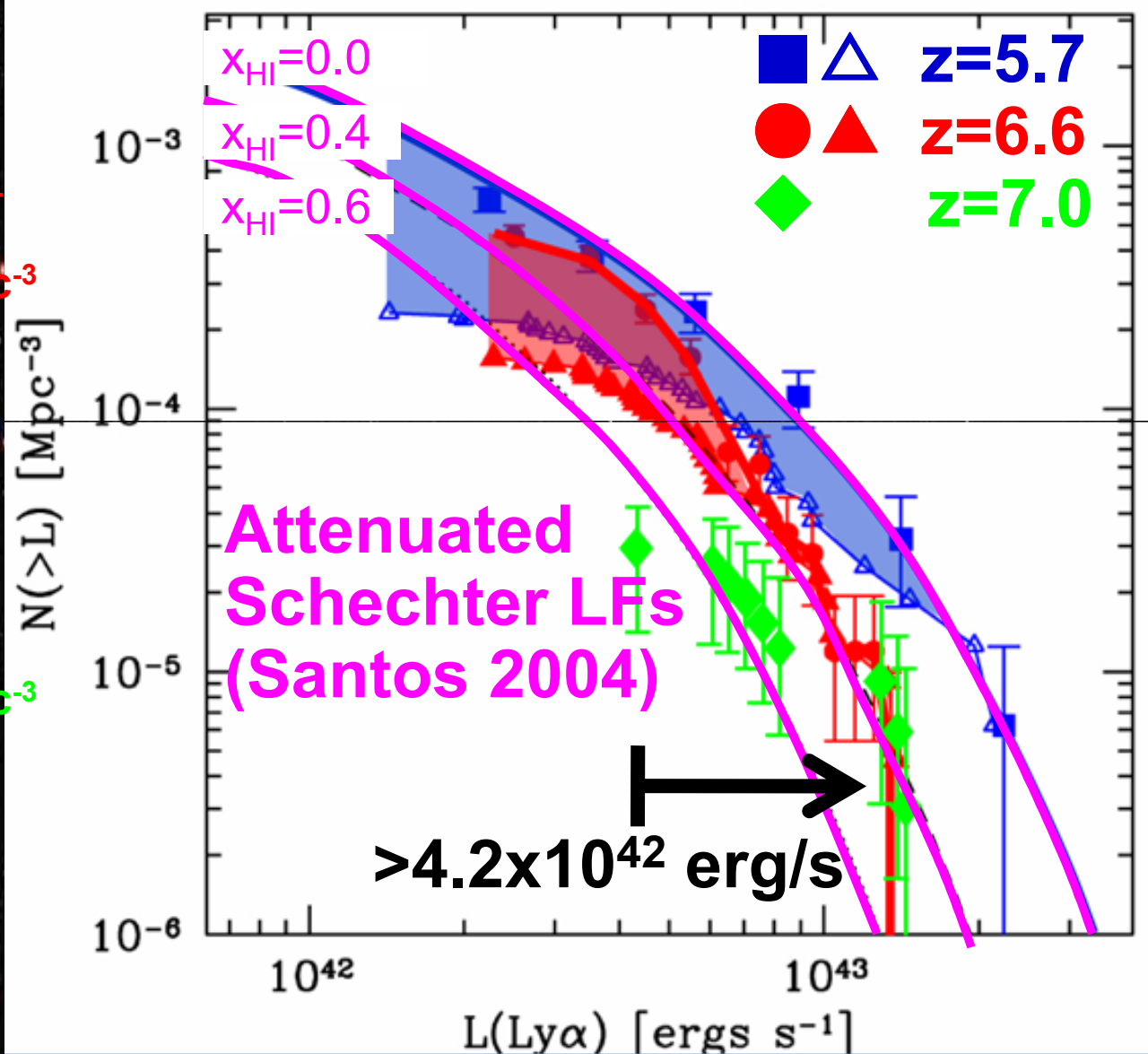
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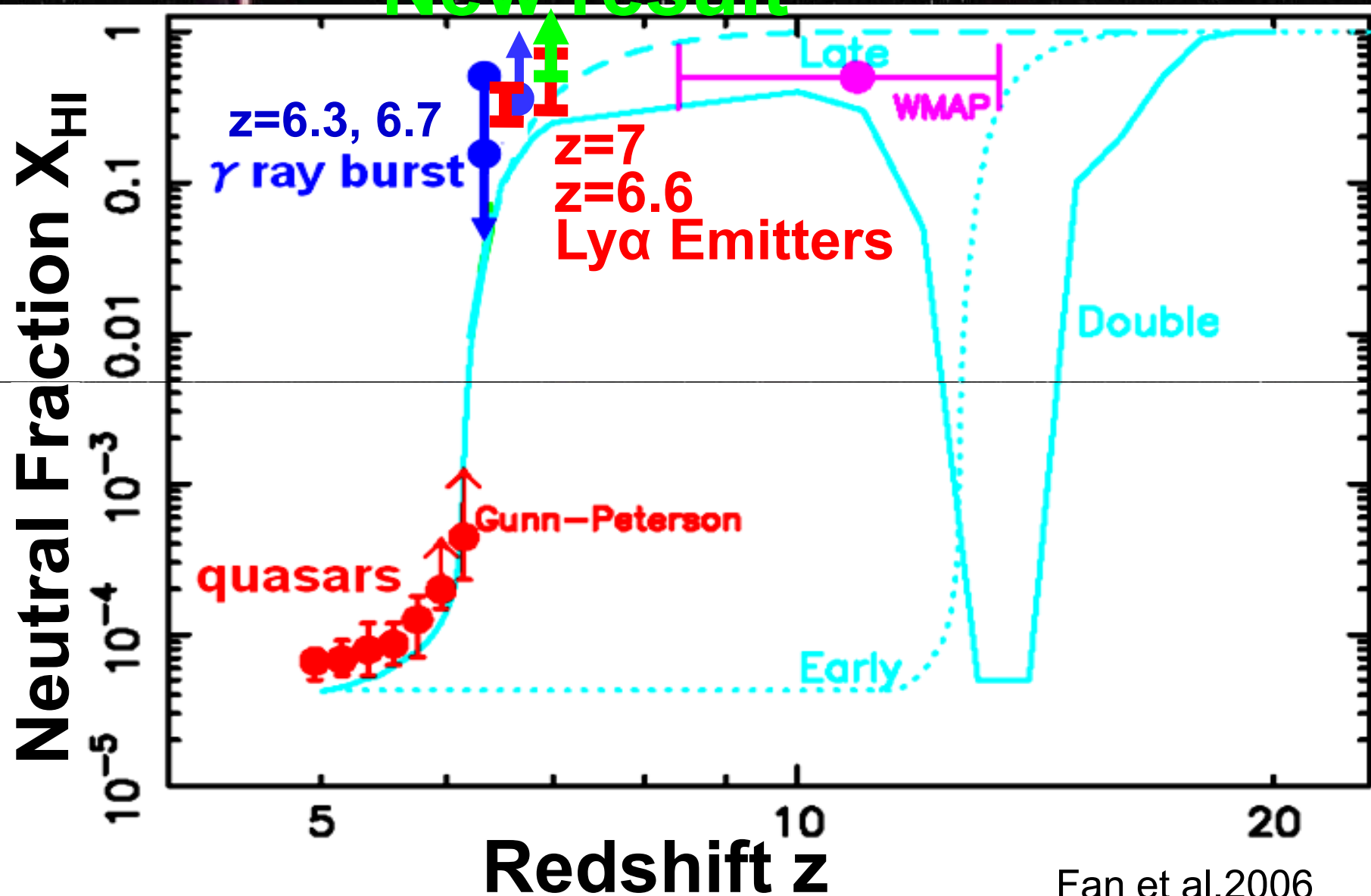
(Kobayashi et al, 2007
 LAE evolution Model)
 $n_{\text{Ly}\alpha}: 1.8 \times 10^{-4} \text{ Mpc}^{-3}$
 $\rho_{\text{Ly}\alpha}: 1.2 \times 10^{39} \text{ erg/s/Mpc}^{-3}$

Neutral Fraction
 $z=7.0 \quad \sim 66\%$



New result agrees with previous results

New result



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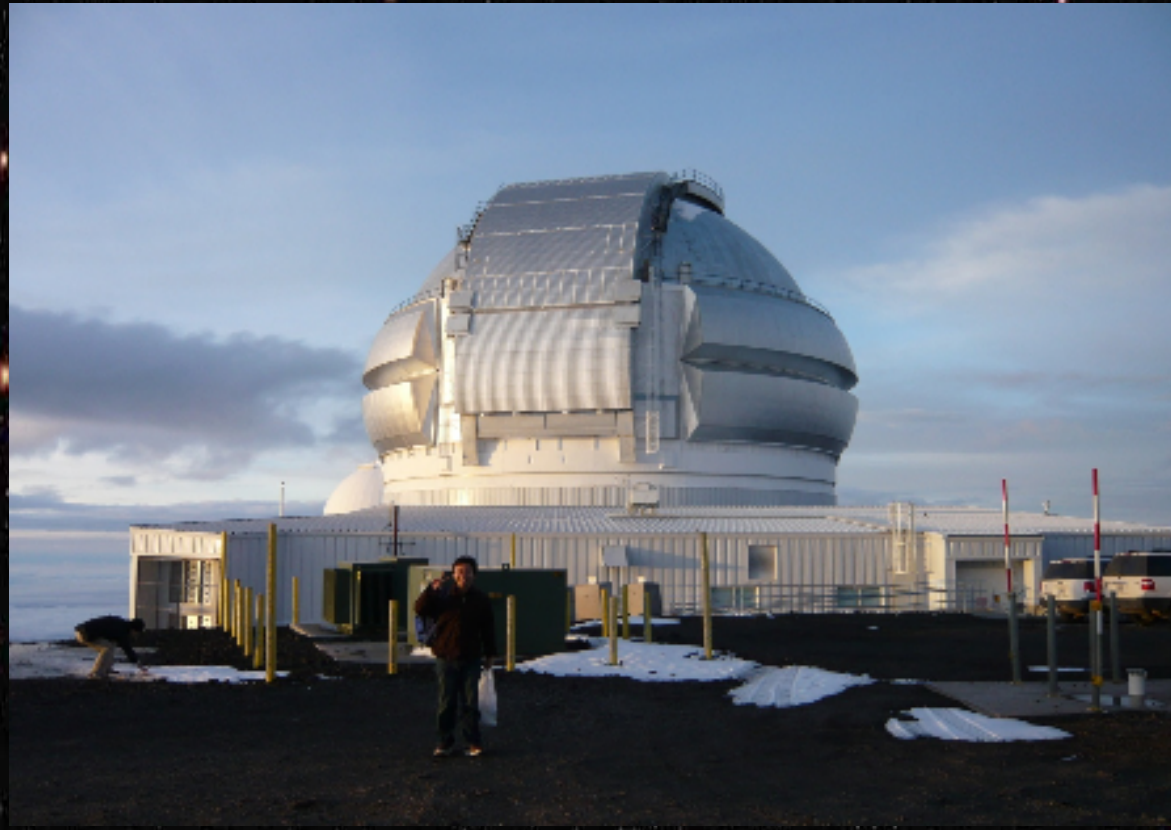
Improved statistics & depth, Observed different sky field



- (1) Number & Ly α luminosity densities of Ly α emitters decrease from $z=5.7$ and 6.6 to $z=7$.
- (2) Neutral Fraction at $z=7$ is $X_{\text{HI}} \gtrsim 49\%$.
- (3) Reionization seems not to be complete at $z=7$.

My Experience at Gemini

We were the First Classical Observers from Subaru-Gemini Time Exchange Program
GMOS spectroscopy of a $z=6$ candidate
protocluster of galaxies (PI Ota, 2008)



Snow for Two Nights!



But, we had really great time at Gemini



We thank all the staff at Gemini.
Especially, Inger Jorgensen, Kathy Roth,
Jesse Ball, Atsuko Nitta, Thomas Dall,
Terry Kaonohi, Gabriela Randrup, Sandy Leggett.
Looking forward to observing with Gemini in the future!