Deep Surveys of z=7 Lyα Emitting Galaxies with Subaru Telescope: Implications for Galaxy Evolution and Reionization

Kazuaki Ota

RIKEN Cosmic Radiation Laboratory

Seminar @ IPMU 5 August 2009

Outline

1. Background

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

2. New Deeper z≅7 Lyα Emitter Survey

- With upgraded Subaru/Suprime-Cam

3. Result:

- Deeper Lyα LF → neutral fraction of the Universe at z=7

4. Conclusion

5. Ongoing & Future Projects

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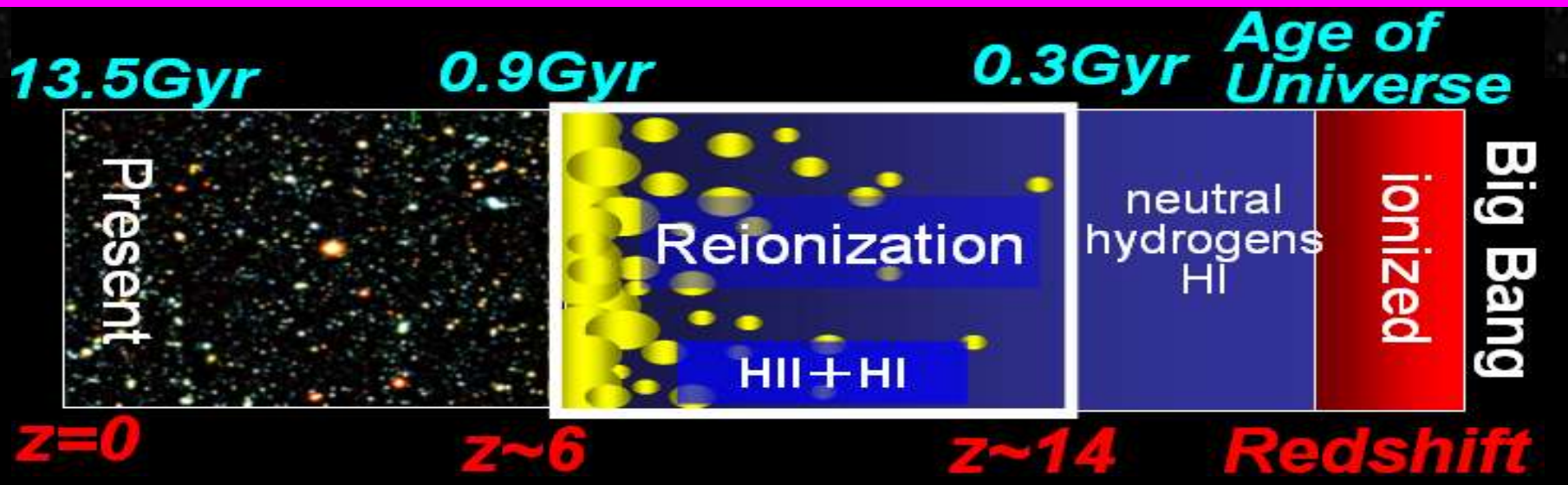
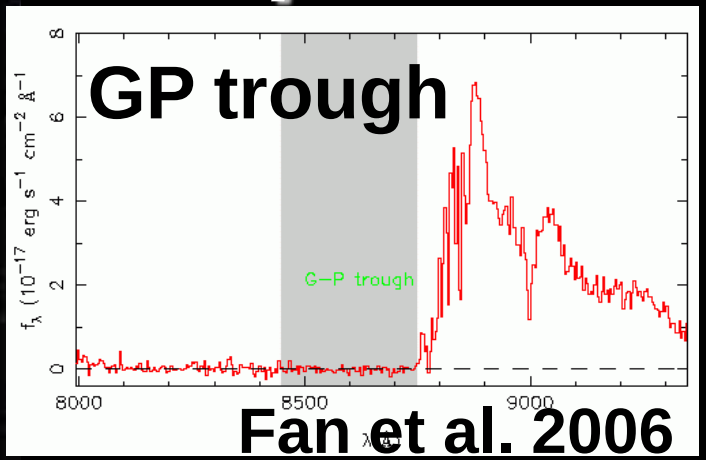
Reionization Probed by Independent Observations



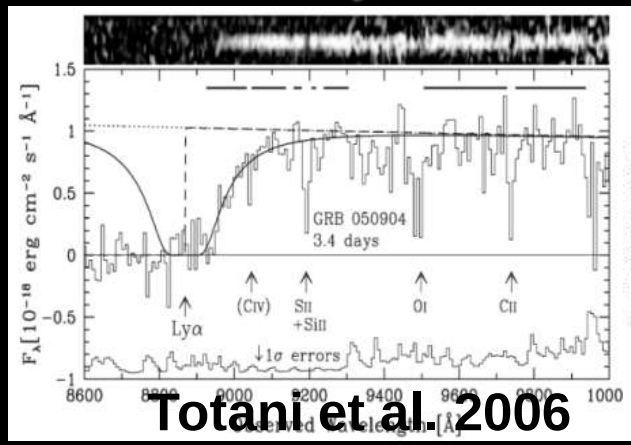
Redshift	6.2	6.3	6.7
Neutral H fraction	1-4%	<17%	>35%

z~6 quasars

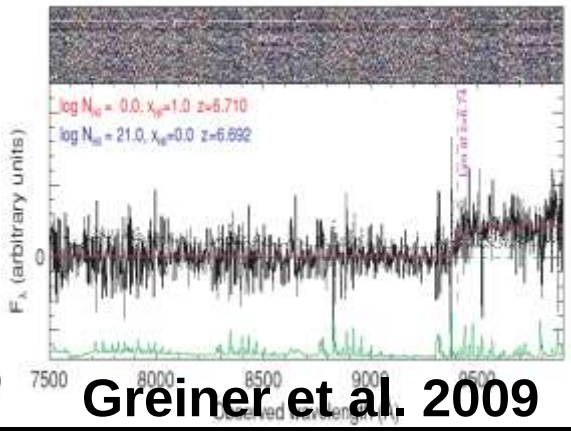


Fan et al. 2006

z~6.3, 6.7 GRBs



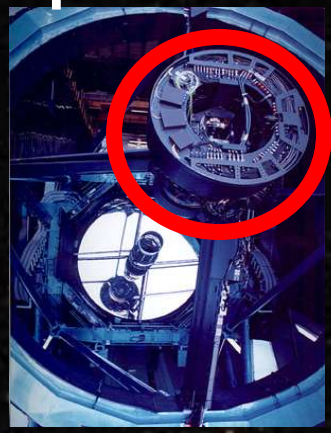
Totani et al. 2006



Greiner et al. 2009

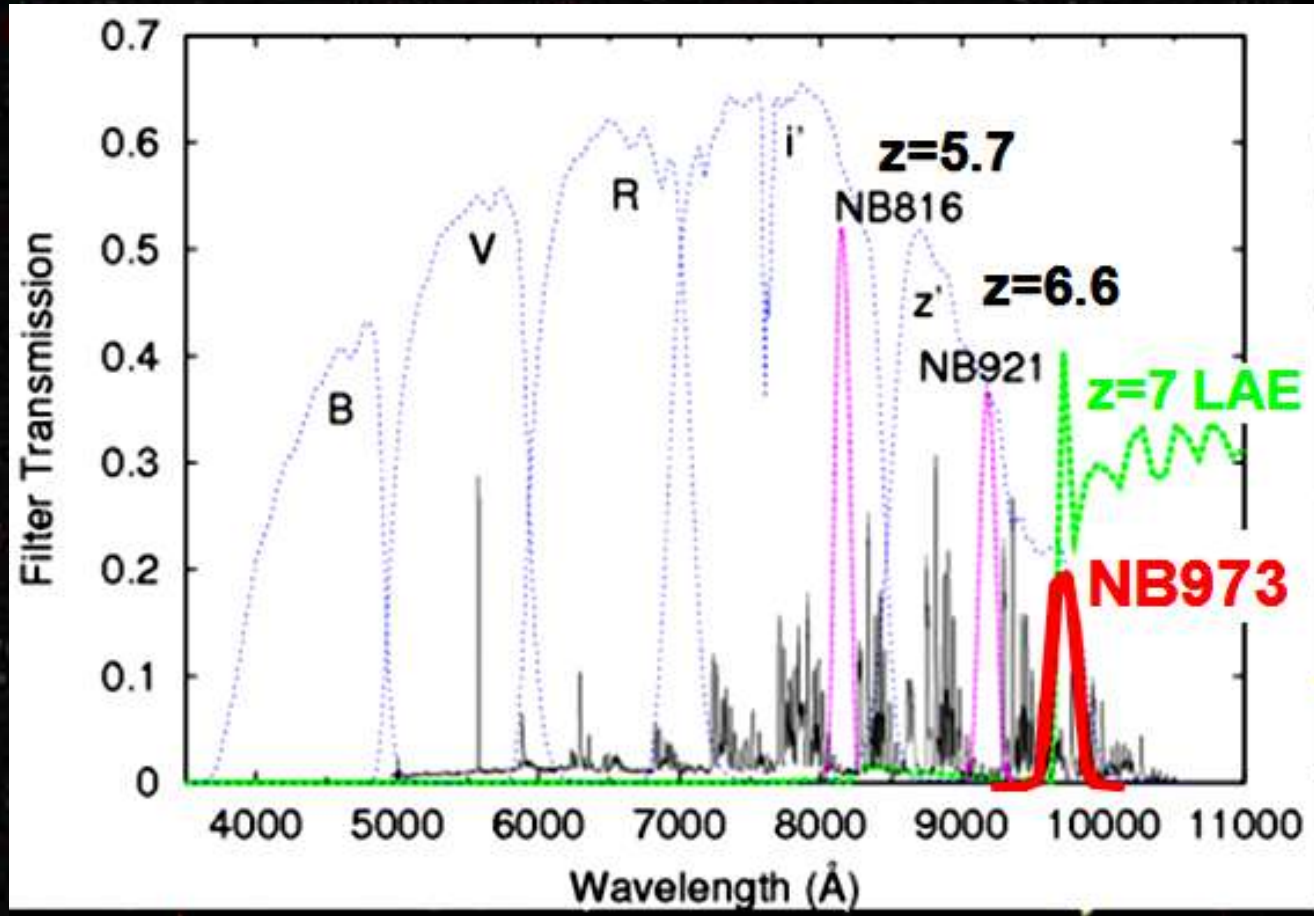
Subaru Deep Field Project

Subaru Telescope
Suprime-Cam



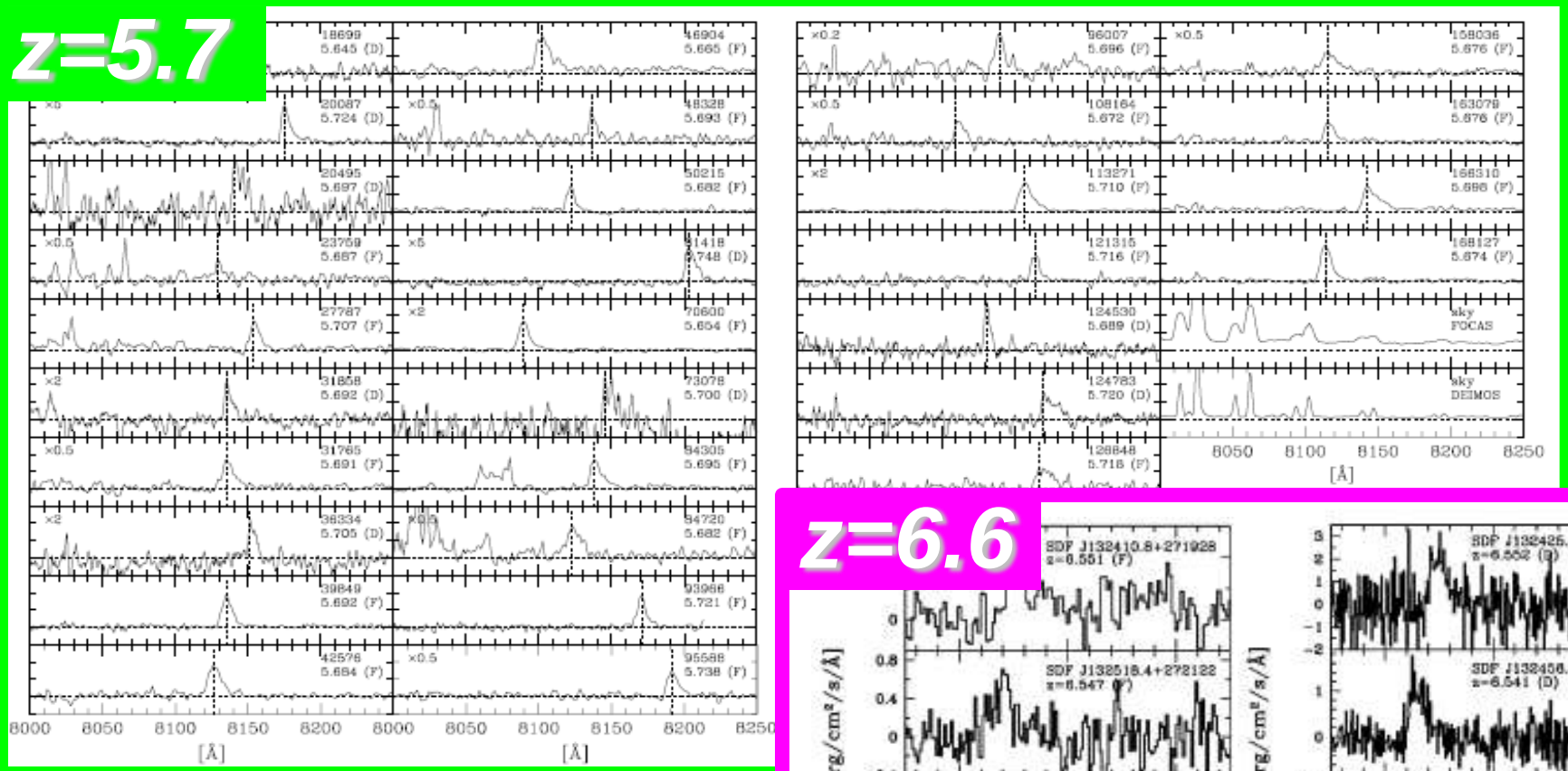
Deep Images:
Broadband filters: B, V, R, i', z'
Narrowband filters: z=5.7, 6.6, 7 Lya

Subaru Deep Field
876 arcmin²

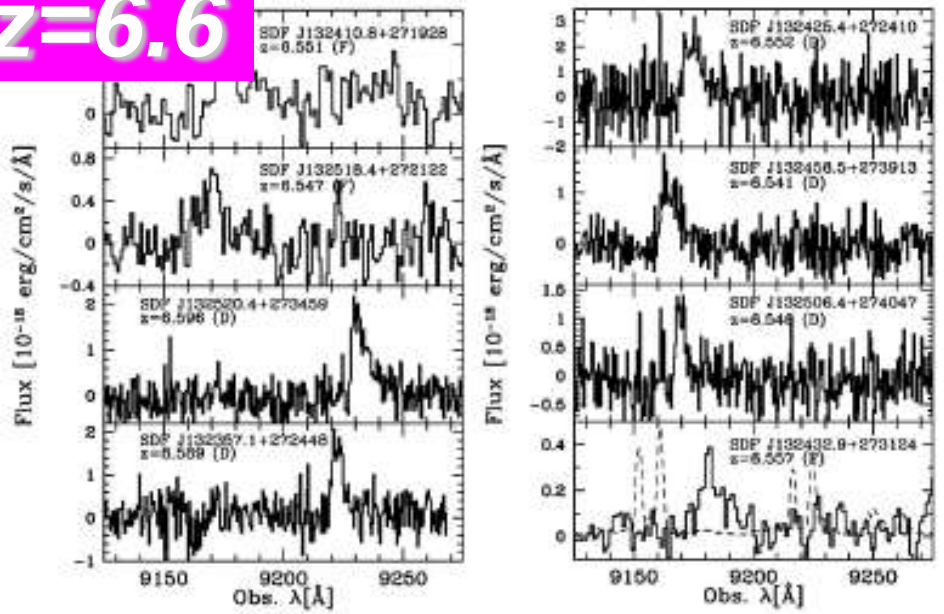


Detection of Lya Emitters at z=5.7, 6.6

z=5.7



z=6.6

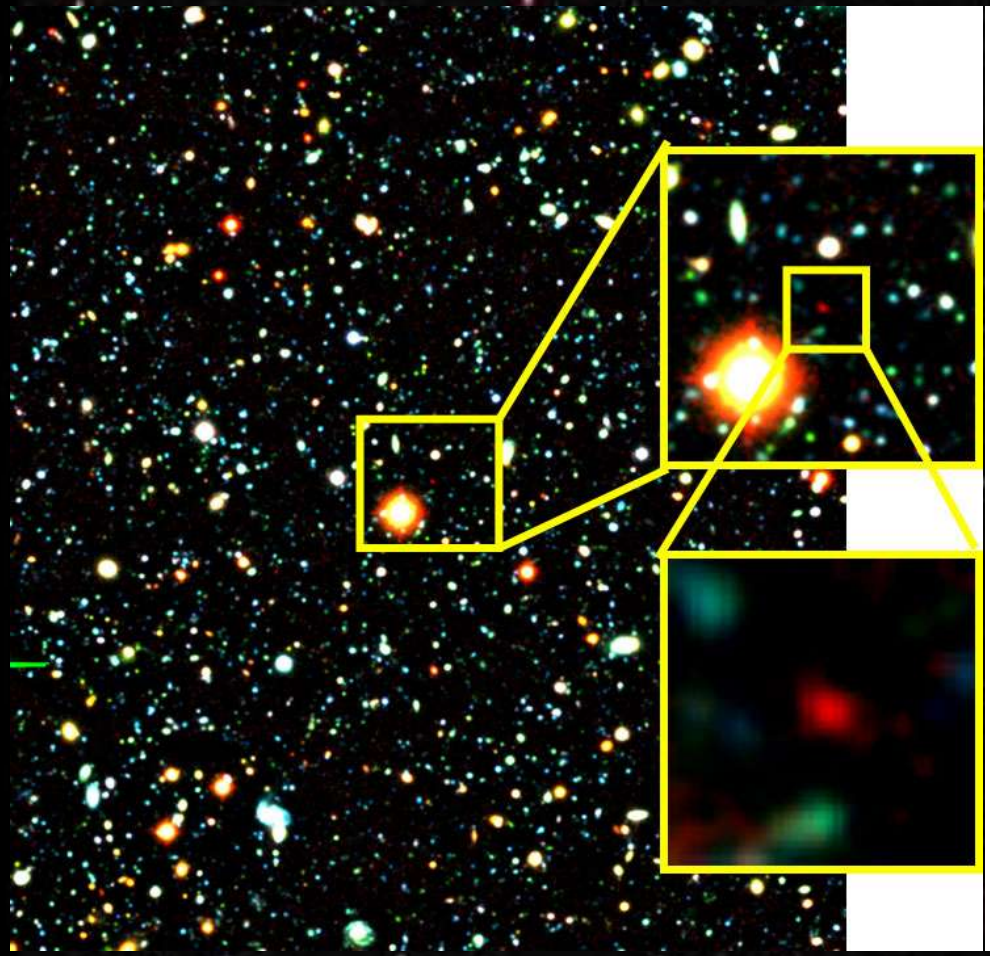


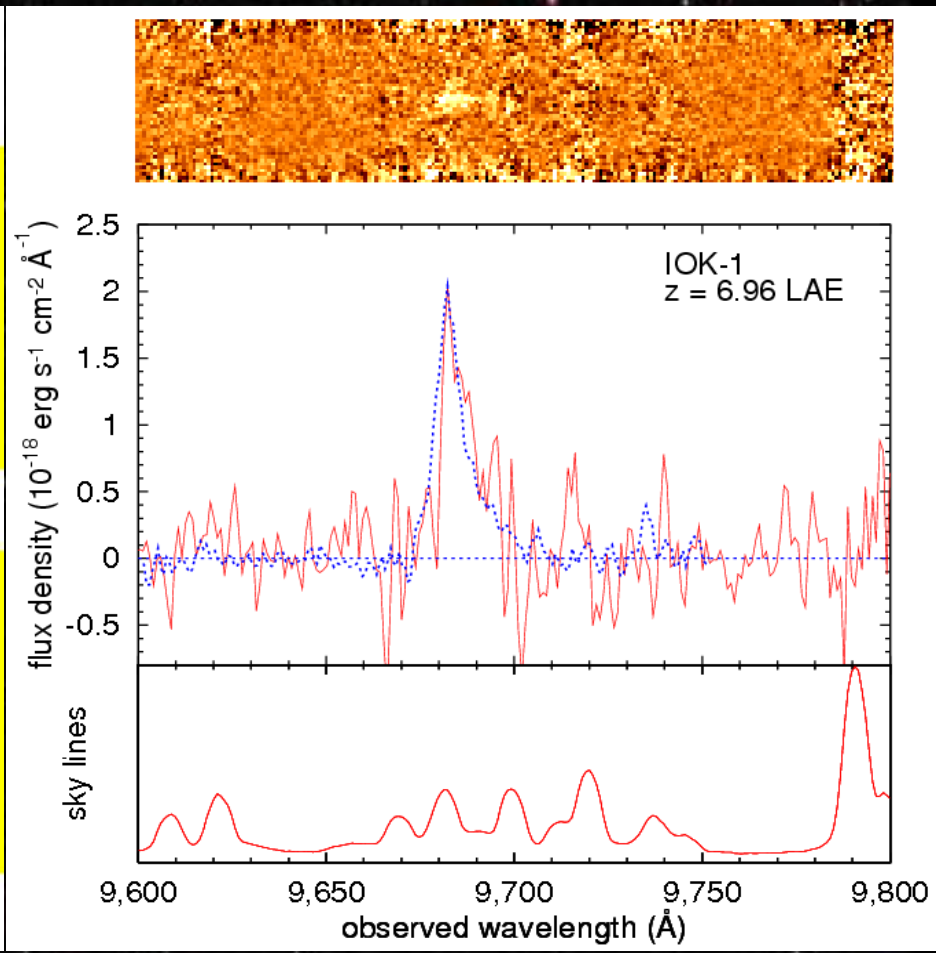
Shimasaku et al. 2006
Kashikawa et al. 2006

Discovery of a z=6.96 Lyα emitter IOK-1

The previously most desitant object ever observed

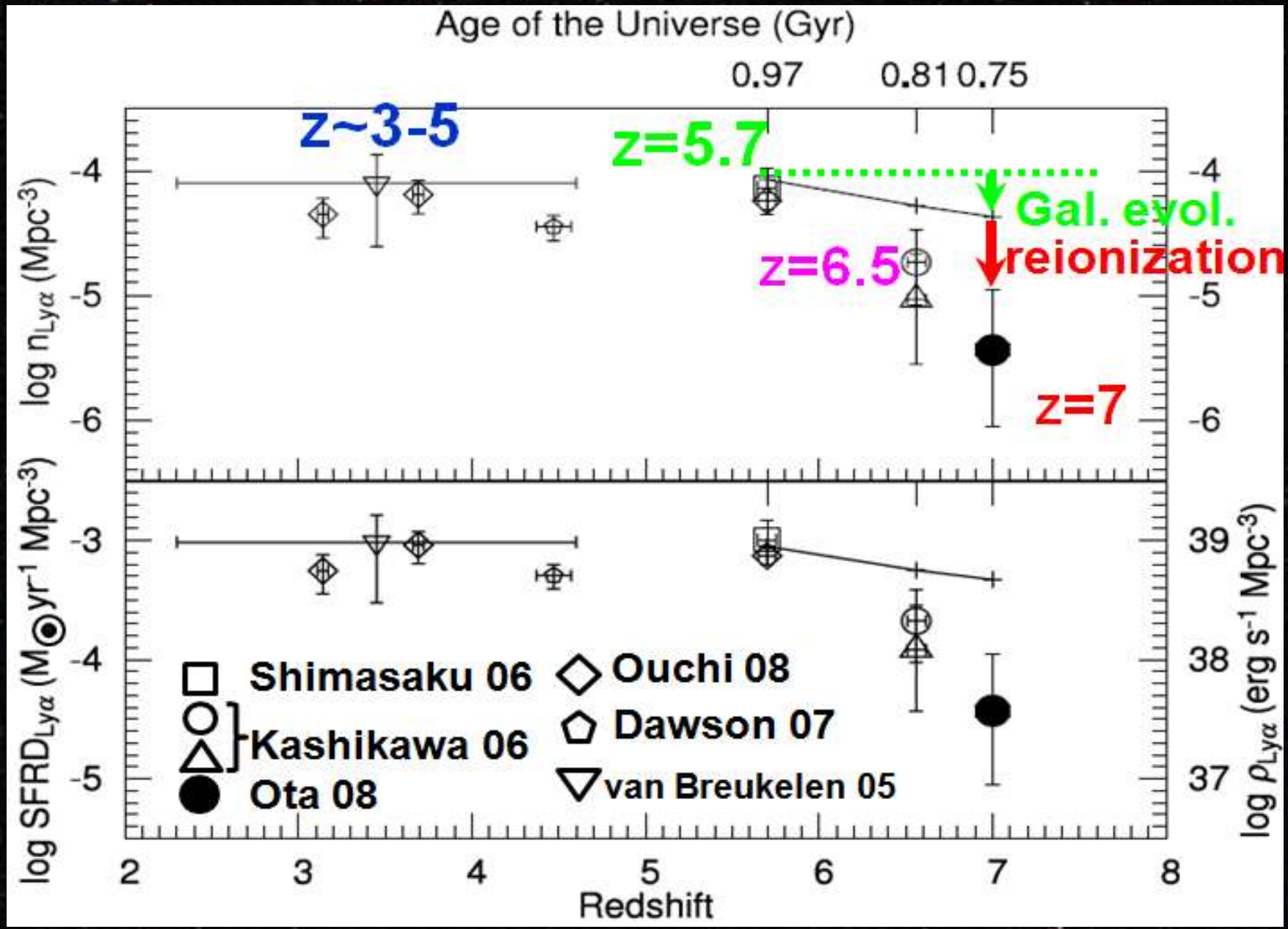
Evidence of galaxy formation only 750 Myr after Big Bang



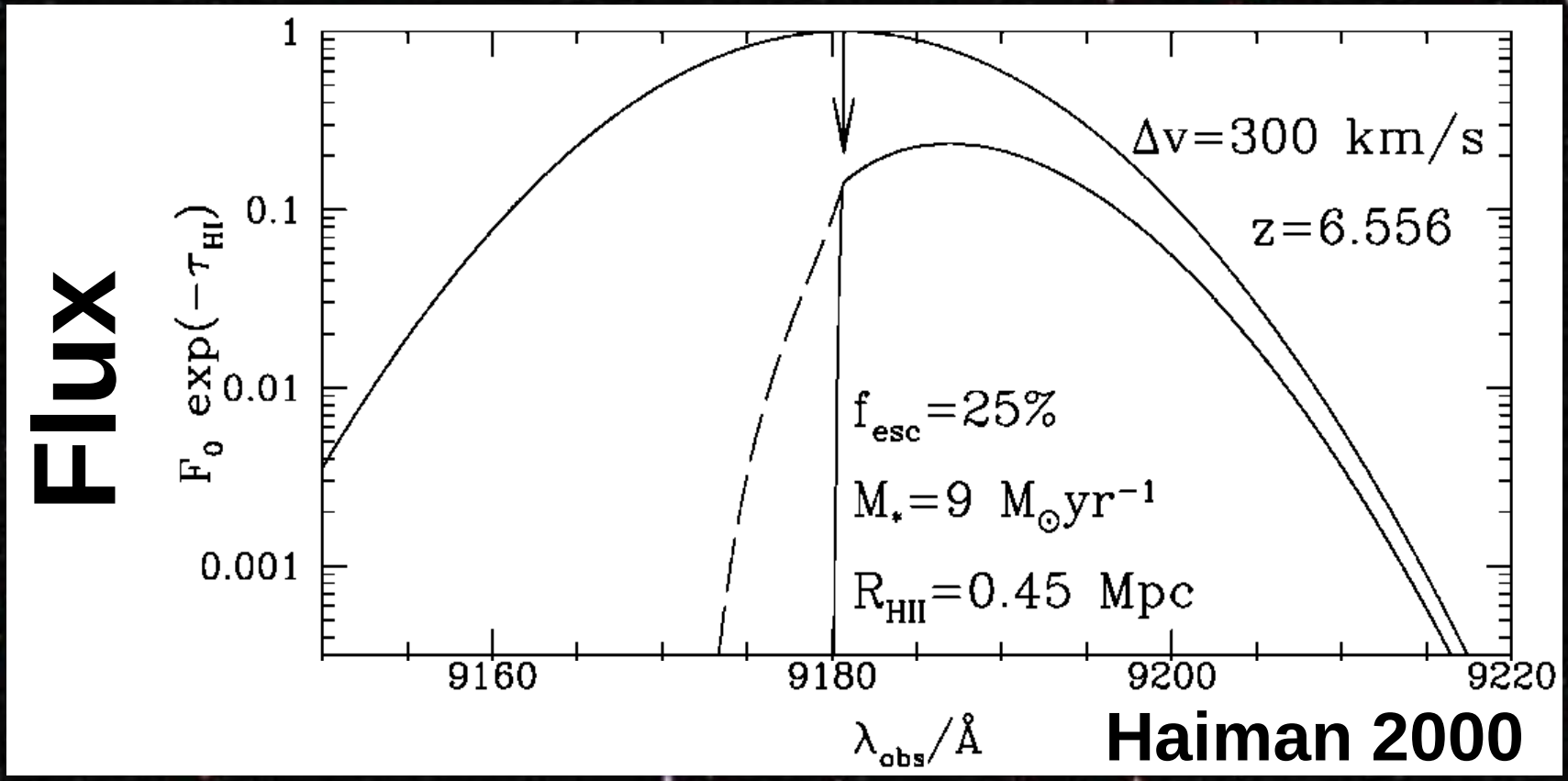


Iye, Ota, Kashikawa et al. 2006

Lya emitter number desnidty decreases at z > 6



Lyα emission line is attenuated if neutral hydrogen exists



If neutral hydrogen fraction is large at z>6, we detect smaller number of Lyα emitters

IGM transmission to Lyα photons: $F^{Ly\alpha}_{obs}/F^{Ly\alpha}_{model}$

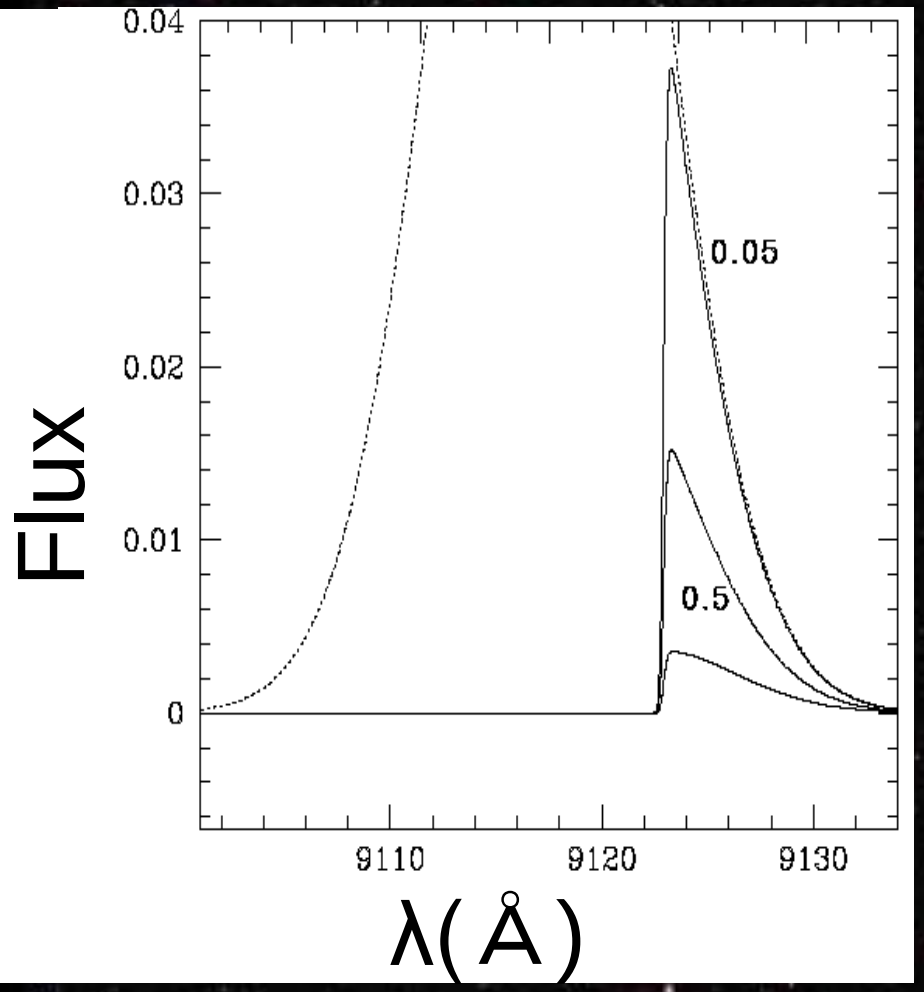
z=6.6: 0.62–0.78

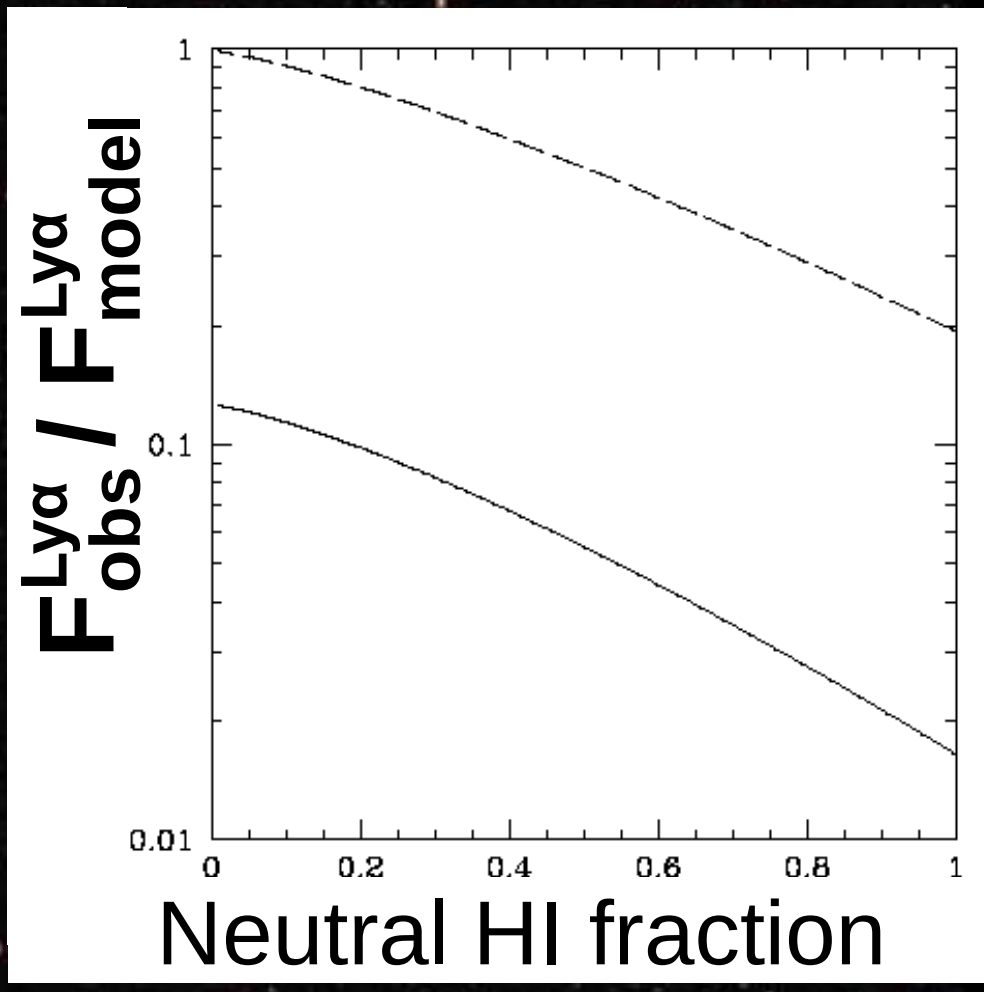
z=7.0: 0.40–0.64

Neutral Fraction

z=6.6 24–36%

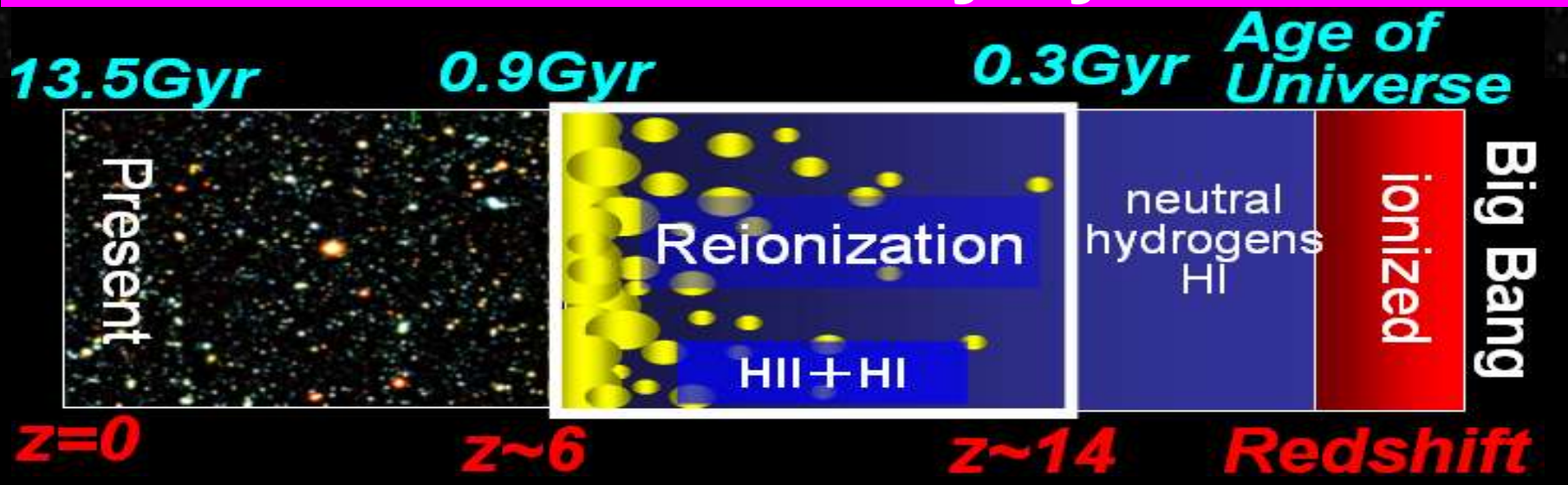
z=7.0 32–64%





Lyα line attenuation: Model of Santos（2004）

Reionization Probed by Lyα emitters



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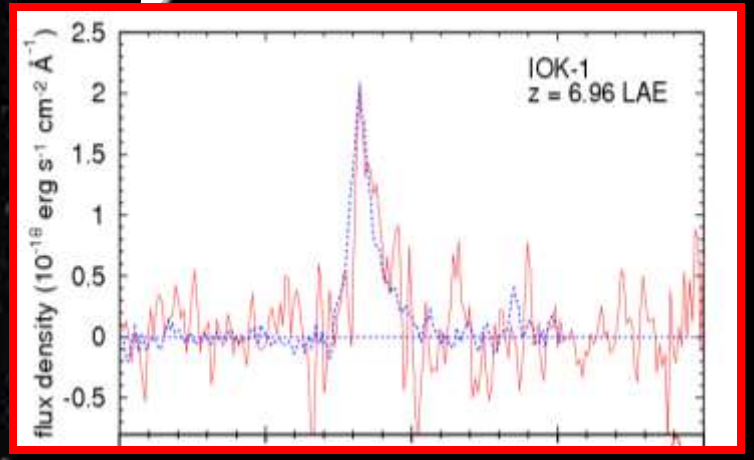
Lyα emitters ***z=6.6*** ***z=7.0***



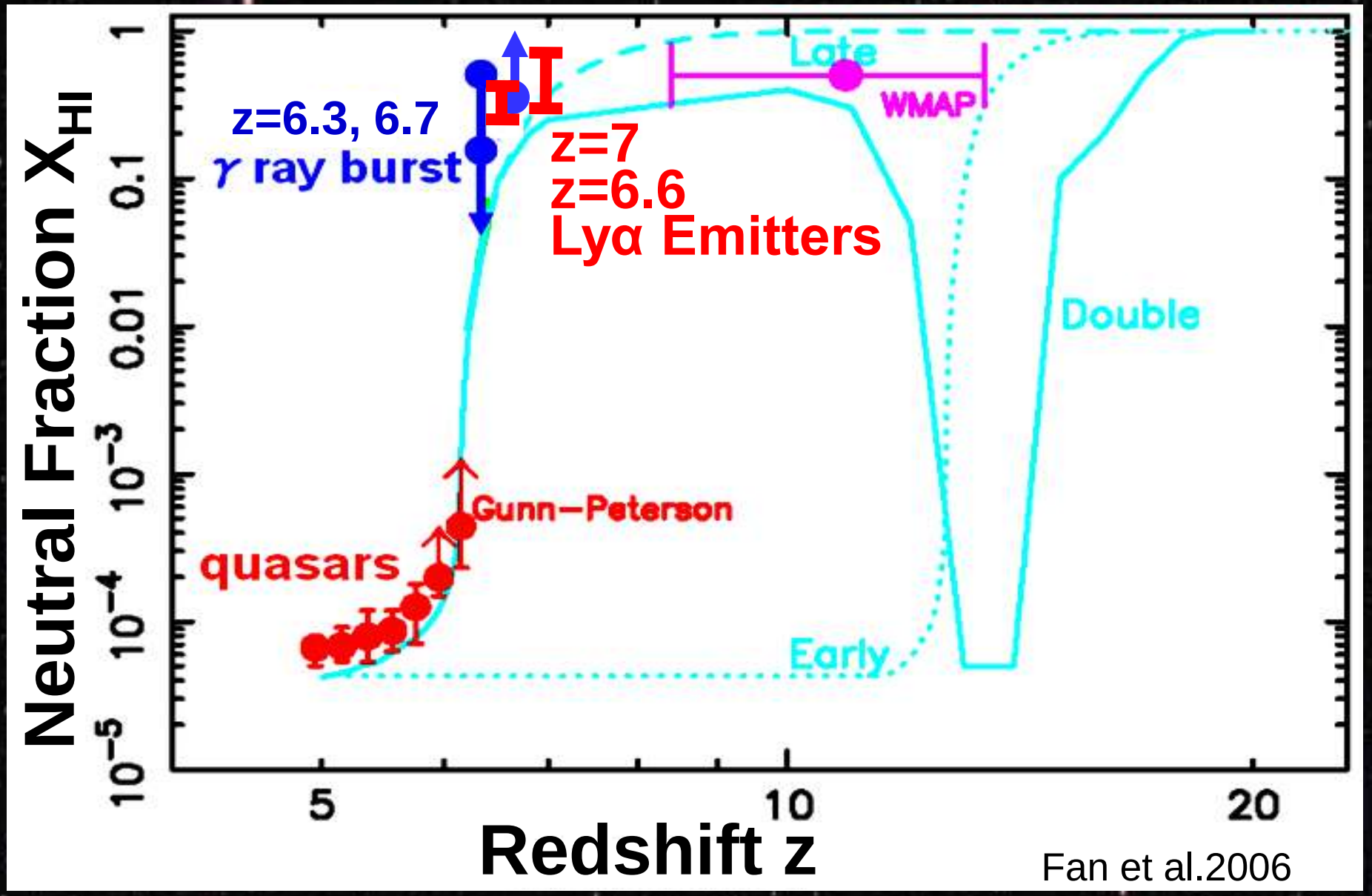
24-36% ***32-64%*** (Ota et al.08)

↑

Attenuation of Lyα flux

Decrease in number density

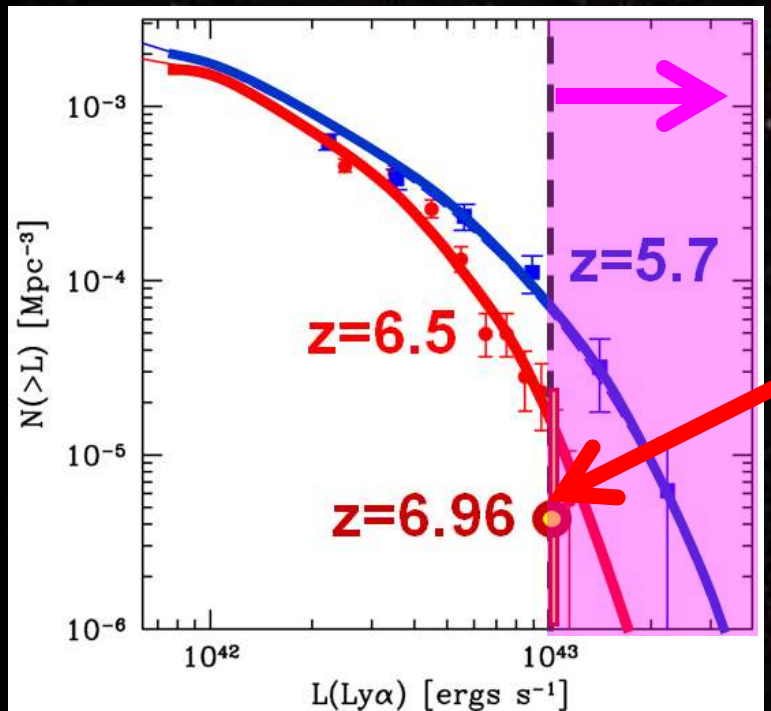
Constraint on reionization from LAEs



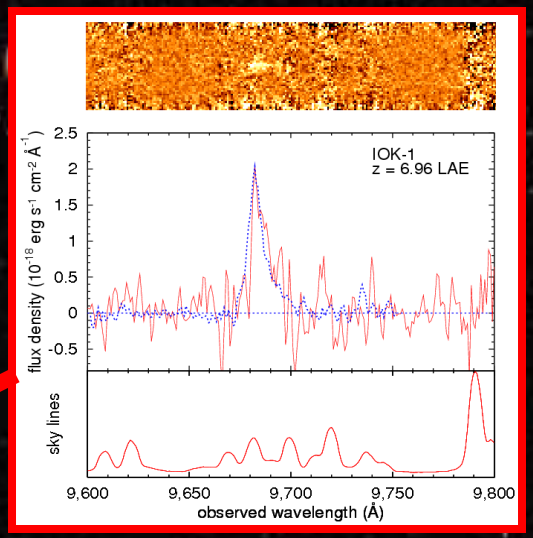
3 weakneses in the previous z=7 survey

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

L(Lyα) > 10^{43} erg/s



Only 1 Lyα emitter



Subaru Deep Field
876 arcmin²

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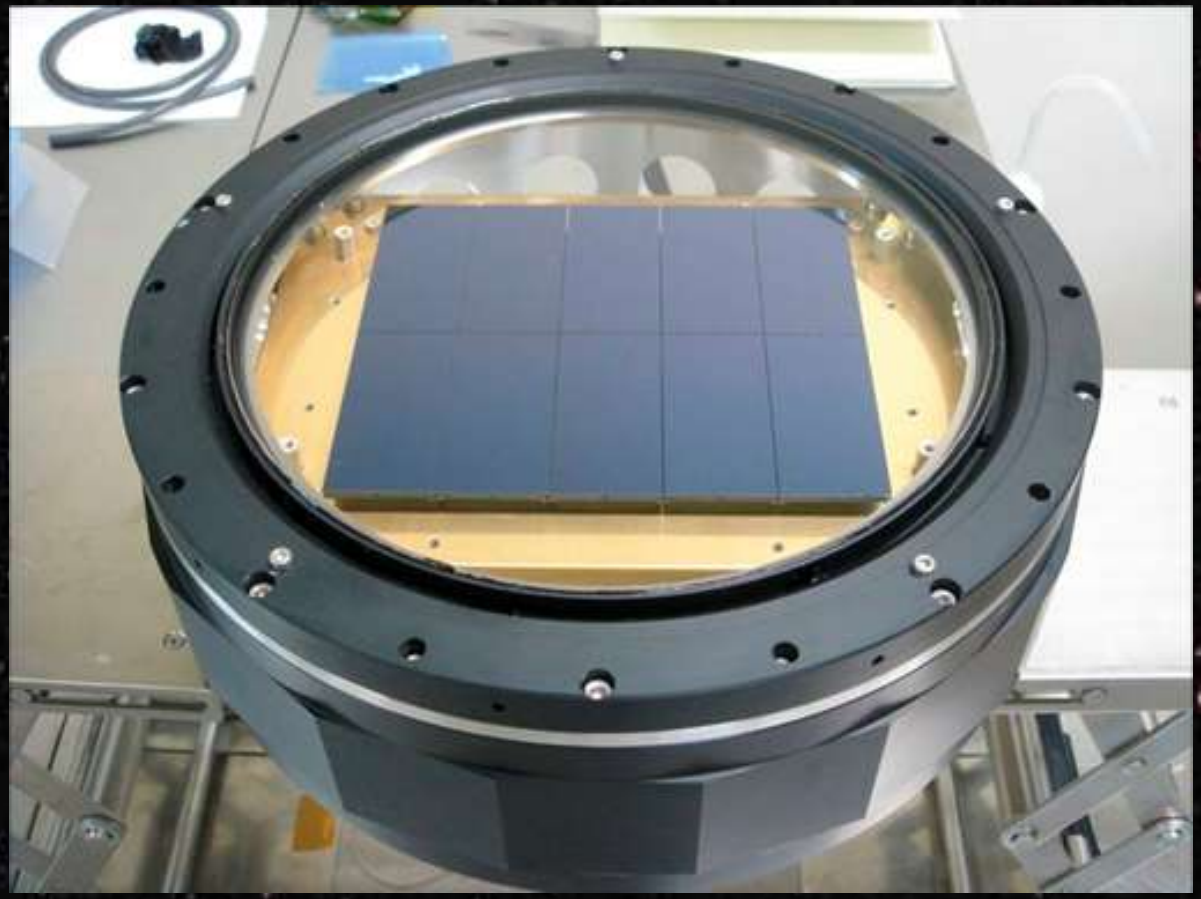
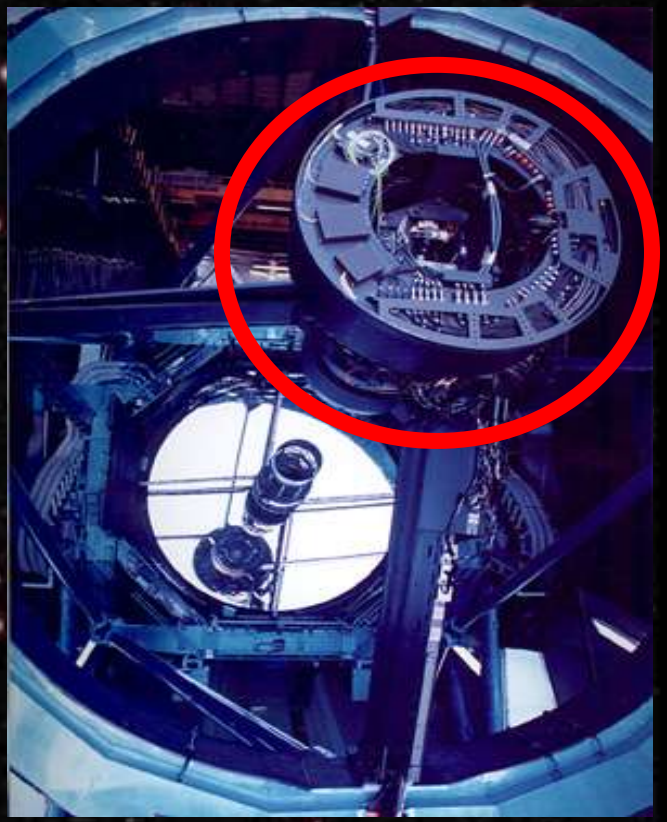
4. Conclusion

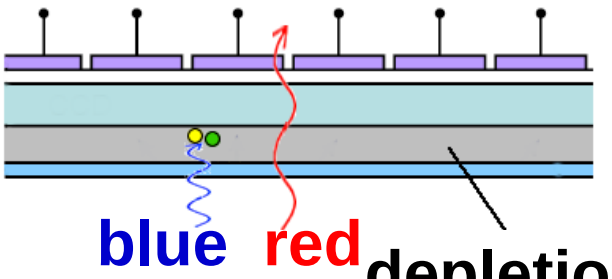
5. Ongoing & Future Projects

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

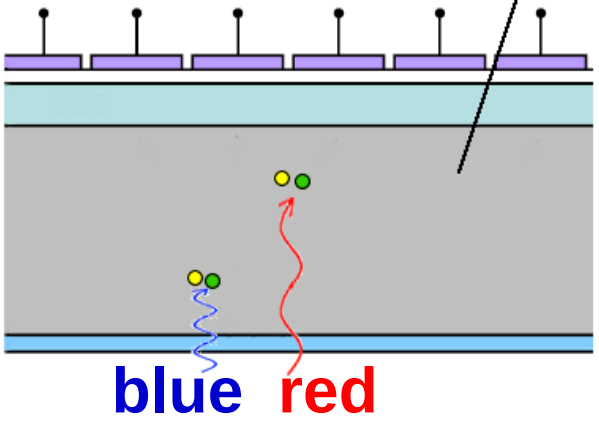




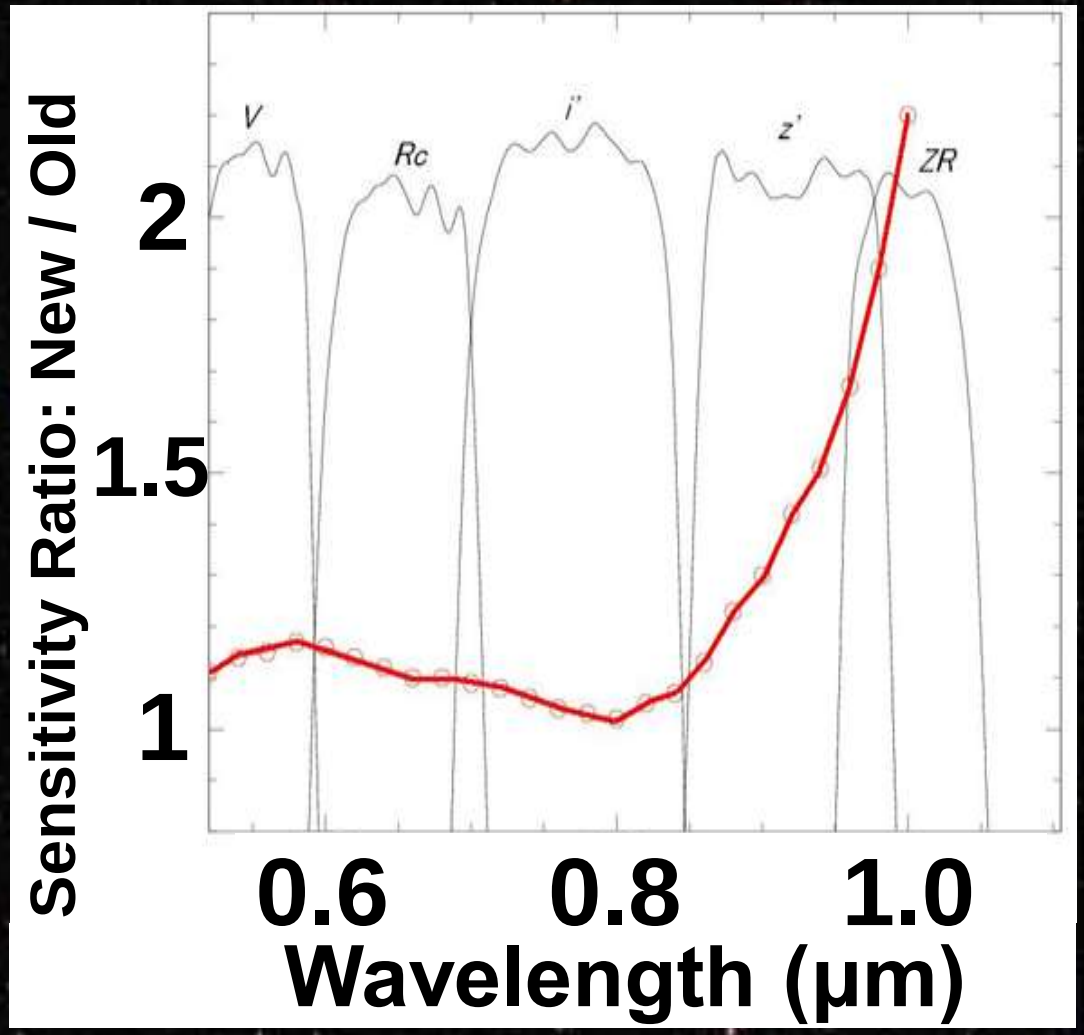
The fully depleted CCD enables >2x better sensitivity at λ~1μm



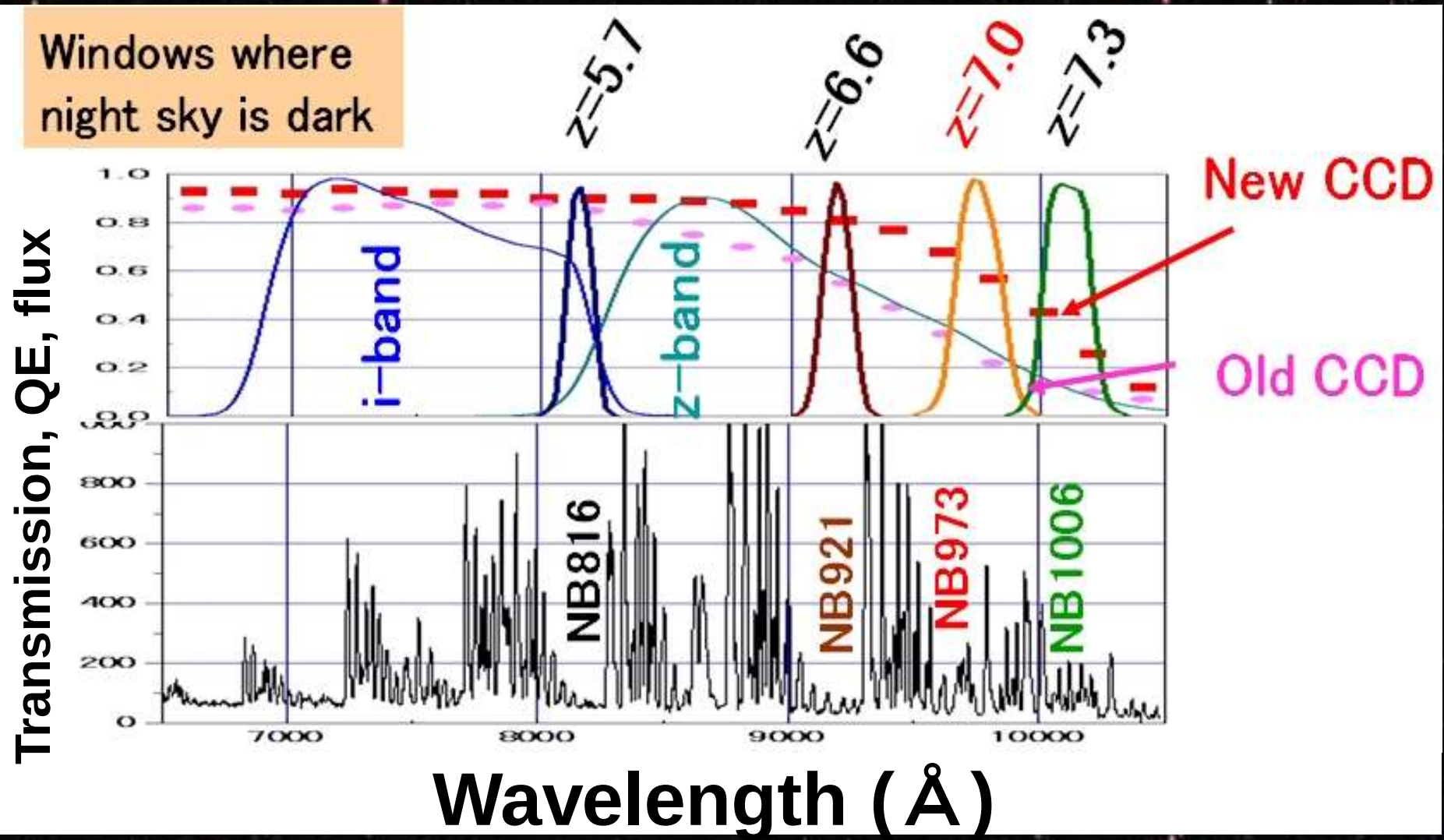
Old CCD



New CCD



2 x more sensitive to z=7 Lyα emission

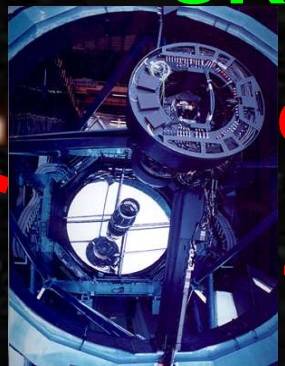


Target Sky Region

Subaru/**X**MM-Newton **D**eep **S**urvey Field（**SXDS**）

Spitzer

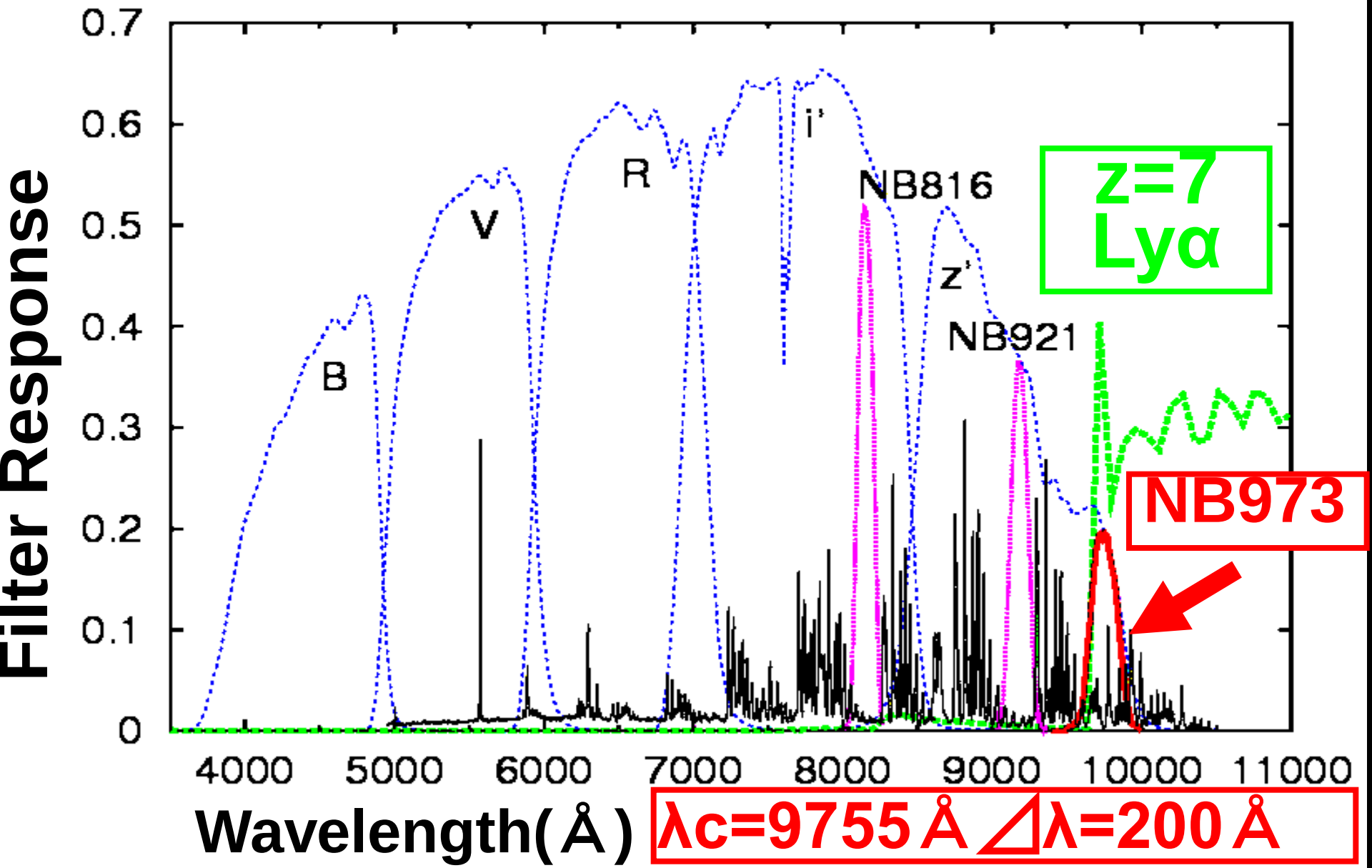
UKIDSS-UDS



Oct, Nov 2008
Subaru
This Work

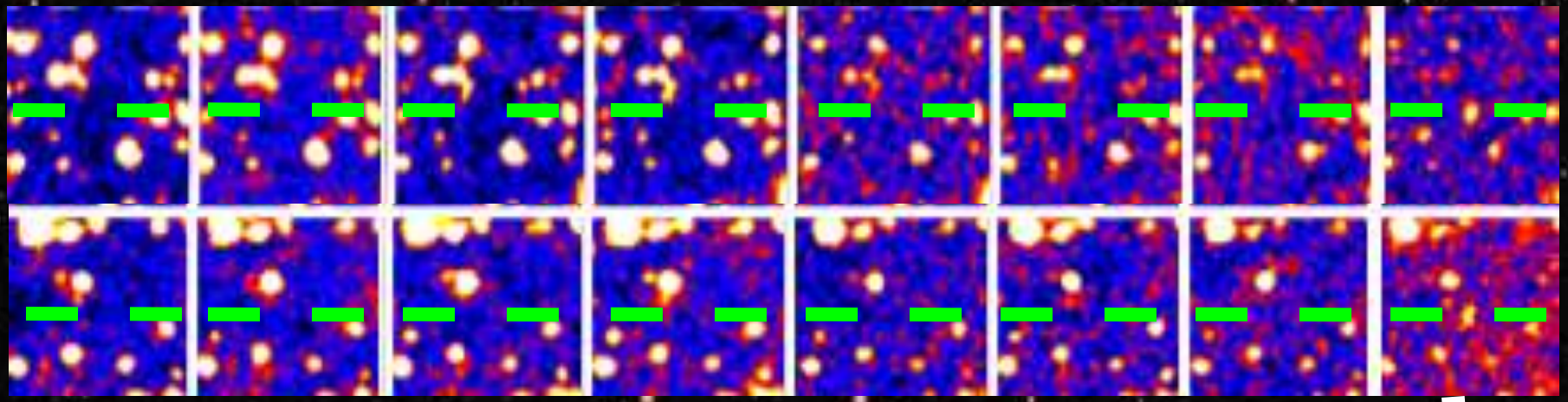
13 hours imaging
NB973 = 25.4 (5σ)
(previously, 24.9)

Narrowband filter to detect z=7 Lyα emitters



New z=7 Lyα emitter candidates

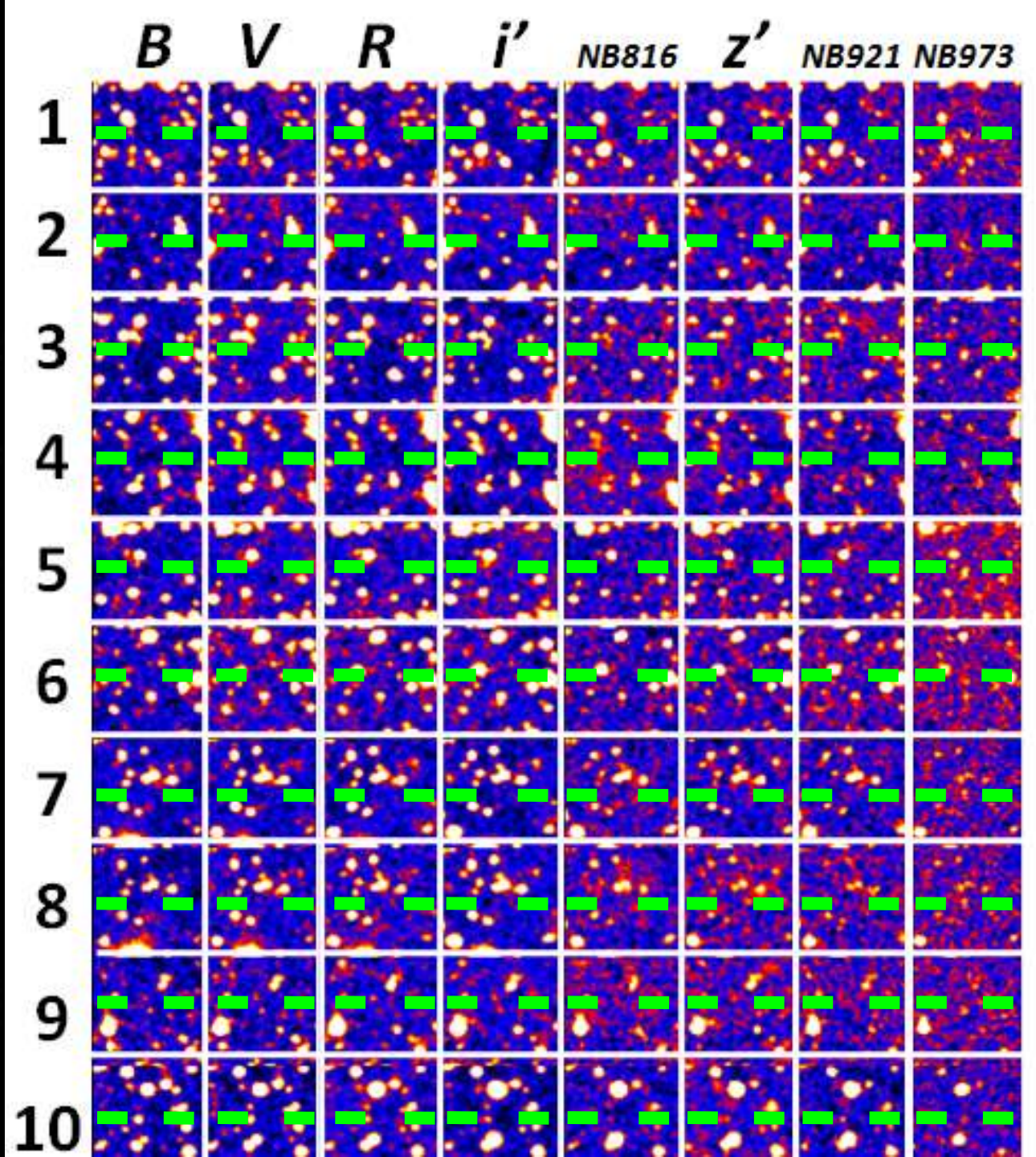
B V R i' NB816 z' NB921 NB973



No detection (< 3σ)

NB973 ≤ 25.4 (5σ)

Equivalently, z' – NB973 ≳ 1



Color Selection

+

Visual Inspection

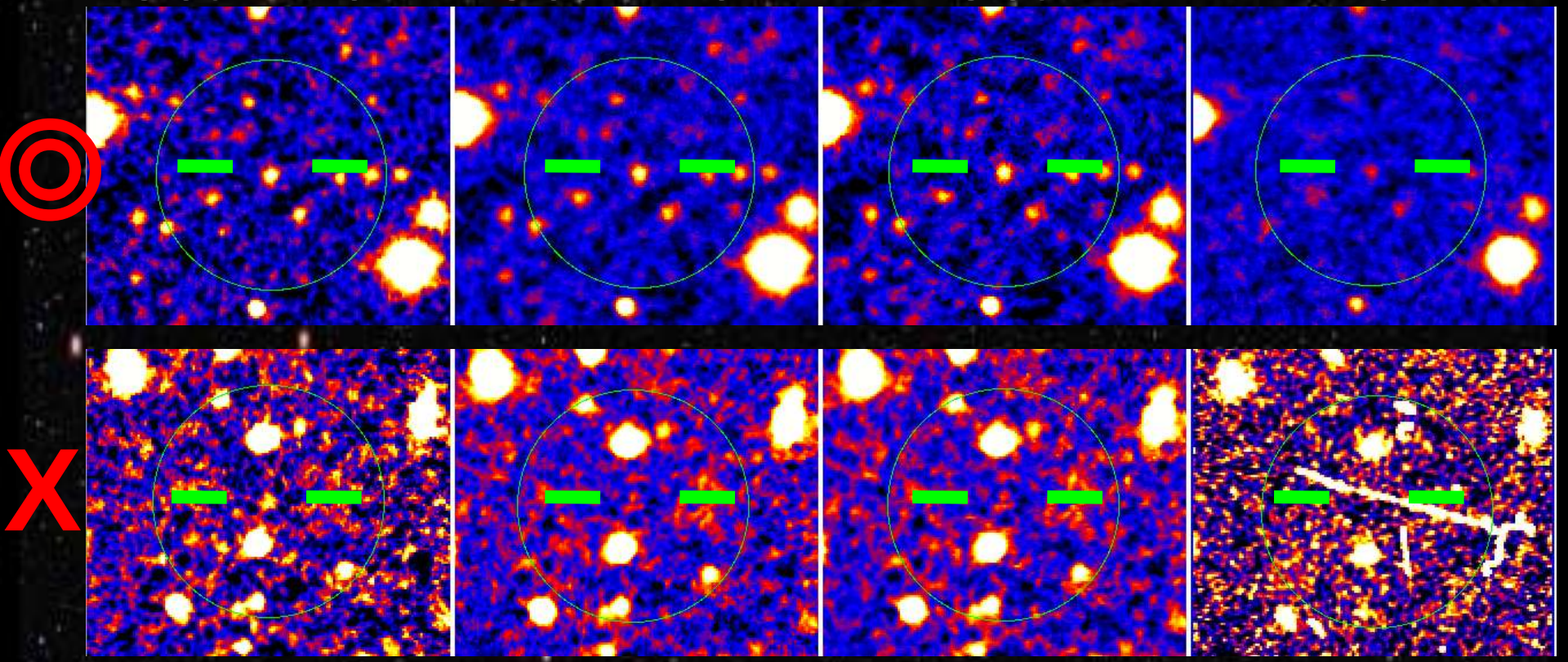
↓

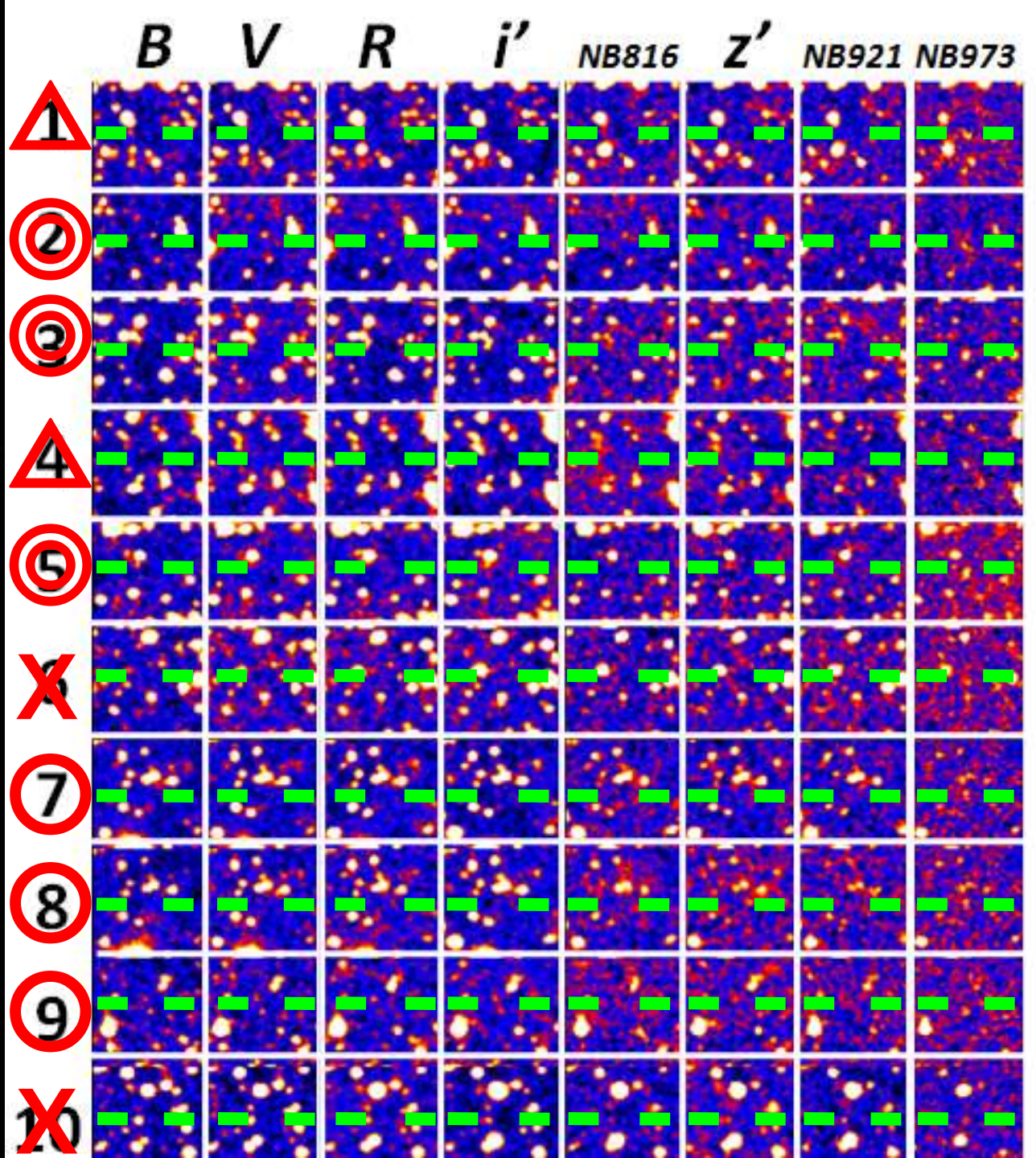
10 z=7 LAE candidates

Checking NB images taken in different periods
Remove spurious and transient objects

13hr 1” 16.7hr 1.”2 11hr 1.”2 5.7hr 1.”2

Oct + Nov Oct + Nov Oct Nov





#Candidates ≤ 7

◎ Promissing 3

○ Probable 2

△ Possible 2

← same object

← Count as 1

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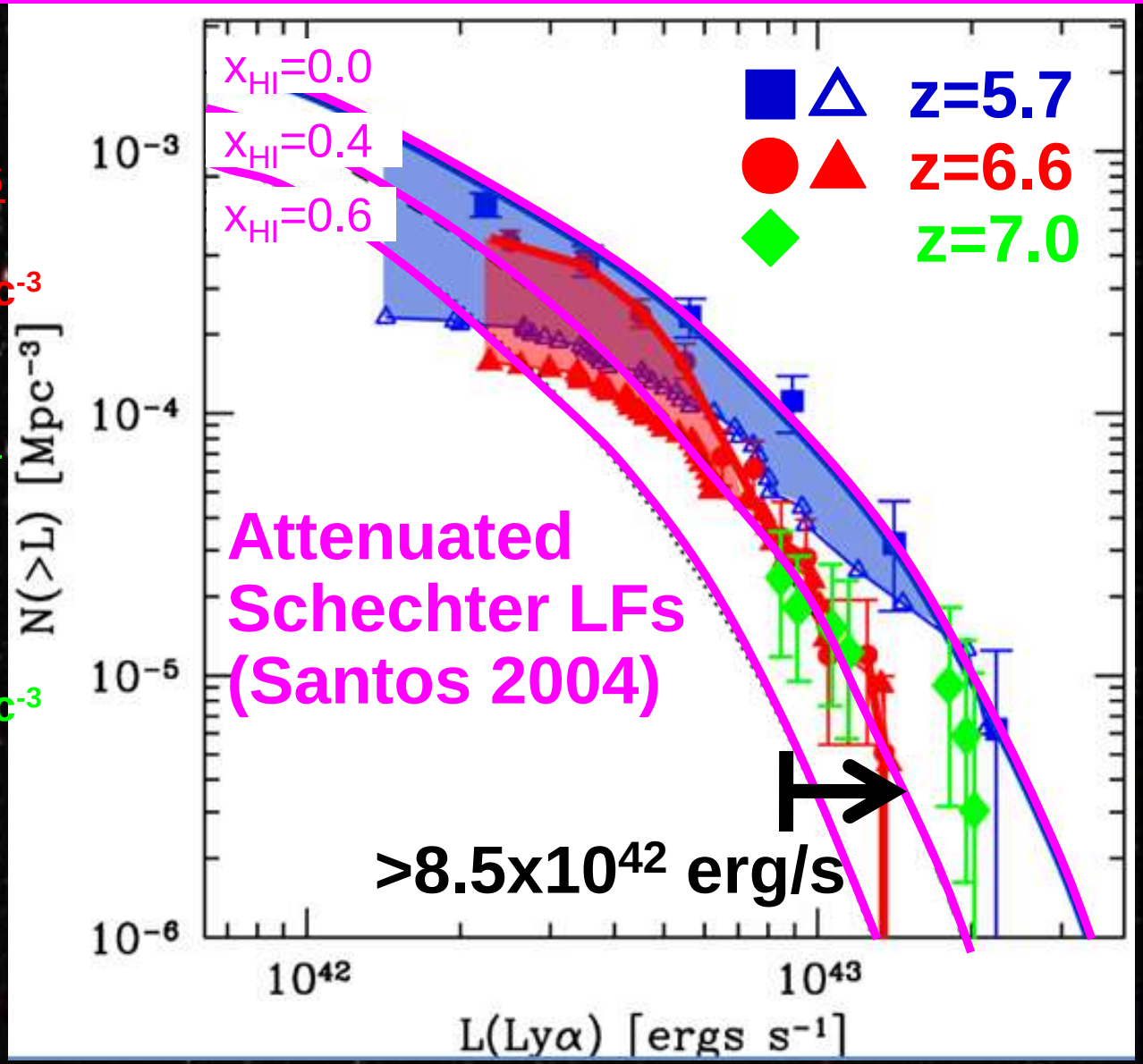
Lyα LF for 7 candidates
F(Lyα) = F(NB filter)

Observed Densities
$n_{Ly\alpha}$: 2.5×10^{-5} Mpc^{-3}
$\rho_{Ly\alpha}$: 3.6×10^{38} erg/s/Mpc^{-3}

Predicted Densities when x_{HI}=0
(Kobayashi et al. 2007 LAE evolution Model)
$n_{Ly\alpha}$: 5.8×10^{-5} Mpc^{-3}
$\rho_{Ly\alpha}$: 6.4×10^{38} erg/s/Mpc^{-3}

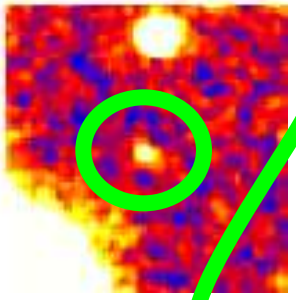
Neutral Fraction
z=7.0 ~43%



Fraction of Lyα flux in NB filter flux

F(Lyα) ~ 0.7 x F(NB973)

NB973 Filter Total Flux

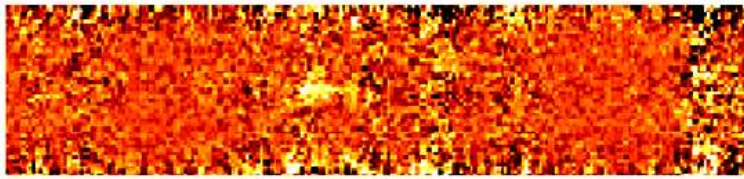


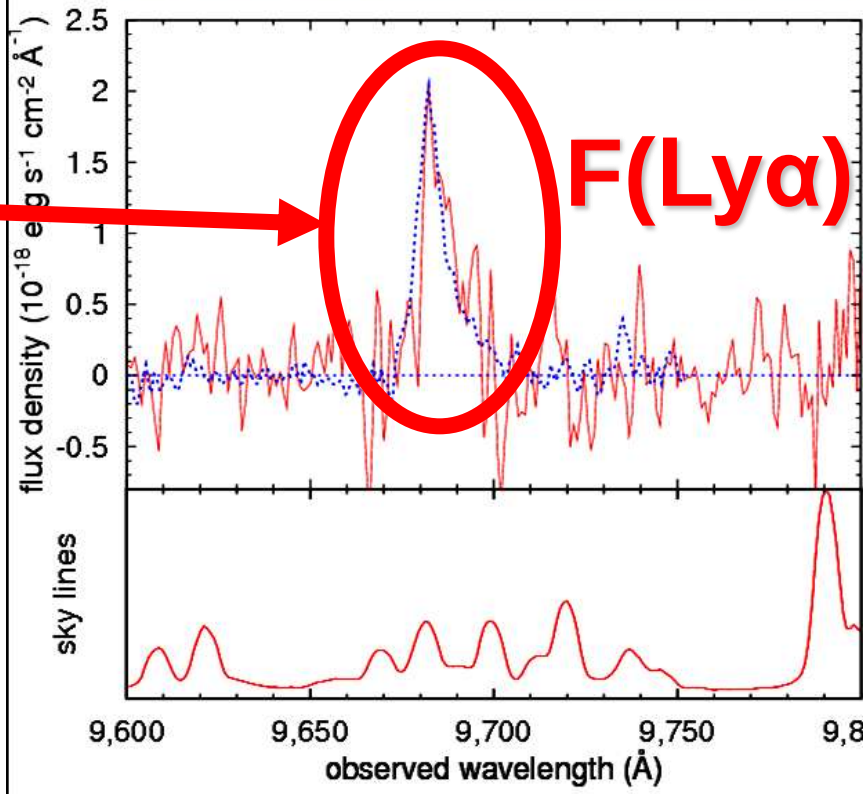
F(Lyα)
~70%

30%
F(UV)

F(NB973)
= F(Lya) + F(UV)

Spectrum





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Predicted Densities when x_{HI}=0

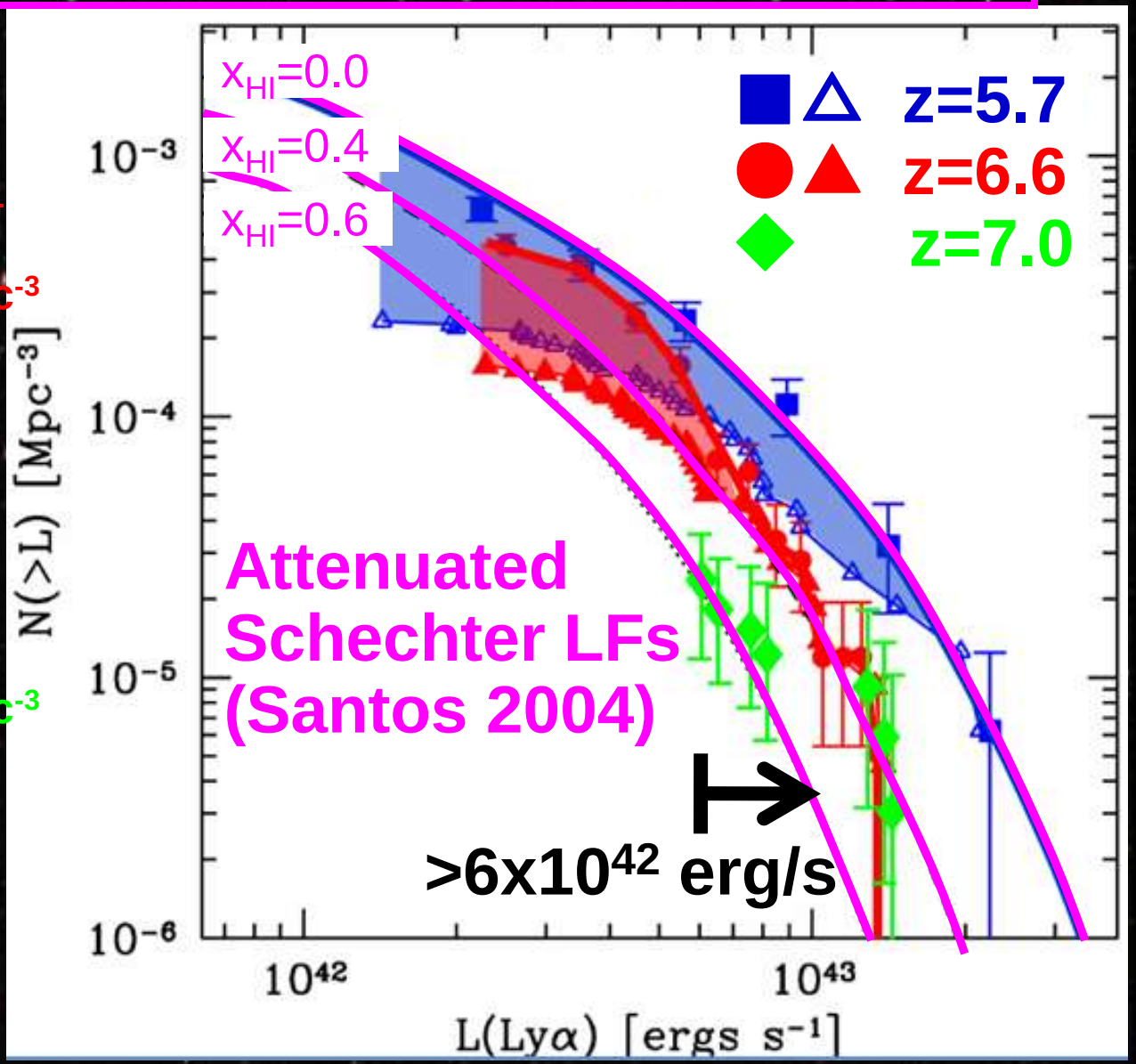
(Kobayashi et al. 2007 LAE evolution Model)

$n_{Ly\alpha}$: 1.1×10^{-4} Mpc^{-3}

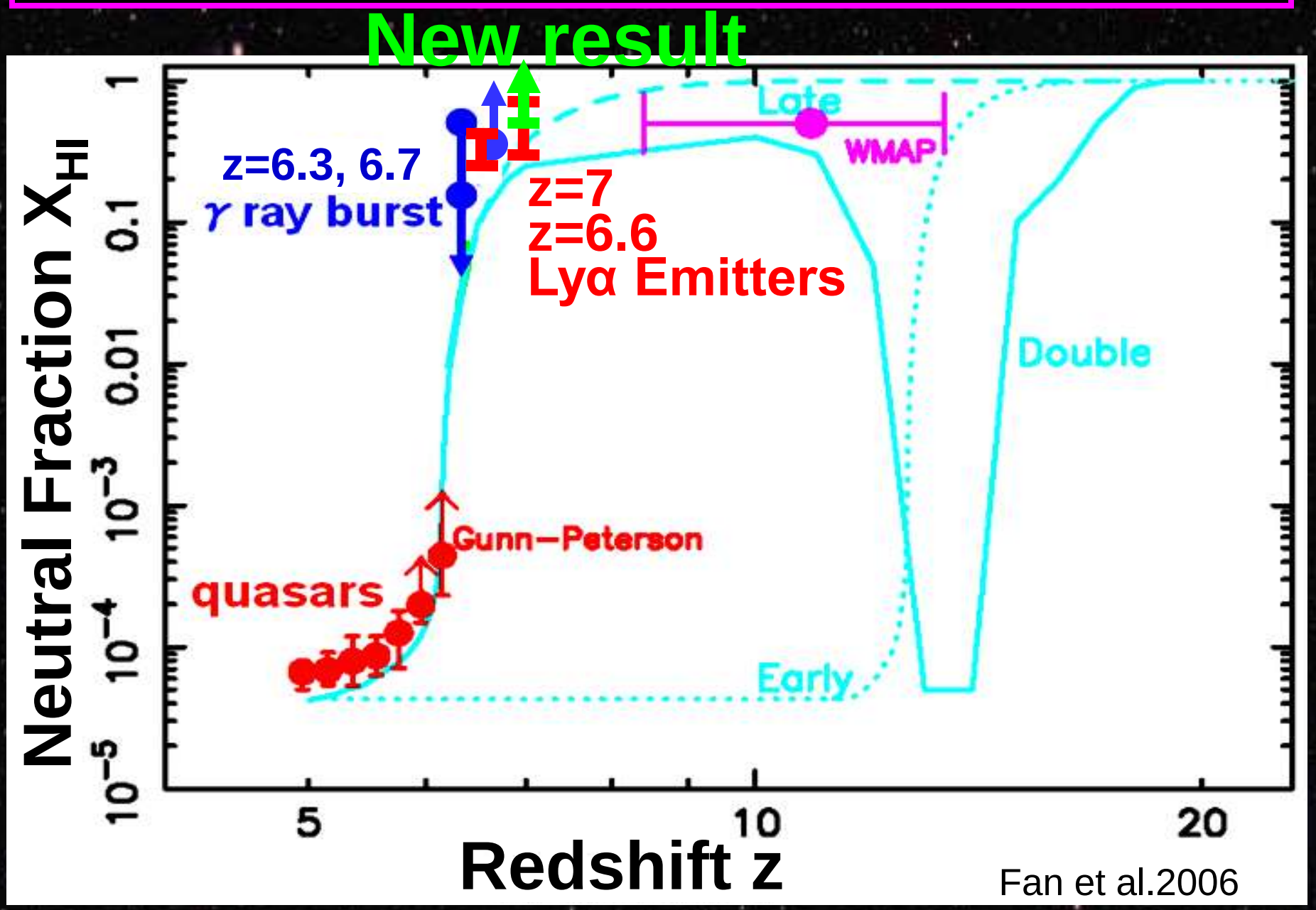
$\rho_{Ly\alpha}$: 9.5×10^{38} erg/s/Mpc^{-3}

Neutral Fraction

z=7.0 ~65%



New reuslt agrees with previous results



Fan et al.2006

Keck DEIMOS Spectroscopy of z=7 LAE Candidates 13 and 14 Nov. 2009

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Conclusion

Improved statistics & depth, Observed different sky field

↓

(1) Number & Lyα luminosity densities of Lyα emitters decrease from z=5.7 and 6.6 to z=7.

(2) Neutral Fraction at z=7 is $X_{HI} \gtrsim 0.43 – 0.65$.

(3) Reionization seems not to be complete at z=7.

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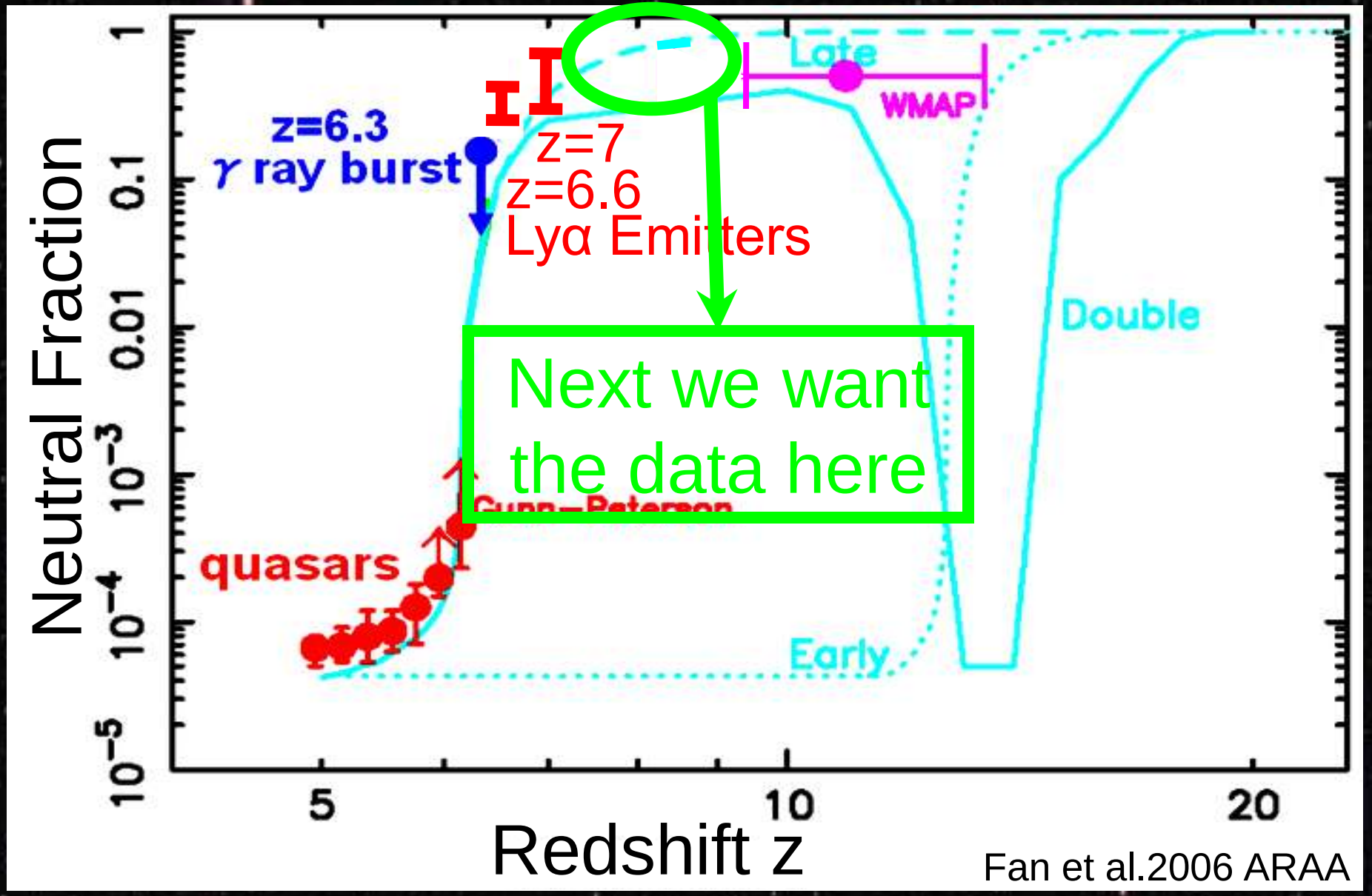
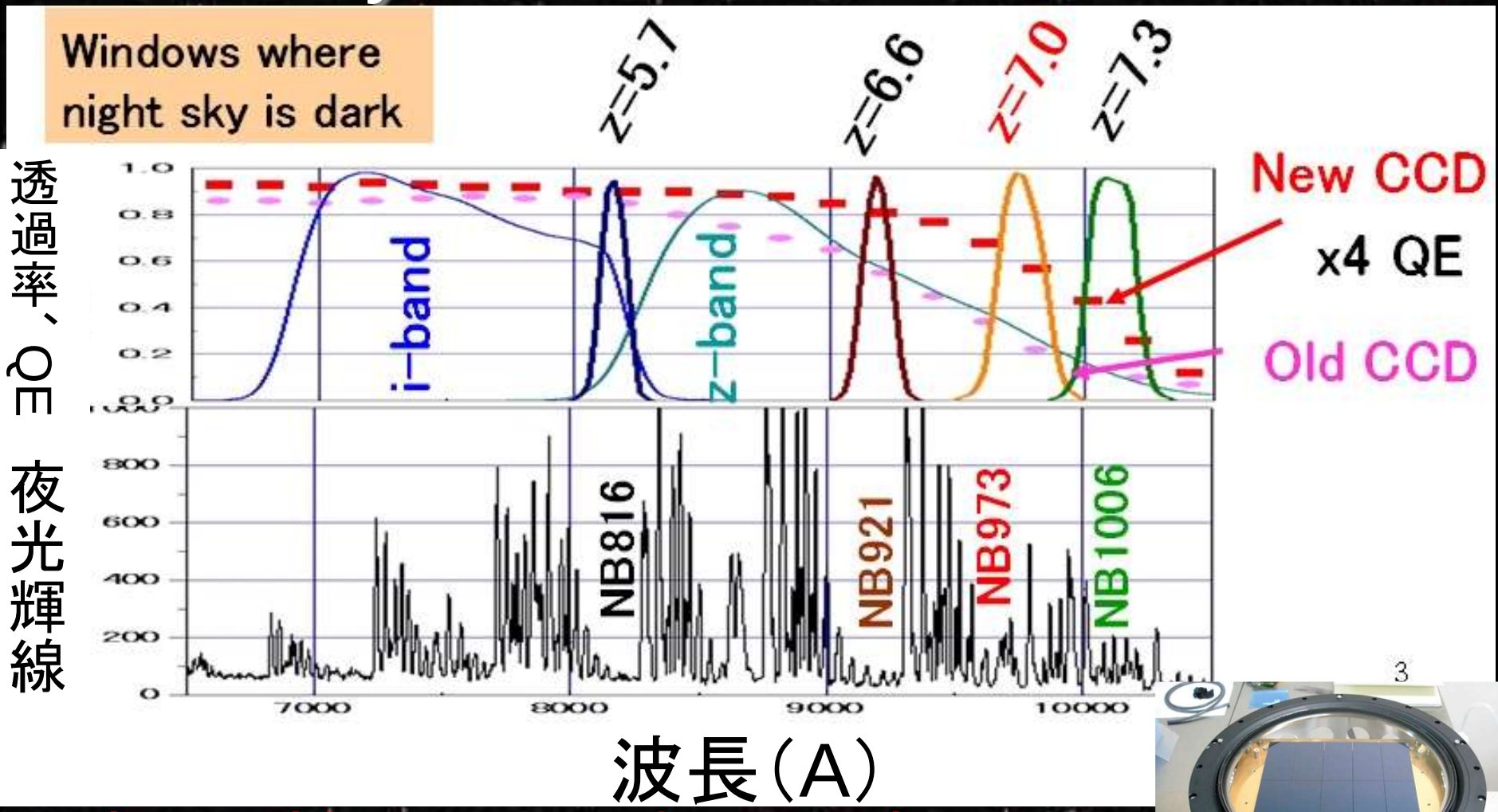
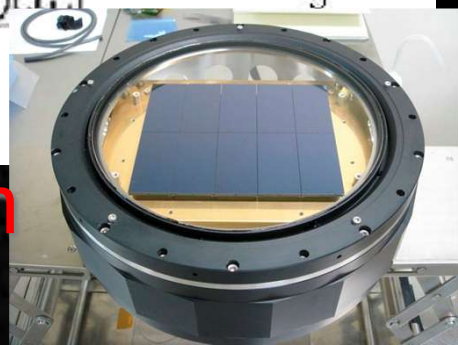
Future Projects



Fan et al.2006 ARAA

Ongoing Project (PI Iye)
z=7.3 Lya Filter + red-sensitive CCD





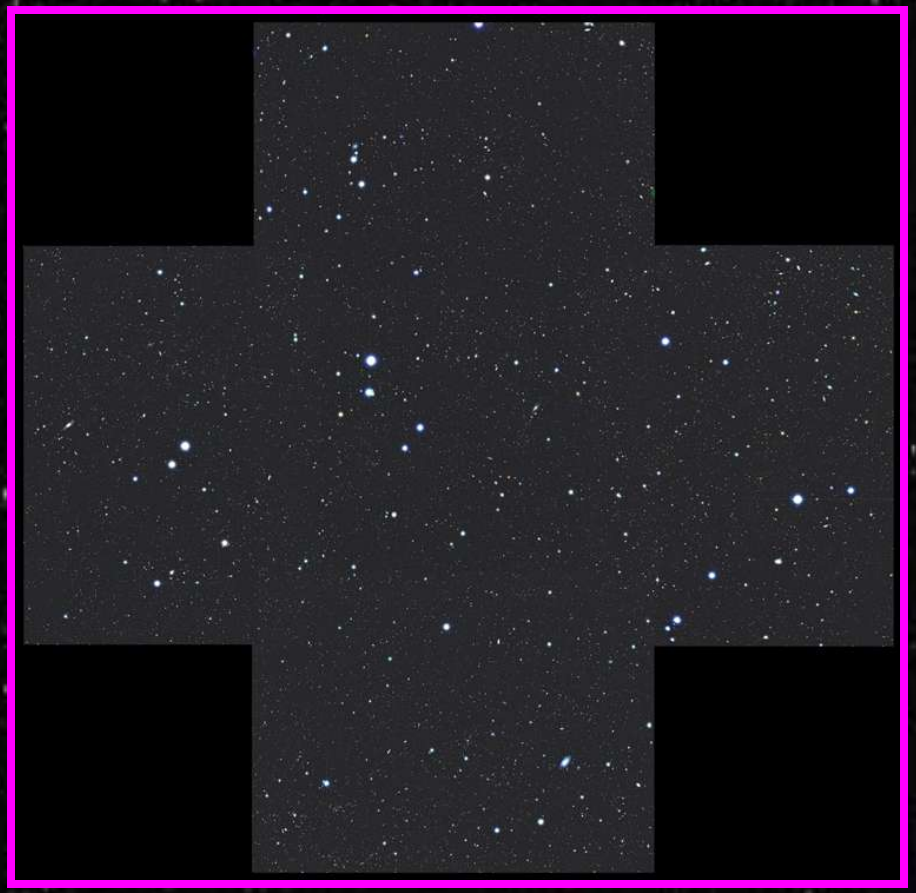
Red-sensitive CCDs for Suprime-Cam

QE @ 1μm ~ 0.422

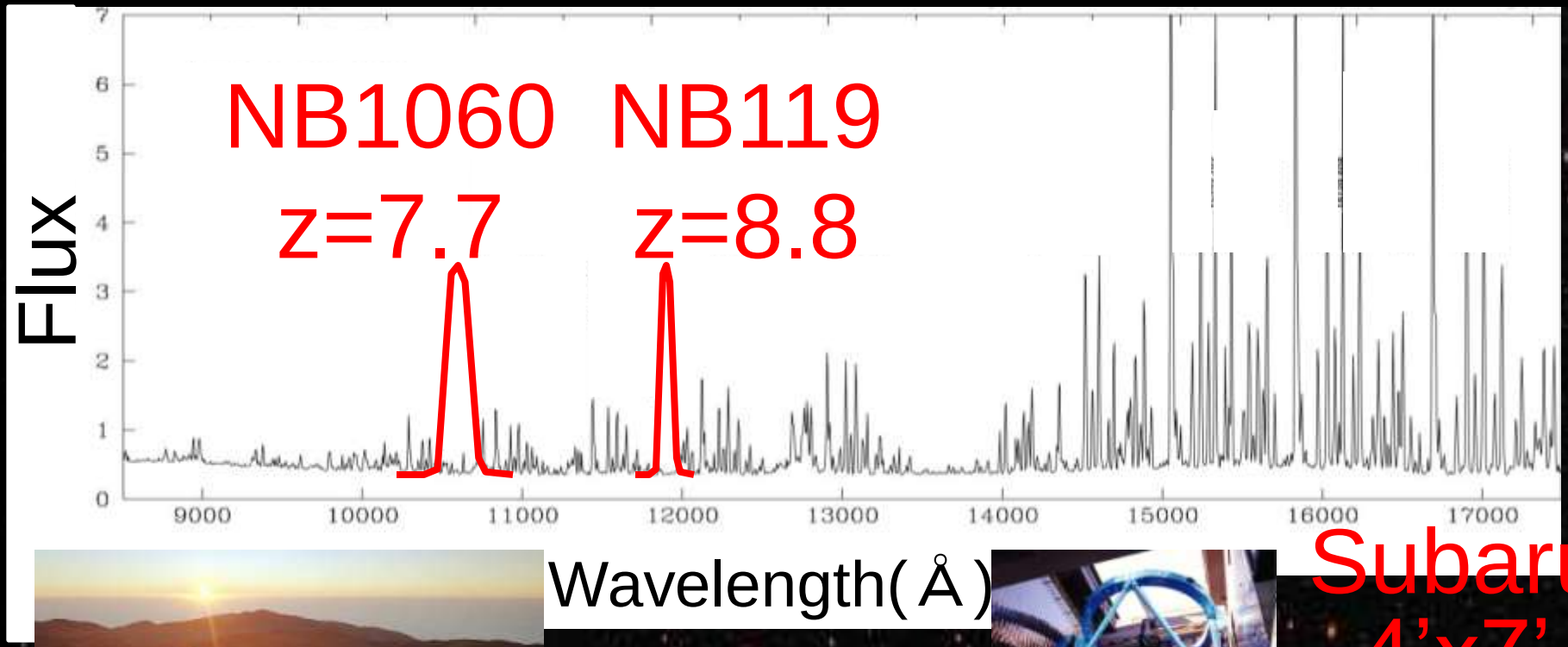
z=7.3 Lya emitter survey

2009 Feb, April
Subaru Deep Field
17hr Imaging
Analysis in Progress

2009 October
Subaru/XMM Deep Field
16hr imaging
Observation Scehduled



Future Projects: We submitted proposals, but ….



VLT
7.’5x7.’5
Hawk-I

Subaru
4’x7’
MOIRCS

8 gravitational lensing clusters, magnification μ～1-5mag target depth: NB～25-30mag

Hubble ACS: Optical g, r, i, z～27-28mag

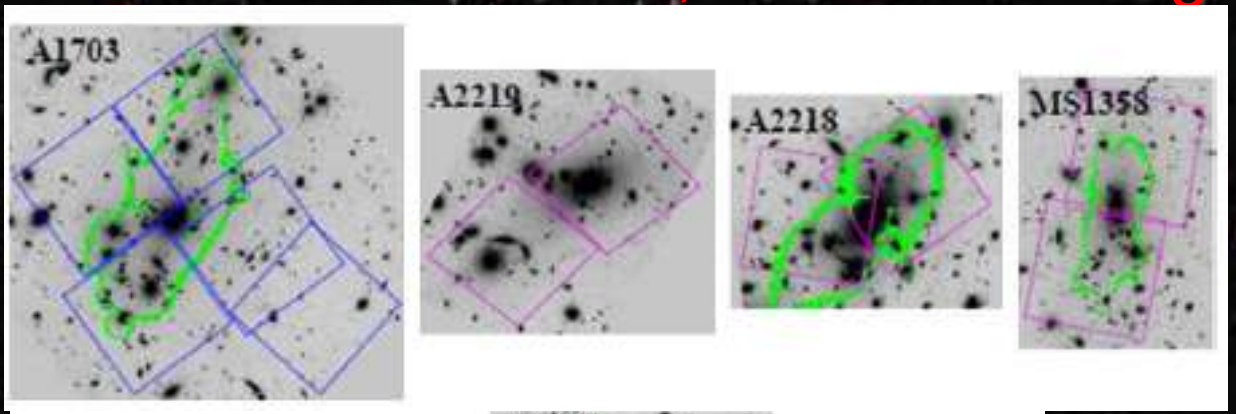
Hubble NICMOS: Near-infrared J,H～26-27mag

Spitzer IRAC: Mid-infrared 3.6, 4.5um～24mag

Hubble

Spitzer

Optical to Mid-infrared



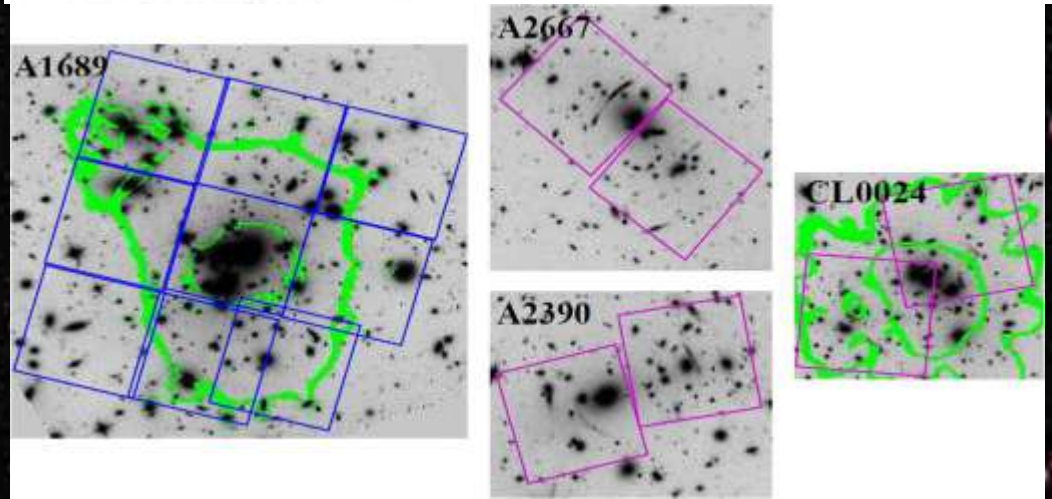


Fig: Bouwens et al.(2008)