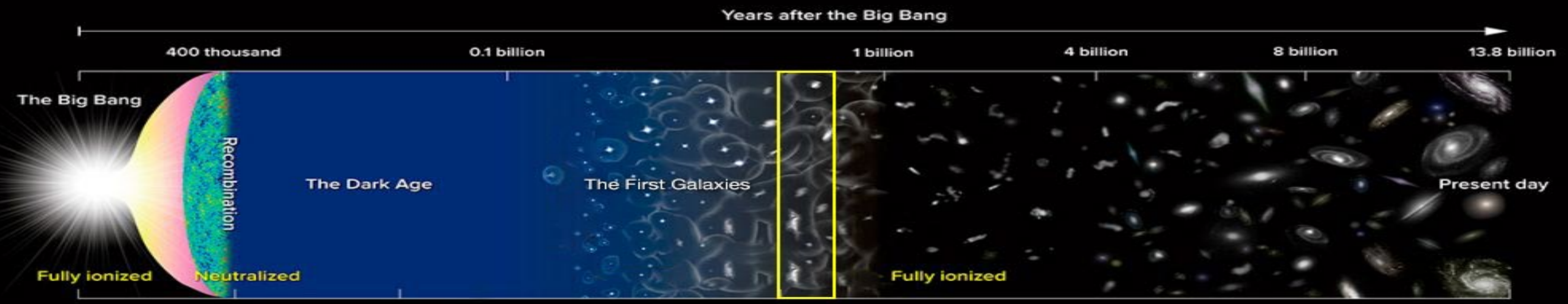
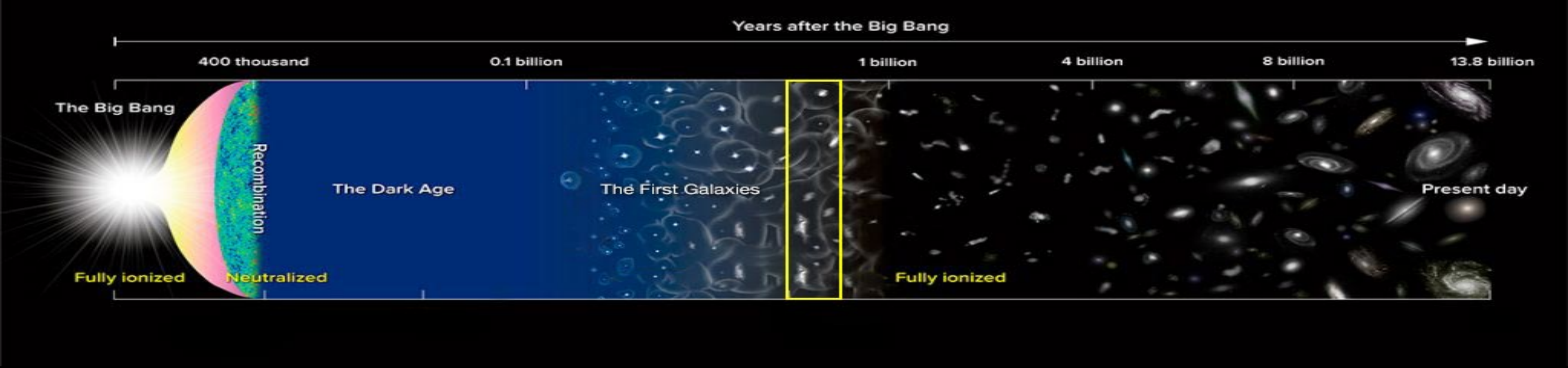


Probing Cosmic Reionization at z~7 with Lya Galaxies from the LAGER Survey

LAGER: Lyman Alpha Galaxies in the Epoch of Reionization

Zhenya ZHENG
Shanghai Astronomical Observatory

On behalf of the LAGER Team



Lyman Alpha Galaxies in the Epoch of Reionization (LAGER)

CHINA

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Steven Finkelstein (U. Texas), …

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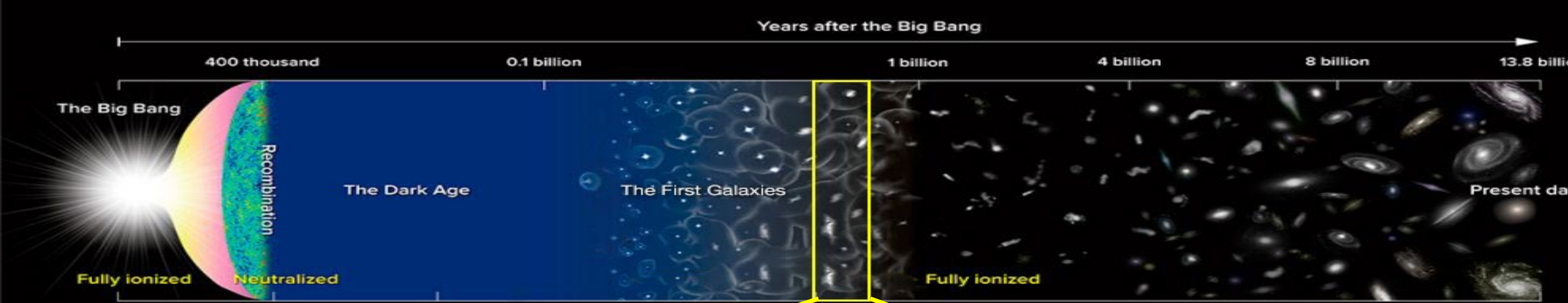
Felipe Barrientos (PUC),
Huan Yang (LCO),
Pascale Hibon (ESO),
Gaspar Galaz (PUC),
Franz Bauer (PUC), …



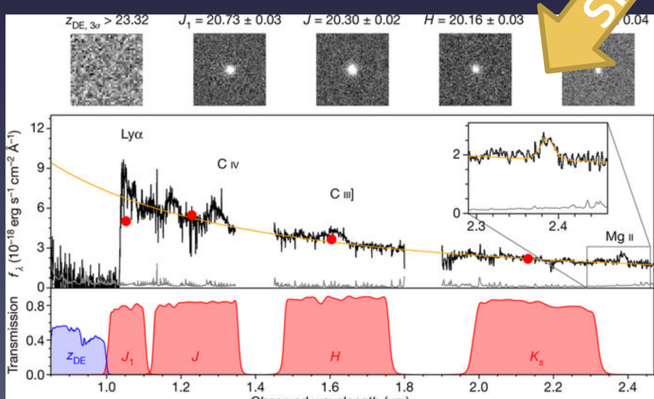
Epoch of Reionization

1. Reionization History
2. Topology
3. Contributing Sources

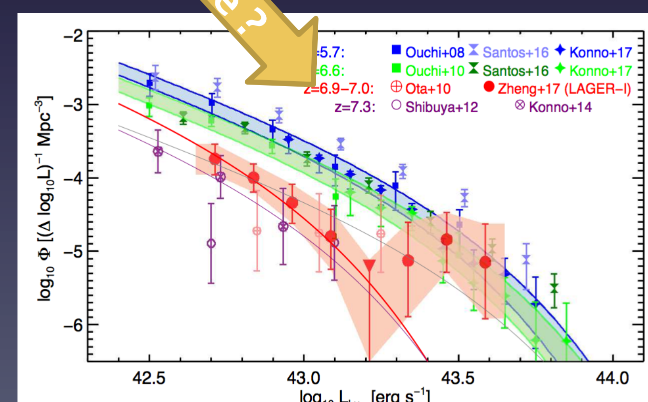
SMBH

Bubble ?

Banados+2017,
J1342+0928, z=7.54



Zheng+2017, z=6.94
Bright-end Excess
LAGER-COSMOS



Quasars,
GRBs,
Galaxies,
21cm signals,
CMB.

Zhenya Zheng @ SHAO

Image credit: Top: NAOJ;
Middle: Robin Dienel & Carnegie Obs.

Probing Reionization with High-z Galaxies

- **Lyman-α luminosity function (LF) test**

  (Rhoads & Malhotra 2001, Malhotra & Rhoads 2004, Ouchi+2010, Kashikawa+2011, Konno+2014, Ota+2017, Zheng+2017, Konno+2017)

- **Lyman-α visibility test**

  (On LBGs, e.g., Stark et al. 2011, Schenker+14, Bian+2014, Tilvi+2016, etc.; On Lya EW distribution of LAEs, e.g., Choudhury+2015, Kakiichi+2016)

- **Clustering test of Lyman-α galaxies**

  (Theory: Furlanetto+2006, McQuinn+2007, Jensen+2013; Observation: Ouchi+2010, Ouchi+2017)

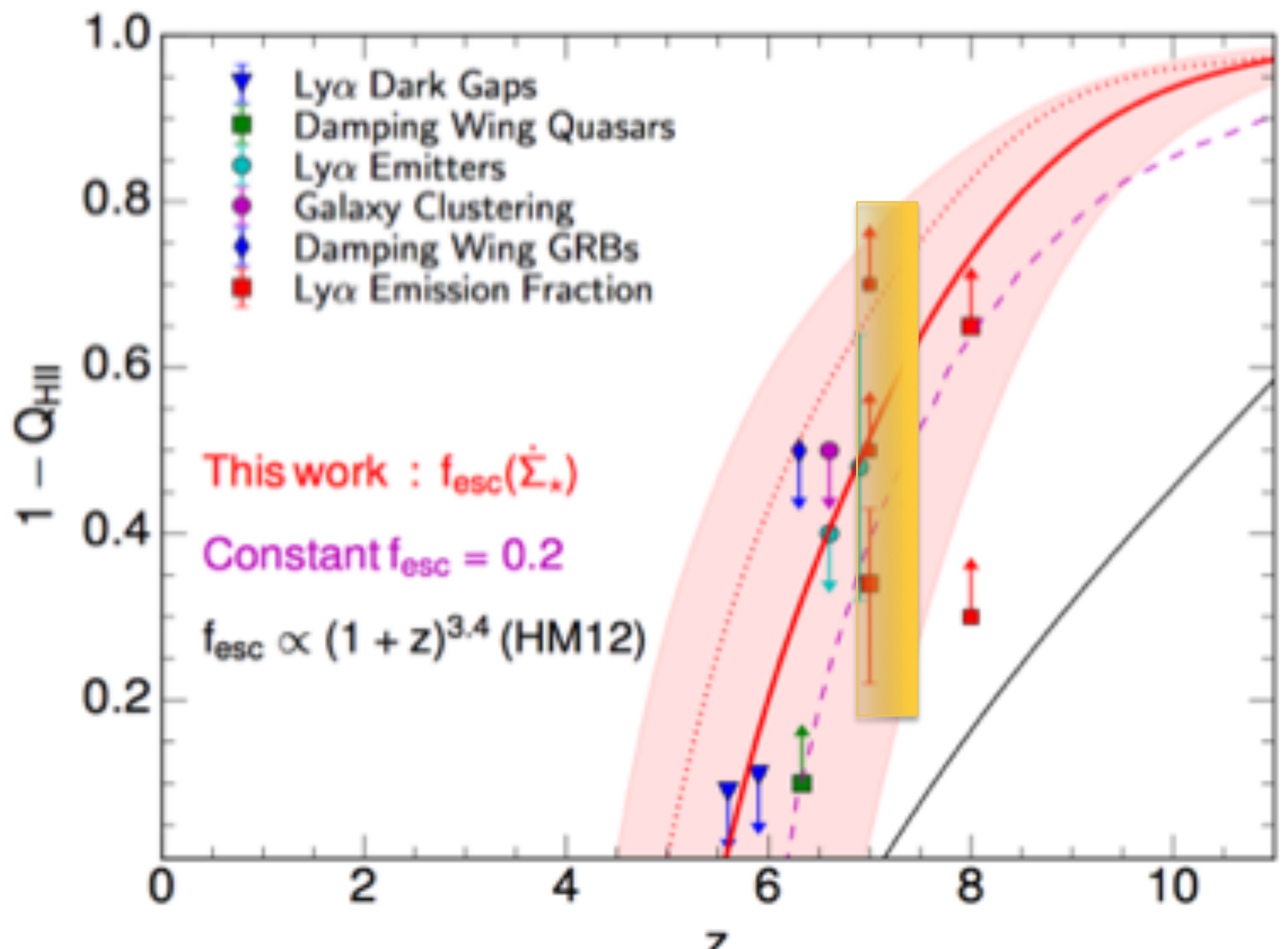
- **Volume test** (Malhotra & Rhoads 2006, 2018)

- **GRB & QSO spectroscopy at z>6**

  (e.g., Salvaterra+2015, Banados+2017)

Image Credit: Jón Pálmason

Global History of Reionization



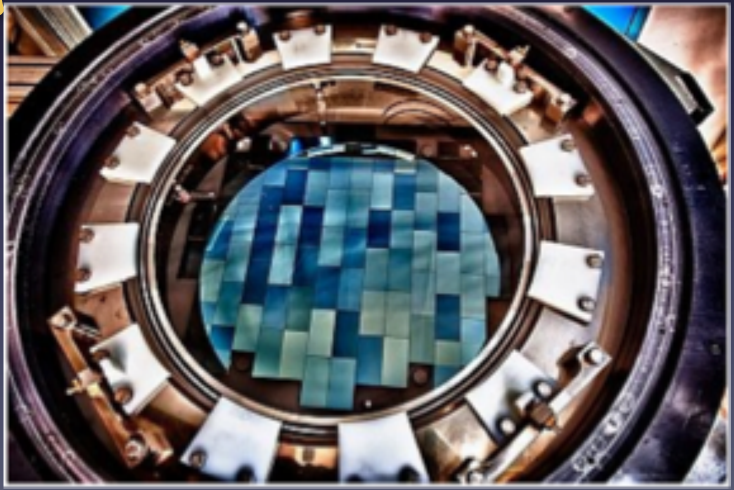
Sharma+16, Robertson+15, Mitra+15, Bouwens+15, Kakiichi+16, Greig & Mesinger17 ...

The LAGER Project:

NB964 Narrowband Filter

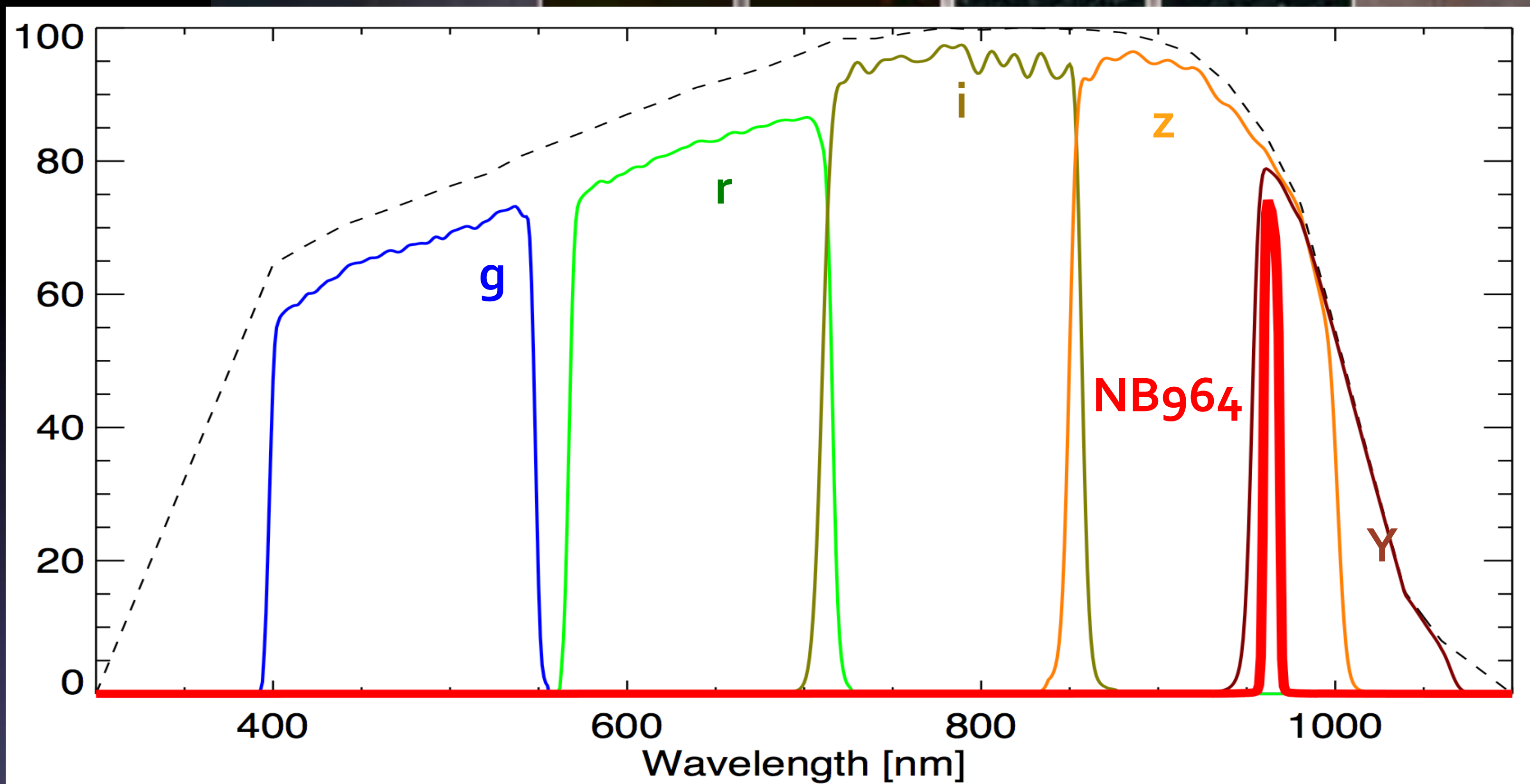
Wc = 9642 Å & FWHM = 92 Å
→ z(Ly-a) = 6.93+/-0.04

CTIO 4m Blanco Telescope
(Cerro Tololo, Chile)

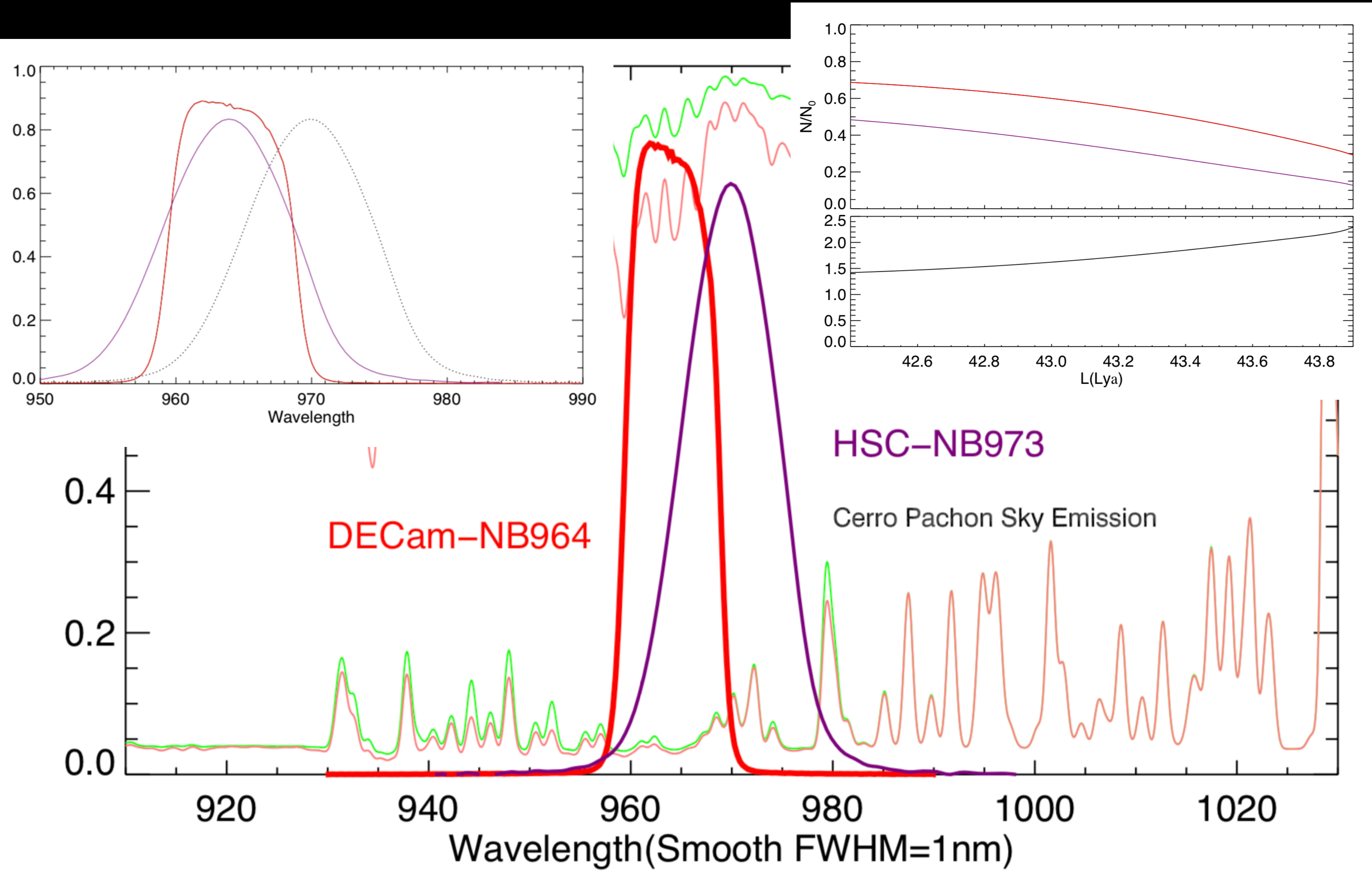


Dark Energy Camera DECam
(FOV = 3 sq-deg)

Why DECam?



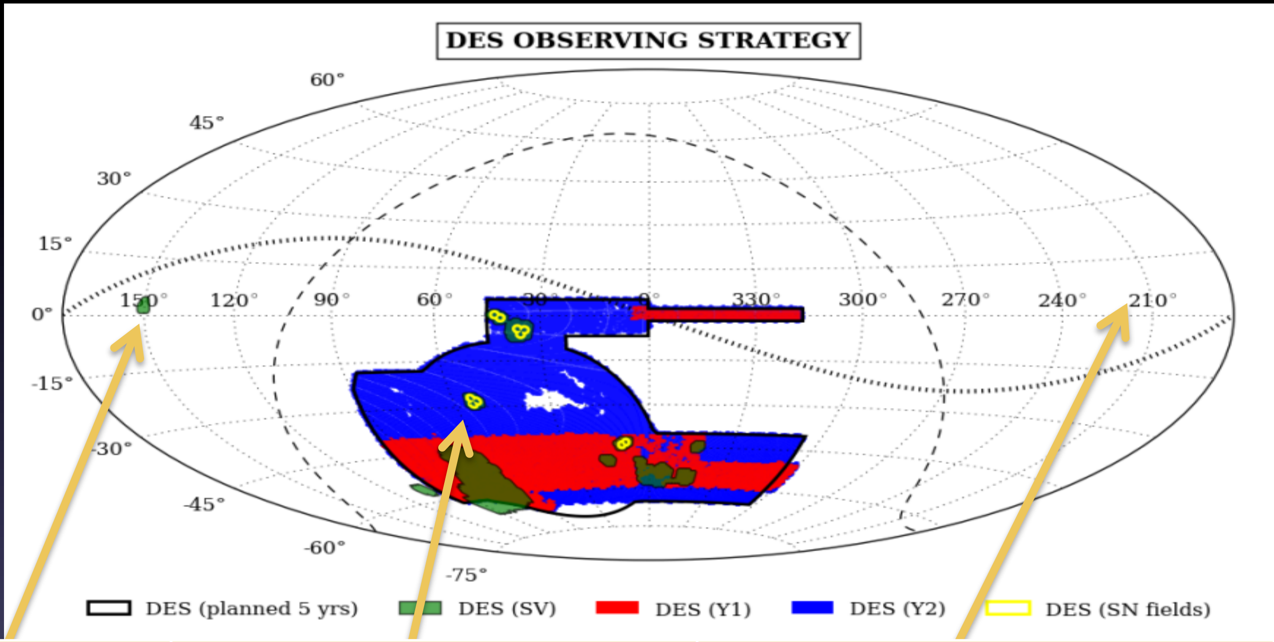
NB964 Filter Profile vs. Sky Lines



LAGER Runs

Summary (2015 Dec. – 2018 Mar.):

- **21 nights** awarded & Observed with DECam & NB964, but 5 with bad weather.
- **4 fields** with NB964 T_exp ~ **20-40 hrs each**.



Fields	COSMOS	CDF-S	GAMA15a,b
NB Exp. T	44 hrs	35 hrs	20 hrs x 2
Date Obs.	Dec. 7 15; Feb. 4-9 16; Mar. 9-12 16; Dec. 24-27 17	Dec. 7 15; Mar. 9-12 16; Nov. 25-26 16	May 24-29 17 (w. bad weather); Mar. 5-10 18

First results from LAGER:

LAGER-COSMOS in 34 hrs NB964

Inhomogeneous Distribution of

23 z~7 LAEs in LAGER-COSMOS:

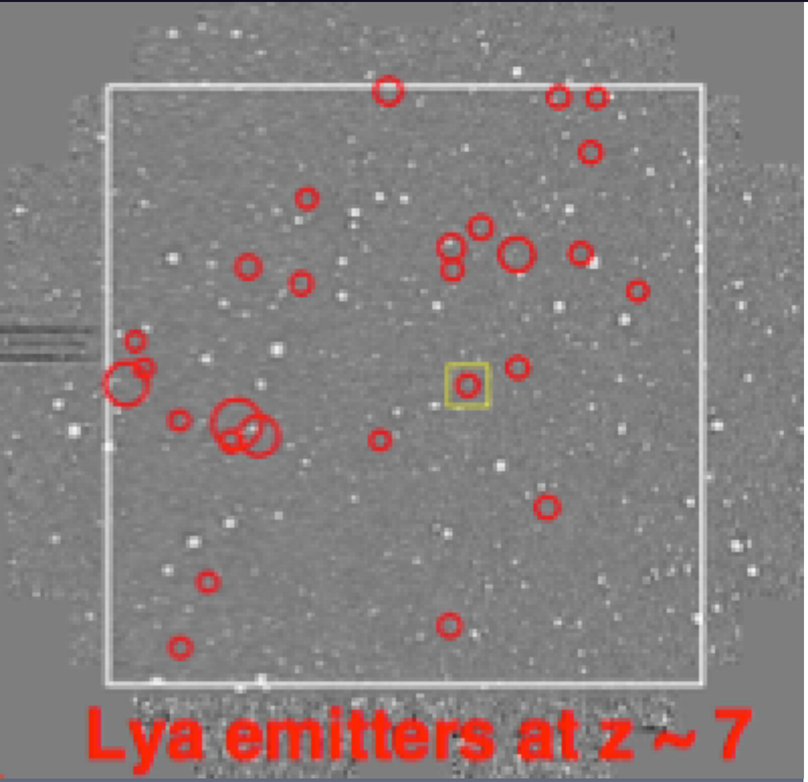
Patchy Reionization?

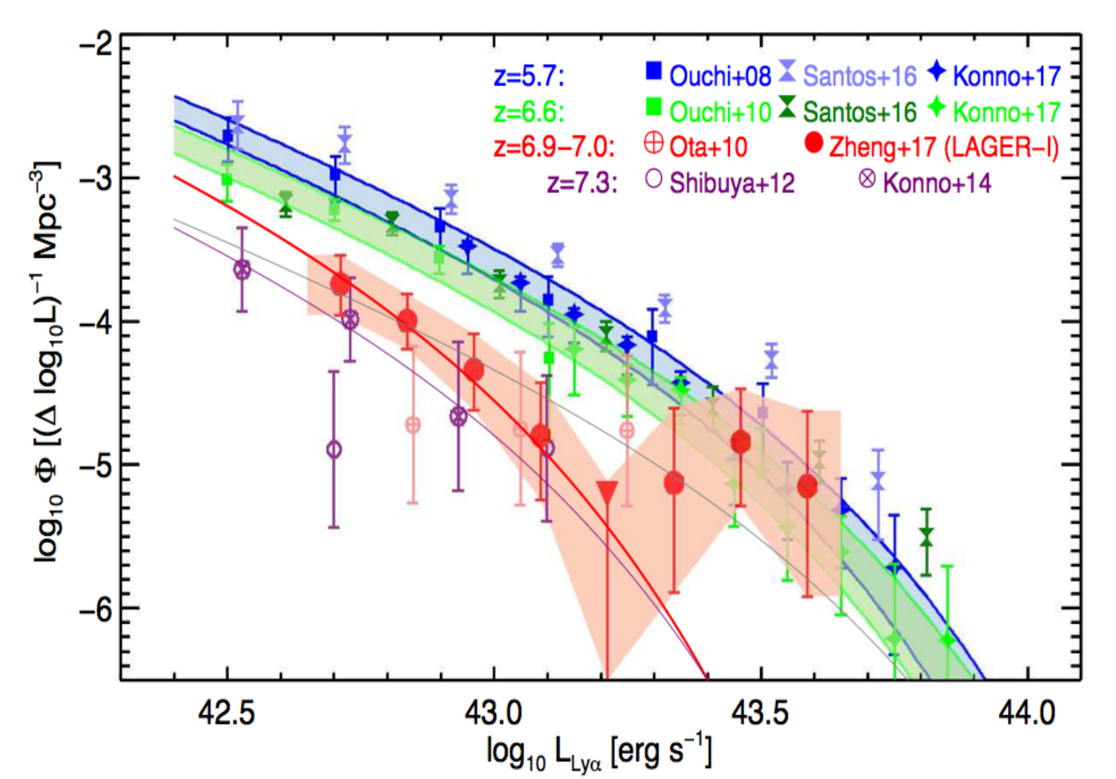
- Little Evolution of Lya LF at z ~ 3-6 :

(Ouchi+08, Faisst+2014, Zheng+2016, ..)

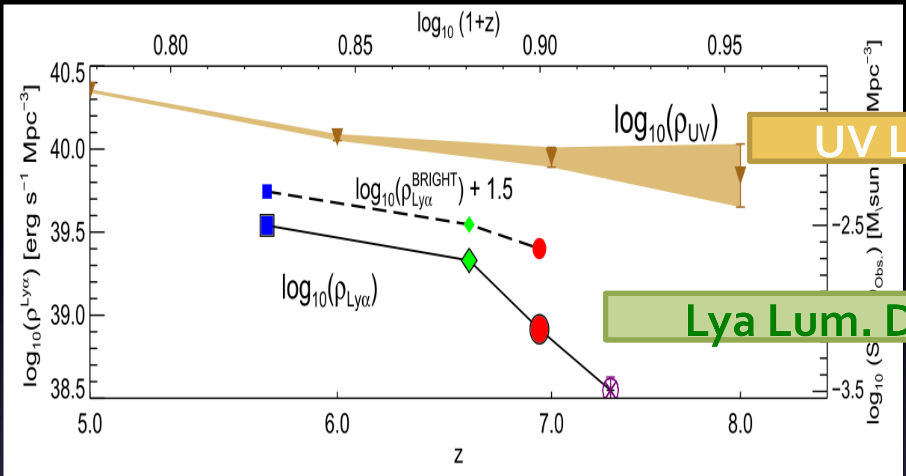
At z~7 (Zheng+2017) :

1. **Different Evolution at Bright & Faint Ends.**
2. **Bright-End Excess.**





1. Probing IGM Neutral Fraction at z~7

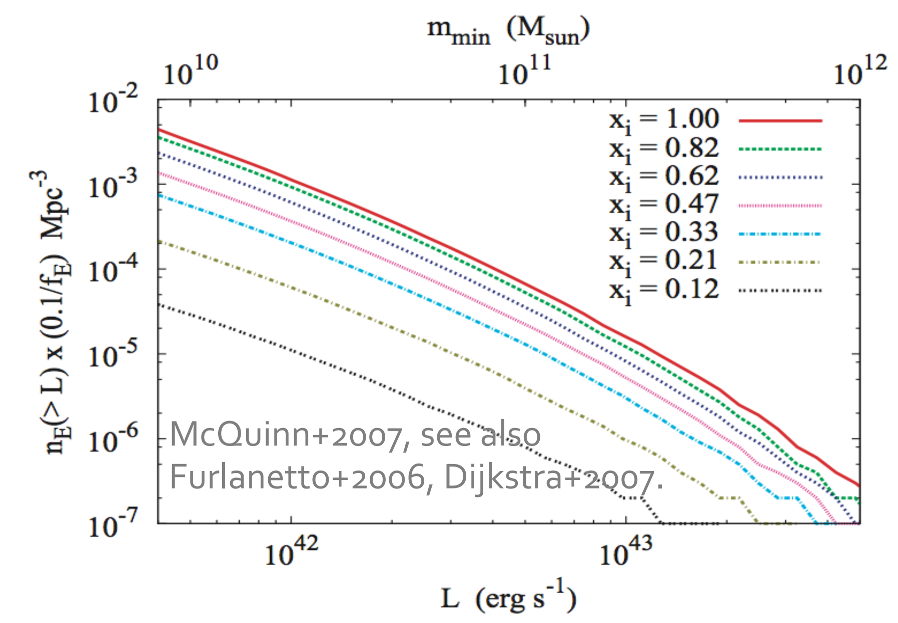


UV Lum. D.

UV LD represents the Galaxy Evolution

Lya Lum. Density

Lya LD represents the joint effect of
1) Galaxy Evolution &
2) resonant scattering by neutral IGM.

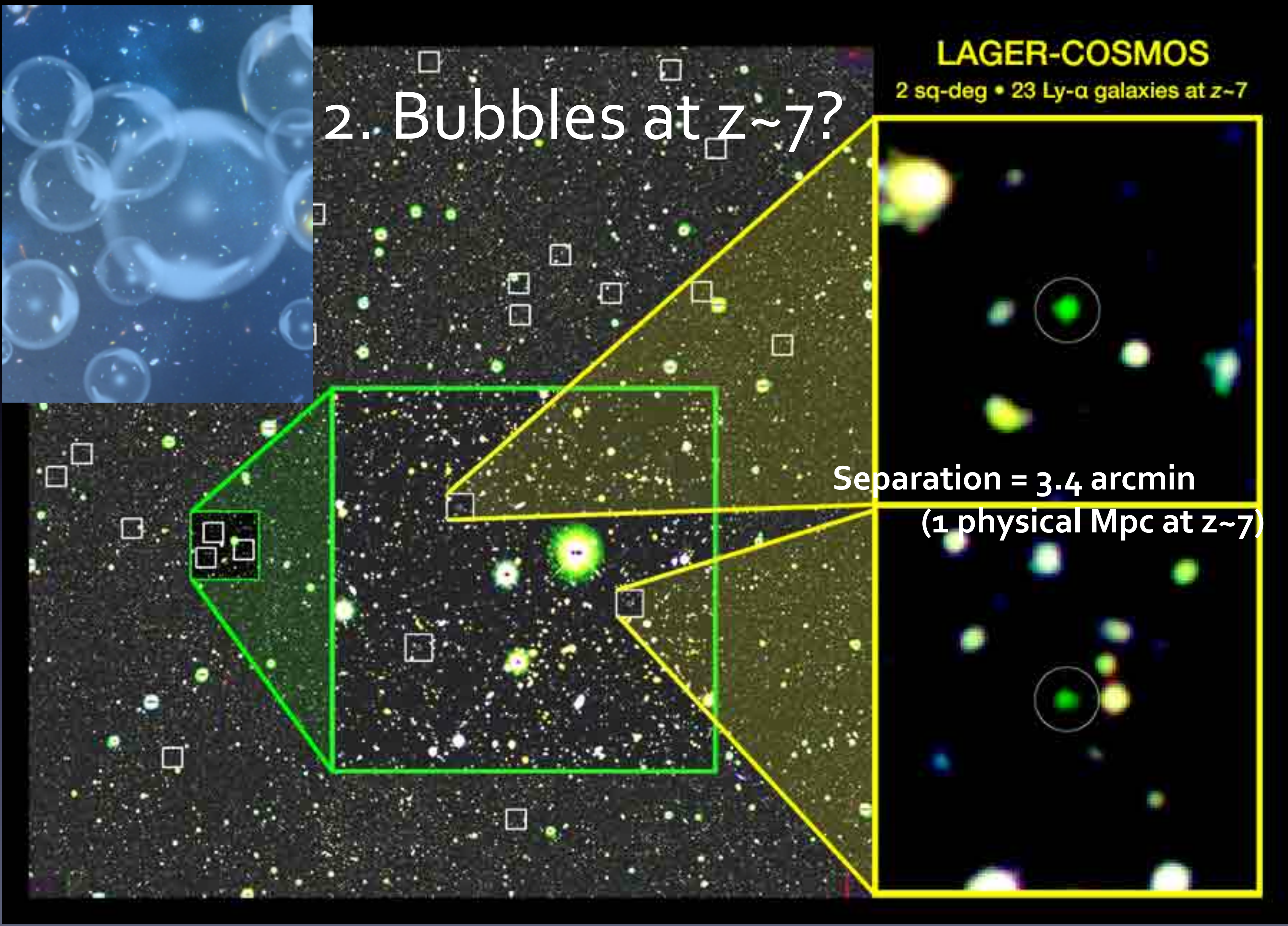


IGM Transmission factor T':
(UV from Finkelstein+15)

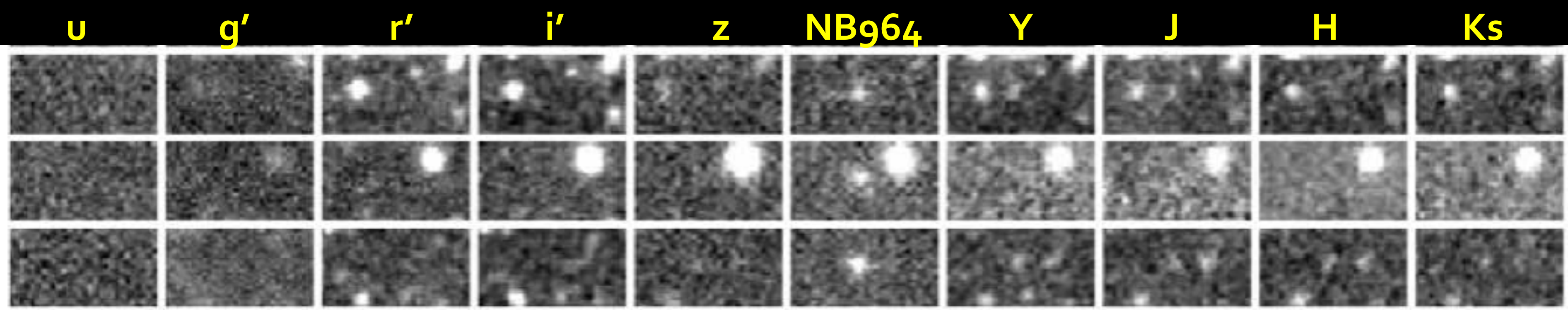
$$T'_{z=6.9} = \frac{T^{\rm IGM}_{Ly\alpha,z=6.9}}{T^{\rm IGM}_{Ly\alpha,z=5.7}} = \frac{\rho^{Ly\alpha,tot}_{z=6.9}/\rho^{Ly\alpha,tot}_{z=5.7}}{\rho^{\rm UV}_{z=6.9}/\rho^{\rm UV}_{z=5.7}}.$$

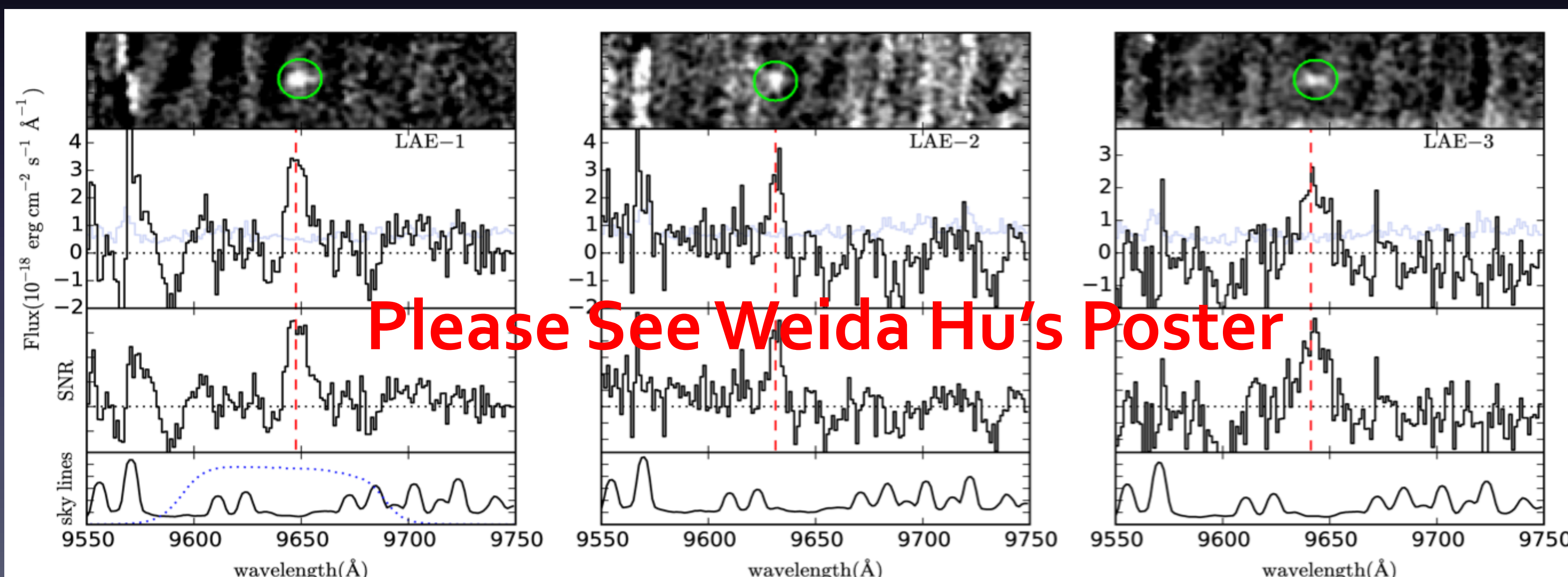
T' = 0.37 ➔
x_HI ~ 0.4-0.6 at z~7

2. Bubbles at z~7?



Spec. Confirmation of the 3 Brightest LAEs



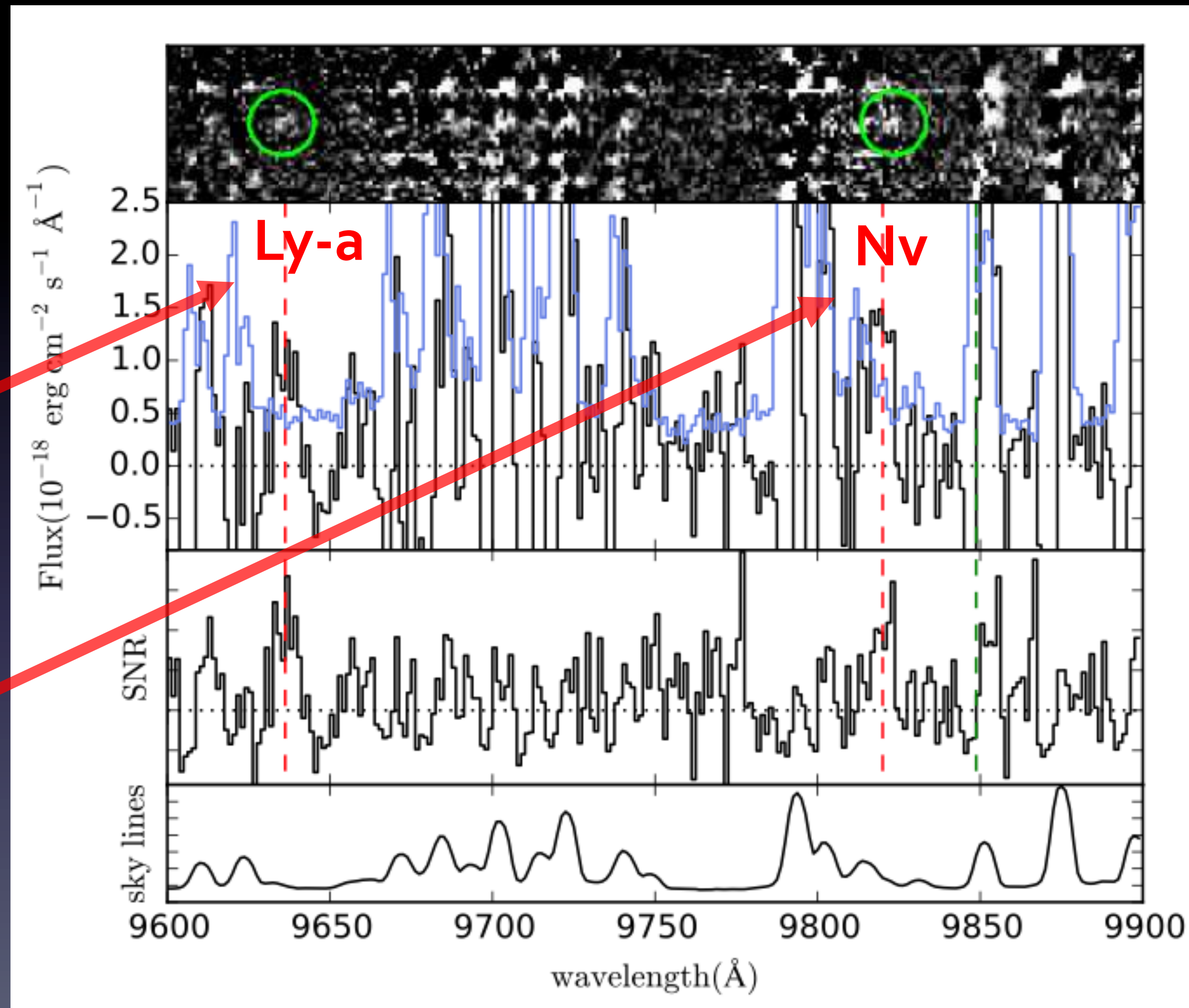


Please See Weida Hu's Poster

6 hrs Magellan/IMACS obs. on Feb 6-8, 2017 (**FWHM~200-300 km/s**)

Hu et al., 2017, ApJL, 845, L16 (arXiv:1706.03586).

A faint-AGN at z~7 ?



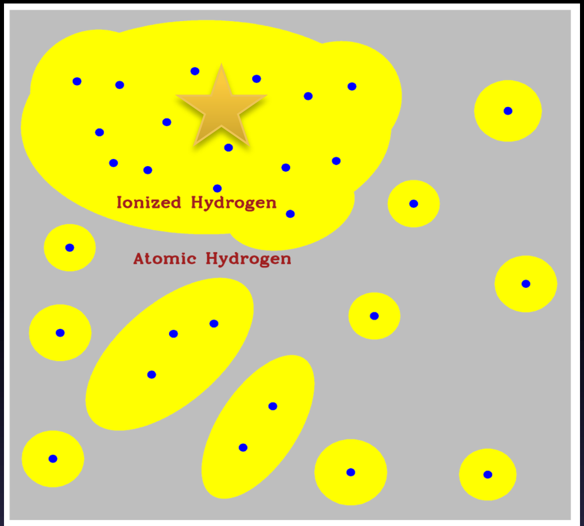
6 hrs Magellan/IMACS obs. on Feb 6-8, 2017 (**FWHM~200-300 km/s**)

Hu et al., 2017, ApJL, 845, L16 (arXiv:1706.03586).

Bubbles at z~7?

– A group of galaxies?

- Bright-end excess of UVLF at z~7 (Bowler+2014)
- Bright LAEs from HST grism survey (Bagley+2017)
- HSC Lya LF at z~6.6 (Konno+2017)
- LAGER Lya LF at z~7 (**Zheng+2017**)



– Strong ionizing power?

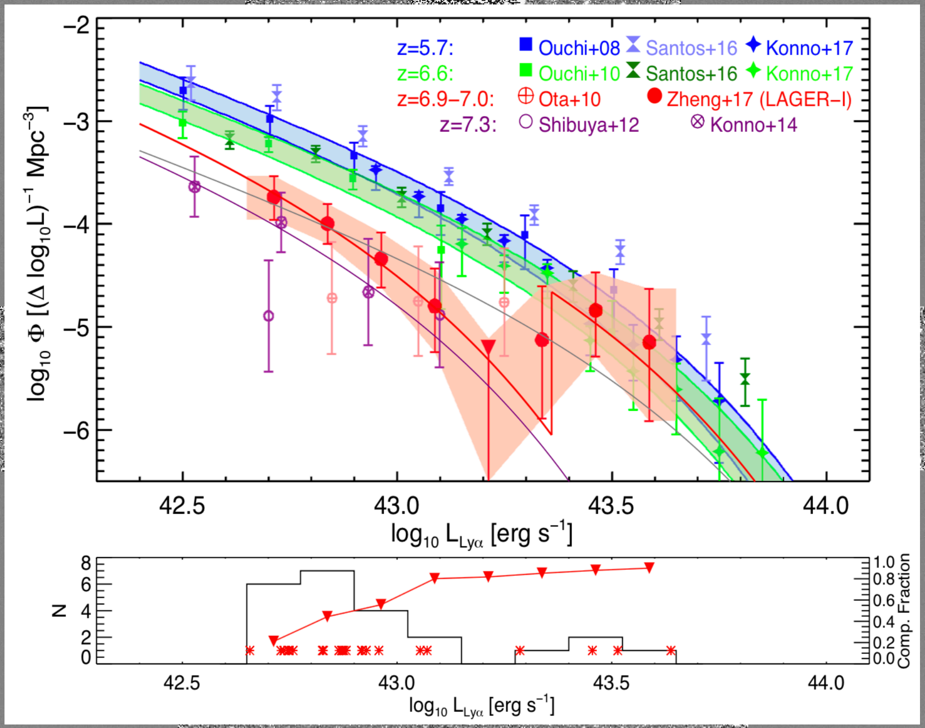
- Faint AGN? (Matsuoka+2016, Jiang+2016, **Hu+2017**)
- PopIII G., Sobral+15; or DCBH, Smith+16. (CR7 is ruled out Shibuya+2017).
- Strong instant SF? (Mainali+2017, high ionized CIV & OIII] at z=6.11.)
- Large velocity offsets for Lya (Willott+2015, Mainali+2017)

We Need: 1. Deeper NB964 Exposure; 2. NIR Spec. Obs. Of z~7 LAEs

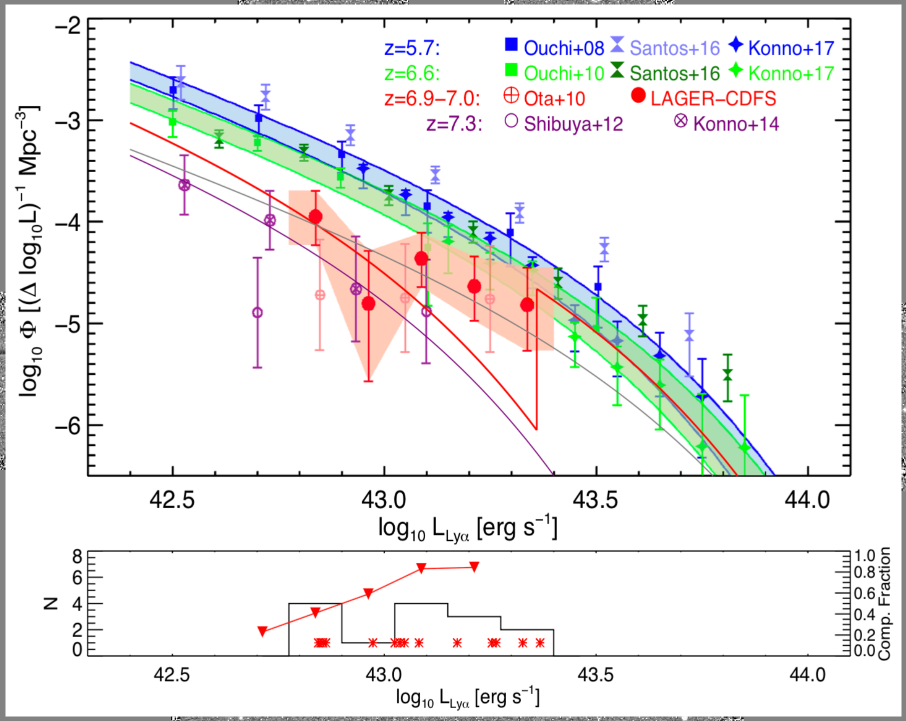
3. Ongoing Process

- More NB964 imaging data
- Improved image stacking methods
- Better & deeper broadband images (HSC & DES)
- Opt. & IR spectroscopic followup (Magellan, VLT, Keck, Gemini, HET)

COSMOS vs. CDFS



Zheng et al. 2017



Preliminary Results

Improve the Lya LF at z~7 and give better constraints on x_{HI}

Probing Reionization with High-z Galaxies

- **Lyman-α luminosity function (LF) test**
  (Rhoads & Malhotra 2001, Malhotra & Rhoads 2004, Ouchi+2010, Kashikawa+2011, Konno+2014, Ota+2017, Zheng+2017, Konno+2017)

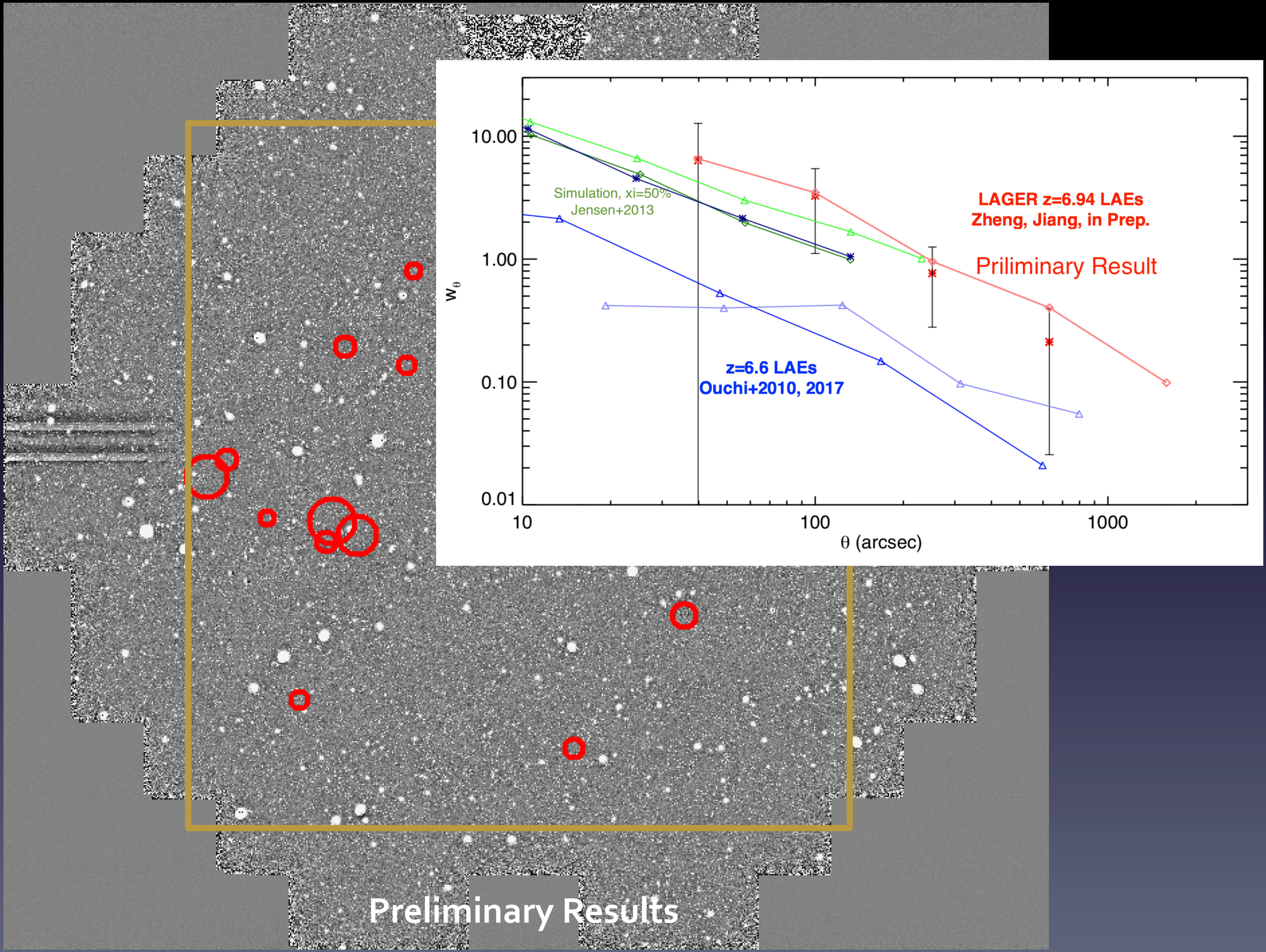
- **Lyman-α visibility test**
  (On LBGs, e.g., Stark et al. 2011, Schenker+14, Bian+2014, Tilvi+2016, etc.; On Lya EW distribution of LAEs, e.g., Choudhury+2015, Kakiichi+2016)

- **Clustering test of Lyman-α galaxies**
  (Theory: Furlanetto+2006, McQuinn+2007, Jensen+2013; Observation: Ouchi+2010, Ouchi+2017)

Need a careful treatment of: 1) faint (and fake) objects; 2) pixel-to-pixel depth on both NB & BB images; and 3) Filter profile.

Image Credit: Jón Pálmason

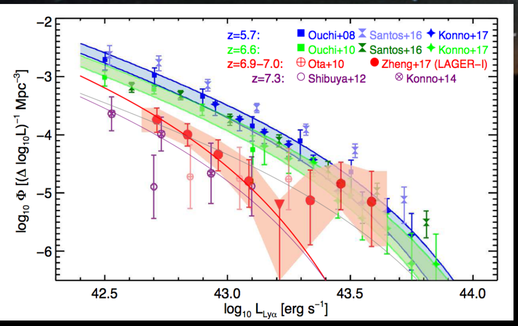
Improved COSMOS Sample



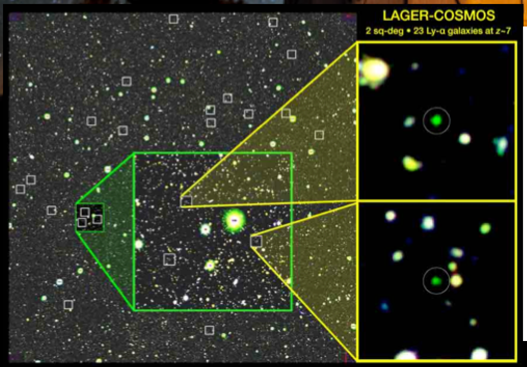
Conclusion

- LAGER is the largest narrowband survey for LAEs at z~7 so far.
- In the first LAGER field (COSMOS), 23 (22 new) candidate LAEs, the largest sample to date of candidate LAEs at z~7, were discovered.
- LAGER helps us to find 4 most luminous LAEs at z~7 , of which 3 were spec. confirmed.
- The new Lya LF from LAGER LAEs shows different evolution at the faint-end and at the bright-end → x_HI ~ 0.4–0.6 and ionized bubbles at z ~ 7.
- More are coming……

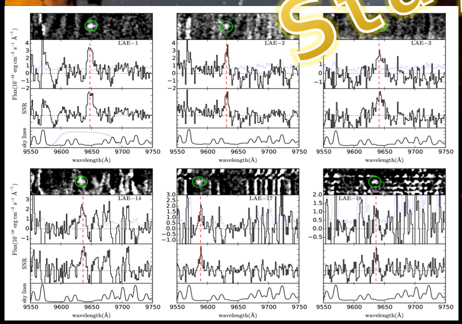
Stay Tuned!



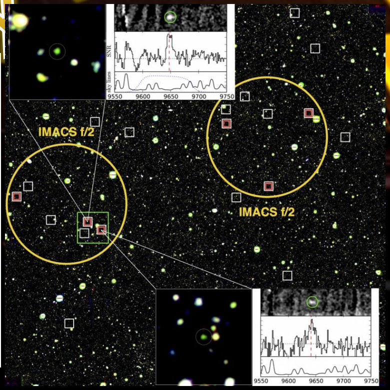
Zheng et al. 2017



NOAO Press Release 1703



Hu et al. 2017

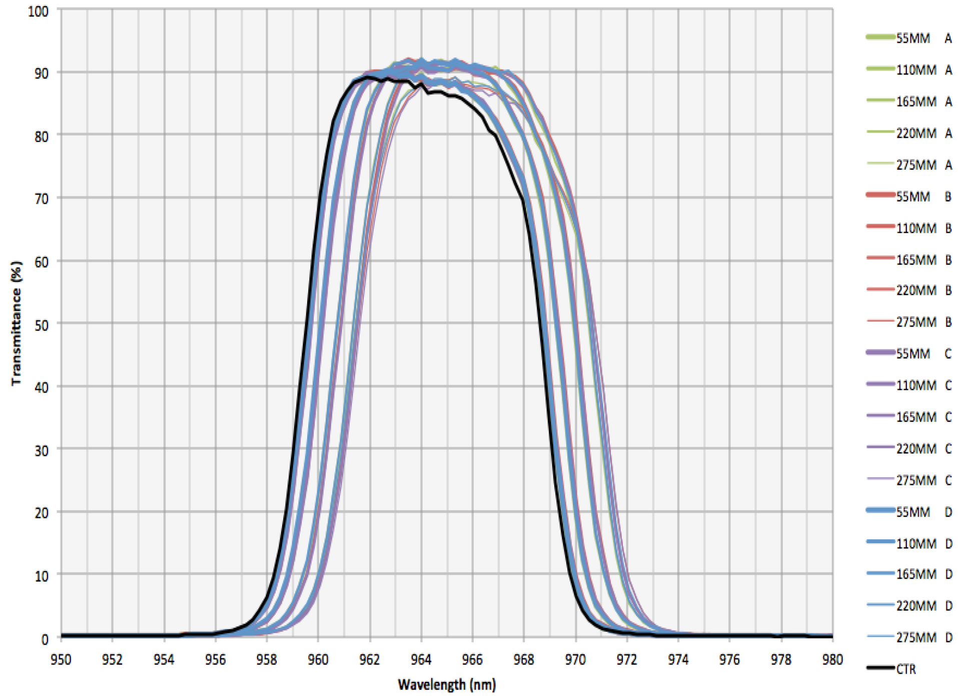


Carnegie Press Release

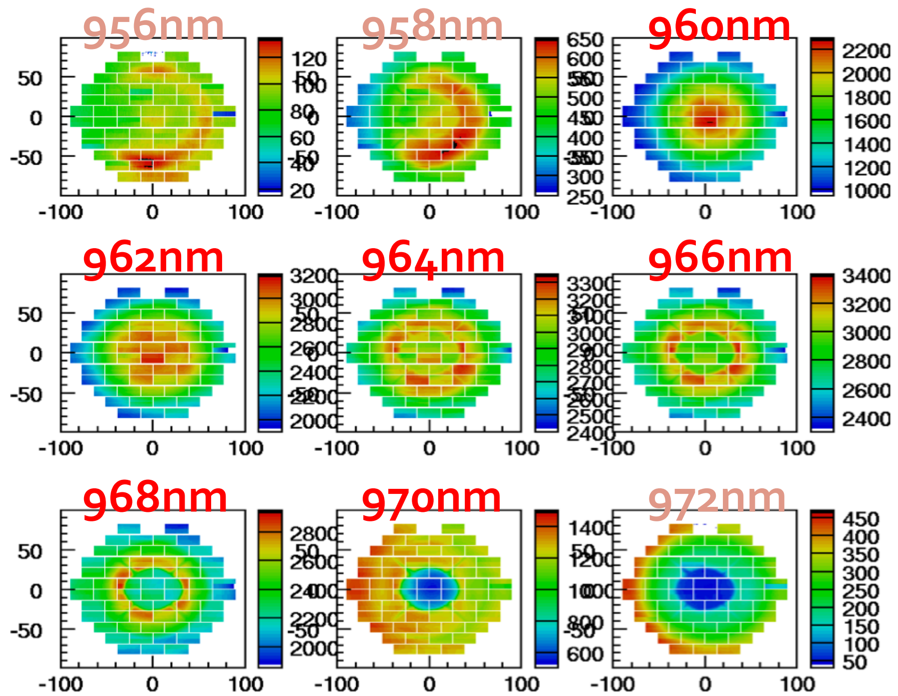
Thank You!

NB964 Filter Performance

1. NB filter lab-test
(Multi-curves for different Radii)



2. NB filter on-site test
(Spatial dist. as a function of λ)



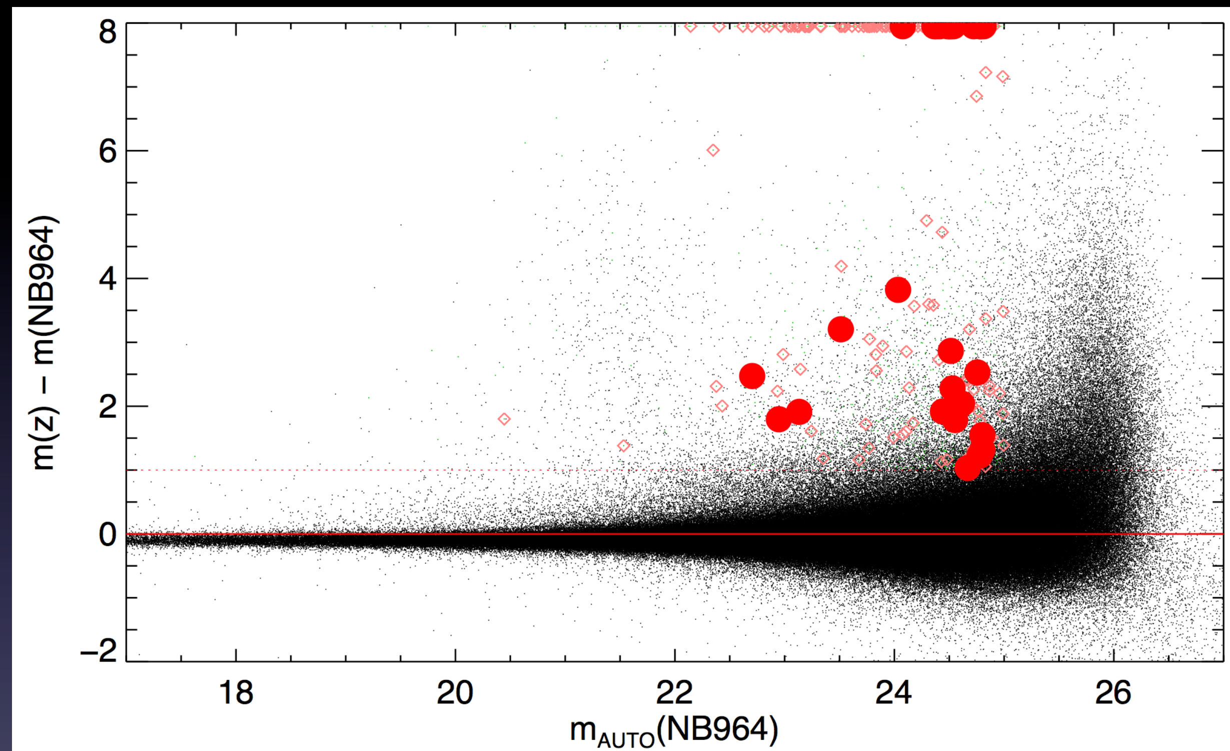
Candidate LAEs at z~7

Selection Criteria:

- Non-Detection in Blue Bands:
  DECam-ugri < 3 σ & Subaru-BVgri < 3 σ & Subaru-NB711, NB816,NB921 < 3 σ
- NB Significant:
  NB964(>5 σ) < 25
- Line Significant:

DECam-z – NB964 >= 1

& EW_r(Lya) > 10 Å

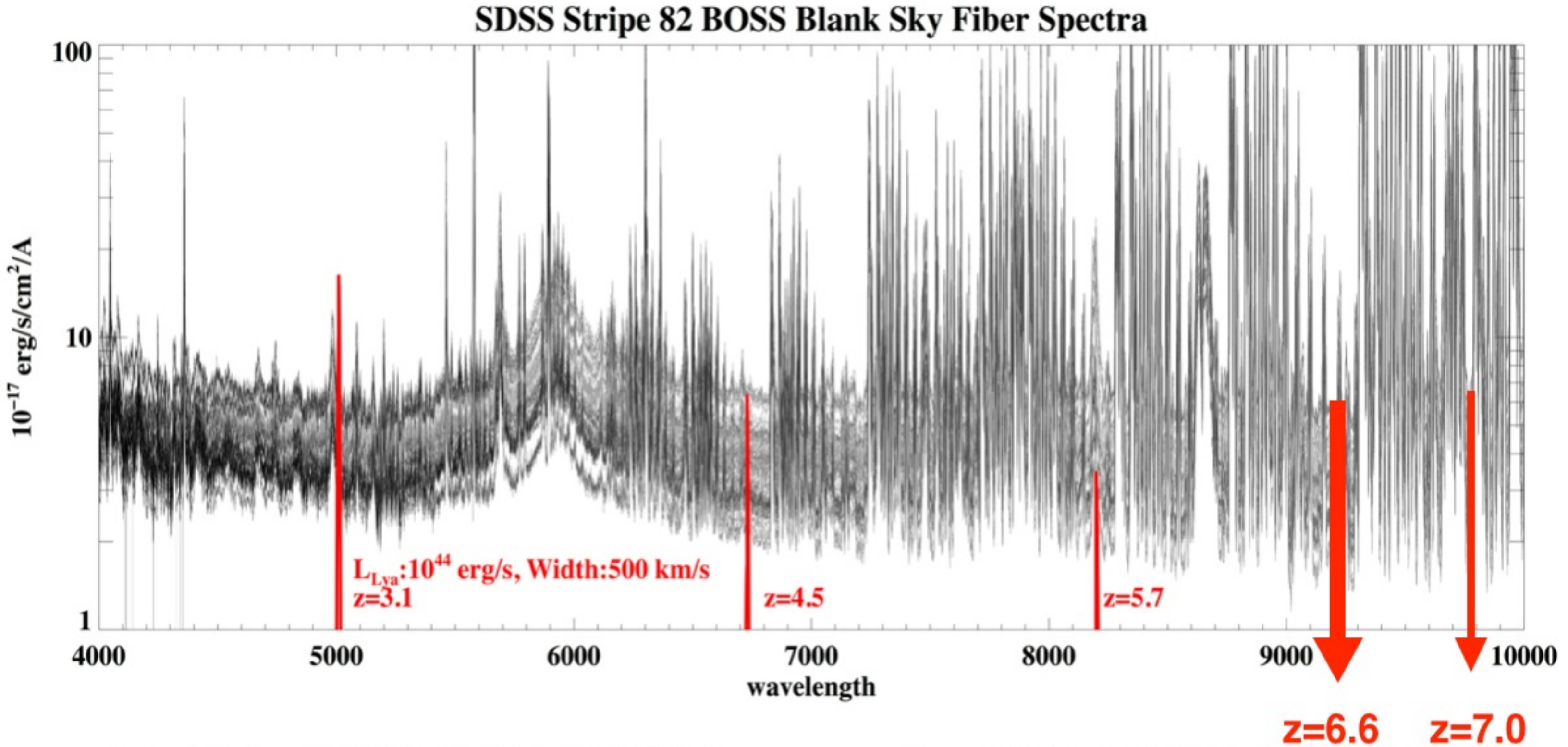


We find 23 (22 new) candidate LAEs at z~7 in the COSMOS field.

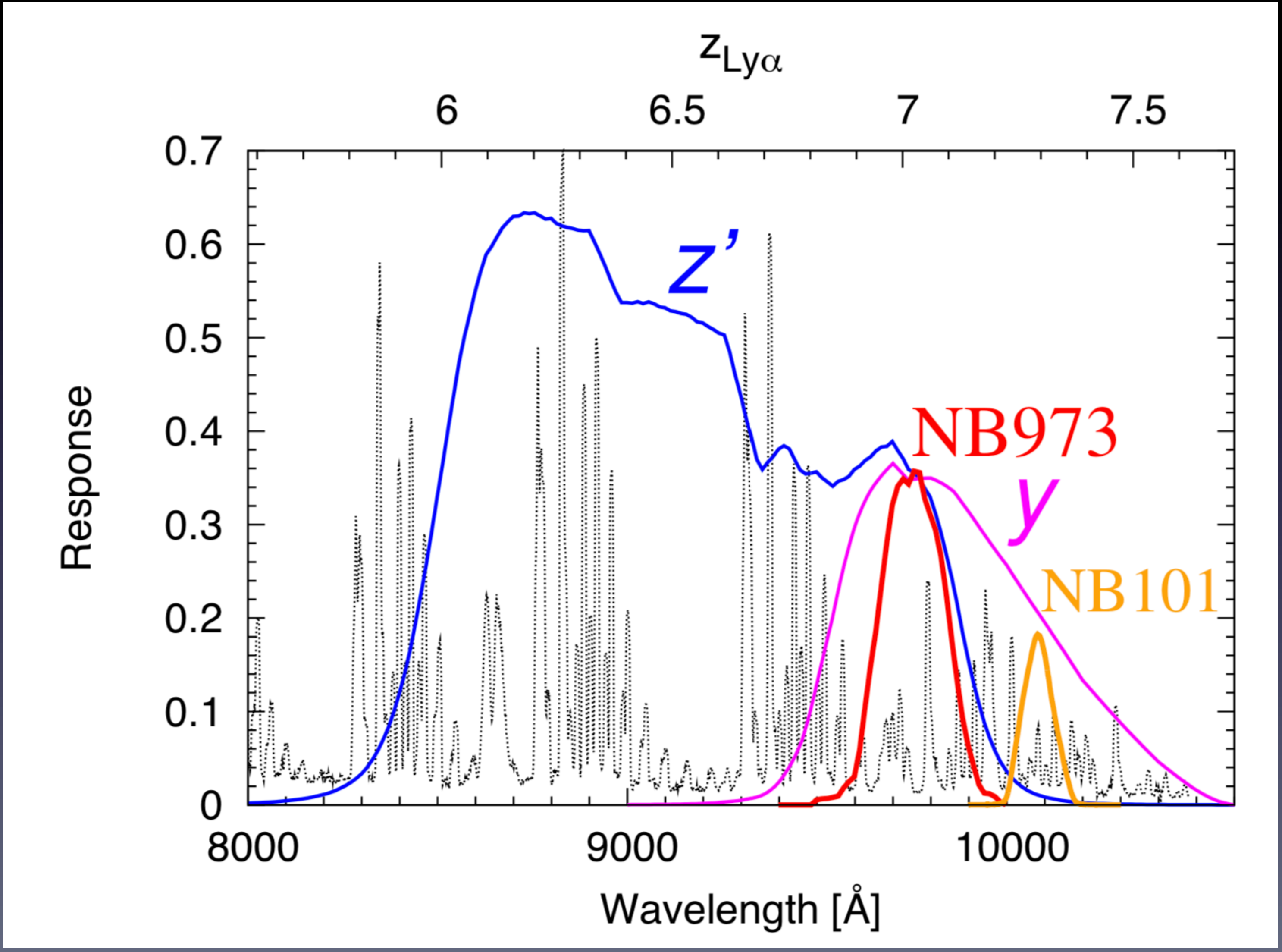
Survey Volume = 1.26 x 10^6 cMpc^3 (>4 V_other_z7)

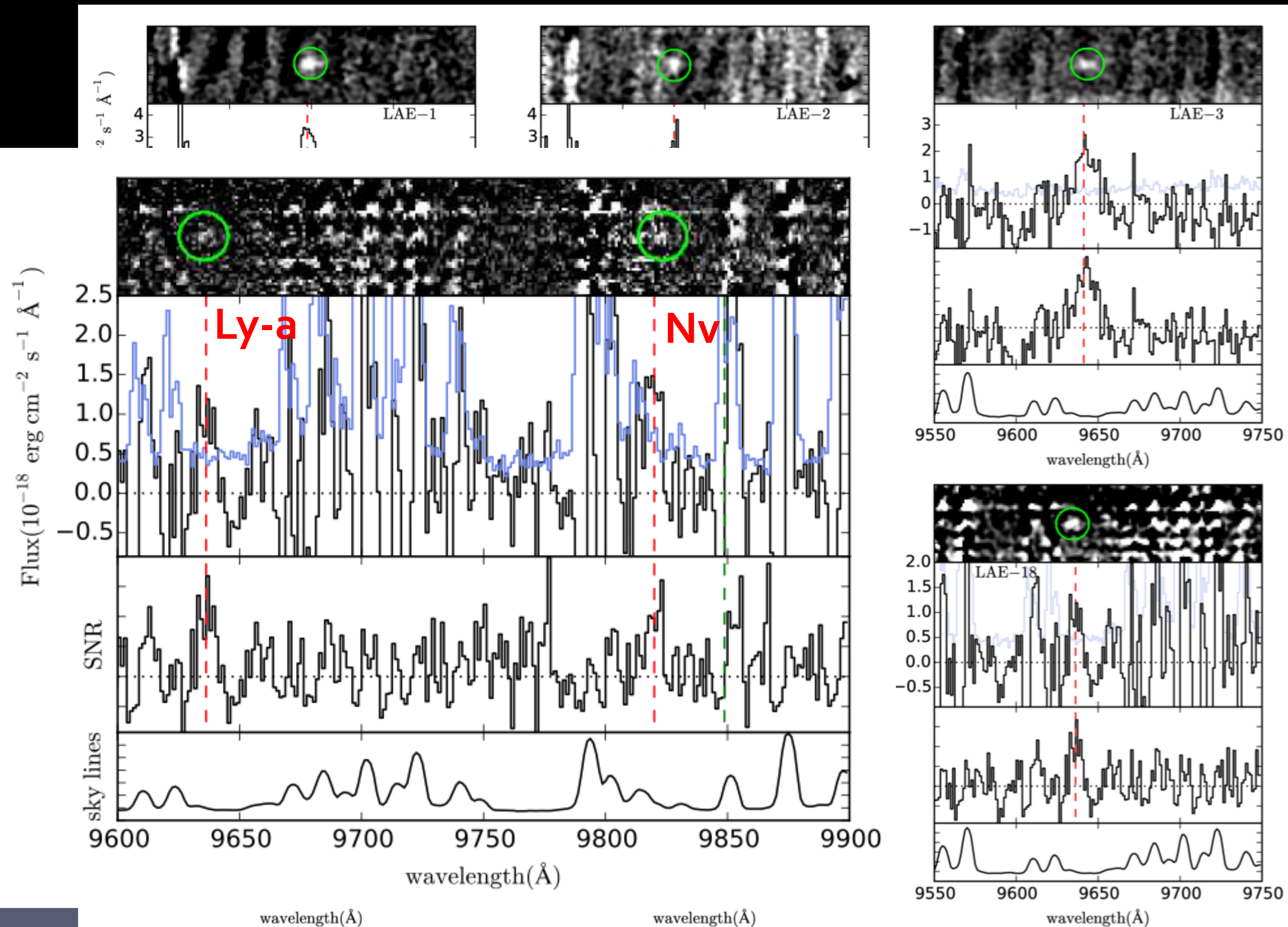
Observational challenges at z >~ 7

Sky Background



Subaru SC NB973 (Ota et al.)





9 targeted, 6 confirmed (successful rate ~ 67%).

Hu et al., 2017, ApJL, 845, L16 (arXiv:1706.03586).