

Progress report of CHORUS (Cosmic Hydrogen Reionization Unveiled with Subaru)

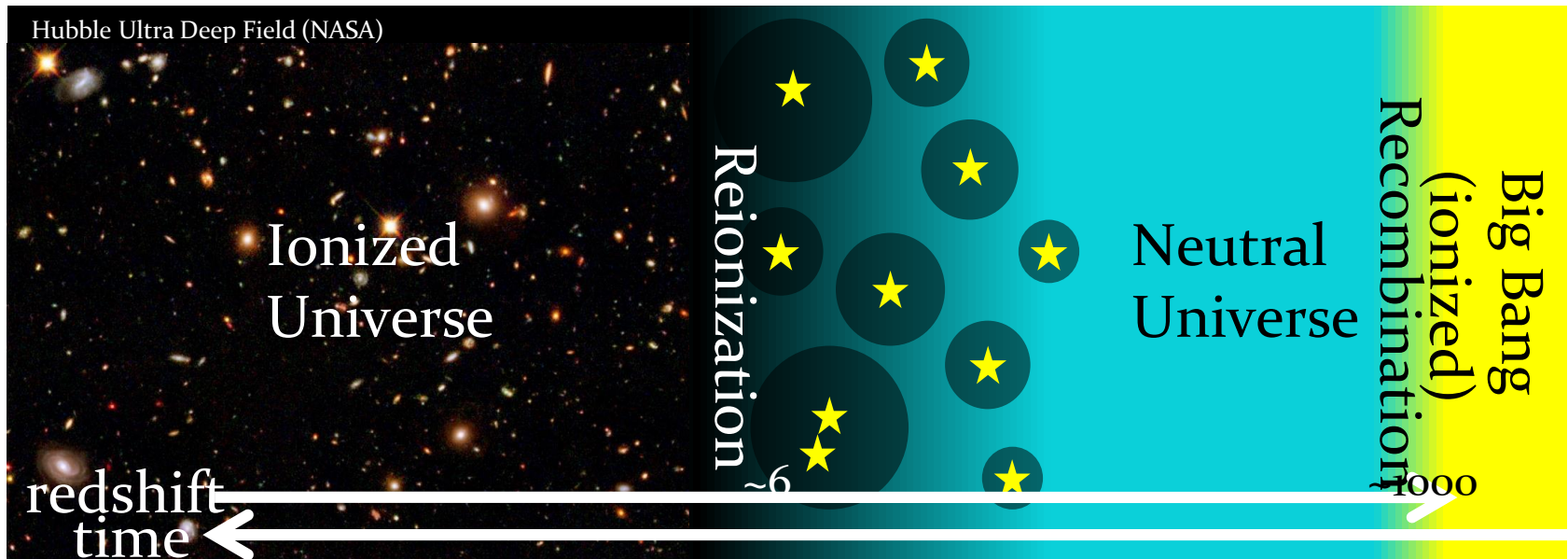
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ON BEHALF OF CHORUS TEAM

REVEALING REIONIZATION

- History
 - Sources
 - Topology
- SSP LAE LF/ACF measurements
- 



STRATEGY

HSC-SSP UD

5 Broadband filters
(g, r, i, z, Y)
1 Narrowband NB921

There are two more NBs in SSP: NB816, NB101

5 Narrowband filters
NB387, NB527, NB718,
NB945, NB973

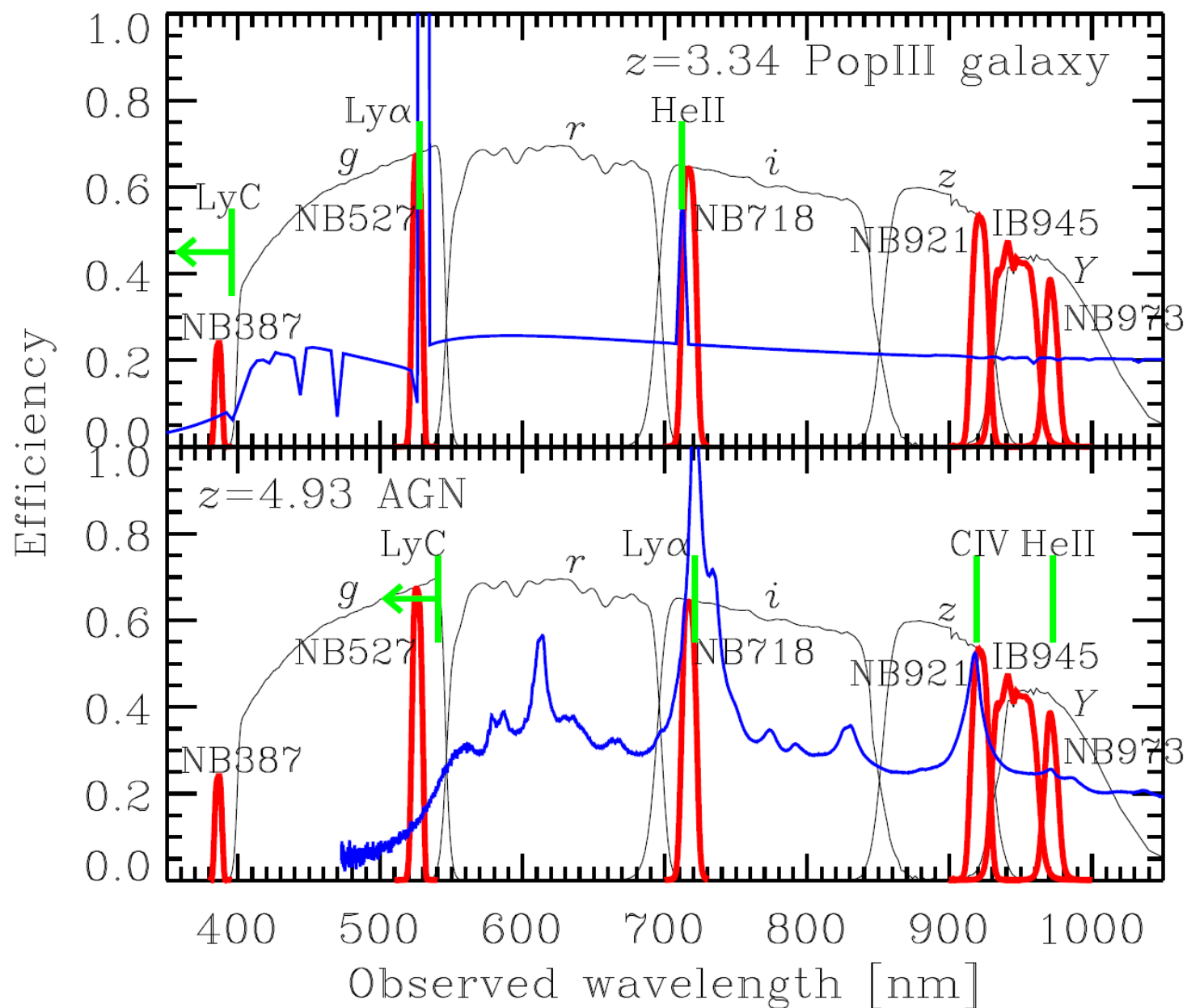
→ CHORUS

CHORUS FILTER SET

Filter	Developer	Budget source
NB387	K. Shimasaku (U. Tokyo)	JSPS Kakenhi
NB527	I. Iwata (NAOJ)	JSPS Kakenhi
NB718	Y. Taniguchi (Ehime U.)	MEXT
NB921 (SSP)	M. Ouchi (U. Tokyo)	JSPS Kakenhi
IB945	A. Inoue (Osaka S. U.)	JSPS Kakenhi
NB973	M. Ouchi (U. Tokyo)	JSPS Kakenhi

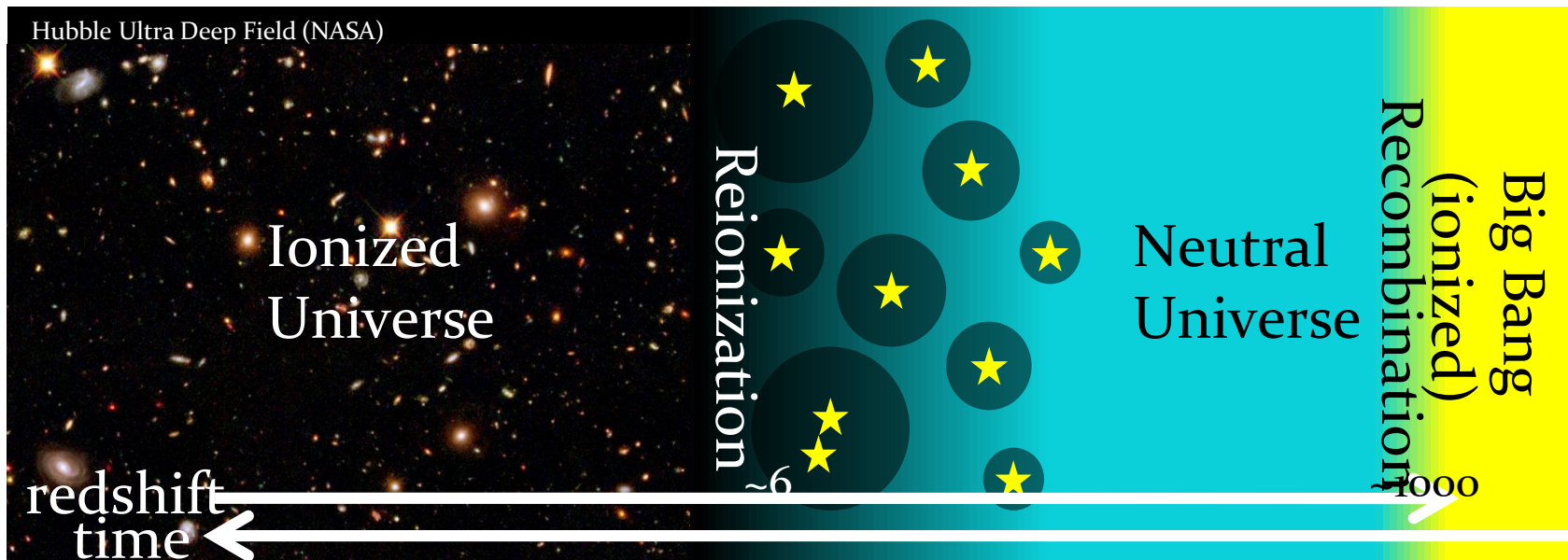
Coordinated by the HSC filter consortium
(and there are more)

CHORUS FILTER SET



REVEALING REIONIZATION

- **History**
 - **Sources**
 - **Topology**
- SSP LAE LF/ACF measurements
 - LyC measurements of galaxies and AGNs
 - Faint-AGN LF measurements
 - Pop-III SFRD measurements
 - Visualization of spatial distribution of xHI



SPECIFIC PROJECTS

As of Jan 15 2018

- #147 Cosmic HydrOgen Reionization Unveiled with Subaru (CHORUS) A. K. Inoue
- #185 CHORUS: Visualization of the neutral hydrogen fraction at $z \sim 7$ A. K. Inoue
- #189 CHORUS: Identifying and Characterizing High- z Galaxies with Population III Stars M. Ouchi
- #190 CHORUS: Evolution of the Extended Line Emission Nebulae Associated with Galaxies at a Redshift Up to $z \sim 7$ M. Ouchi
- #191 CHORUS: Probing the Faint End of the AGN UV Luminosity Function Y. Ono
- #192 CHORUS: Multi-wavelength properties of narrowband-selected AGNs T. Nagao
- #194 CHORUS: Direct measurement of Lyman continuum emissivity I. Iwata
- #197 CHORUS: Probing Cosmic Reionization by Ly α Intensity Mapping with HSC Narrow-band Images Y. Harikane
- #207 CHORUS: QSO environments at high redshifts probed by NB-selected Lyman alpha emitters S. Kikuta
- #240 CHORUS: Data Analysis and Cataloging of Ly α Emitters for Luminosity Functions and Correlation Functions with the CHORUS and SSP Images H. Zhang/R. Itoh
- #254 CHORUS: SHMRs and BCEs of LAEs at $z \sim 2$ H. Kusakabe
- #260 CHORUS: Mapping Out the HI and HII Gas Distribution in the Large Scale Structures Including Galaxies, Proto-Clusters, AGN, and Metal Absorbers at $z \sim 2-3$ M. Ouchi
- #266 CHORUS: Probing emission-line galaxies at $z < 1.7$ with additional four NB filters M. Hayashi
- #267 CHORUS: Searching for metal poor galaxies from line ratios of [OIII] to H α M. Hayashi

14 projects

OBSERVATION SCHEDULE

Dates	Filter	Reports
Jan/26/2017 Jan/28/2017	NB973	~15 h data of COSMOS (+ ~5 h of SXDS UD)
Feb/25/2017	NB718	No meaningful data due to thick clouds
Mar/23/2017 Mar/25/2017	NB718	~6 h data of COSMOS (+ 40min each for 4 points in ELAIS-N1 D)
Dec/16-18/2017	NB527	Almost cloudy, 0.5 h data of COSMOS
Jan/17-19/2018	NB387	3 full nights, COSMOS (+ SXDS D, UD)
Mar/15-16, 18/2018	IB945 ->NB527	3 full nights, COSMOS visibility ~6 hours 'Sukima'-time will be used for the open-use queue.
Total 12.5 nights, rest 0.5 night		

We Are Here



No time for IB945...

OBSERVATION STATISTICS

Dates	Allocation [n]	Filter	COSMOS visible [h]	Success [h]	Fraction [%]
Jan/26, 28/2017	2	NB973	15	15	100
Feb/25/2017	1	NB718	8	0	0
Mar/23, 25/2017	2	NB718	12	6	50
Dec/16, 17, 18/2017	1.5	NB527	15	0.5	3
Jan/17, 18, 19/2018	(3)	NB387	(21)		
Mar/15, 16, 18/2018	(3)	IB945 ->NB527	(18)		
	6.5 (12.5) /13		50 (89)	21.5	43

Clear fraction
(nominal ~70%)

OBSERVATION STATISTICS

Filter	Request [h]	Achieved [h]	Fraction [%]	Used [n]	Dates
NB387	15			(3)	Jan/17, 18, 19/2018
NB527	12	0.5	4	1.5 (+3)	Dec/16, 17, 18/2017 Mar/15, 16, 18/2018
NB718	8	6	75	3	Feb/25, Mar/23, 25/2017
IB945	15				
NB973	15	15	100	2	Jan/26, 28/2017
	65	21.5	33	6.5 (12.5) /13	

- The allocated nights are almost running out.
- We hope to request additional nights in S18B as a NORMAL program.
 - Intensive PI cannot submit other proposals during the intensive.
 - How do we submit? An exception? By another PI?

LIMITING MAGNITUDES

Filter	Request (5σ , 2'') [AB]	Usable exposure [sec]	ETC*1) (5σ , 1.5'') [AB]	Achieved (5σ , 1.5'') [AB]	PSF size [arcsec]	Remarks
NB387	26.8					
NB527	27.5					
NB718	26.8	27,600	27.13	26.2	0.69	
IB945	26.2					
NB973	25.6	52,800 (16,800)	25.90 (25.27)	24.9 (24.2)	0.64 (0.78)	COSMOS (SXDS)

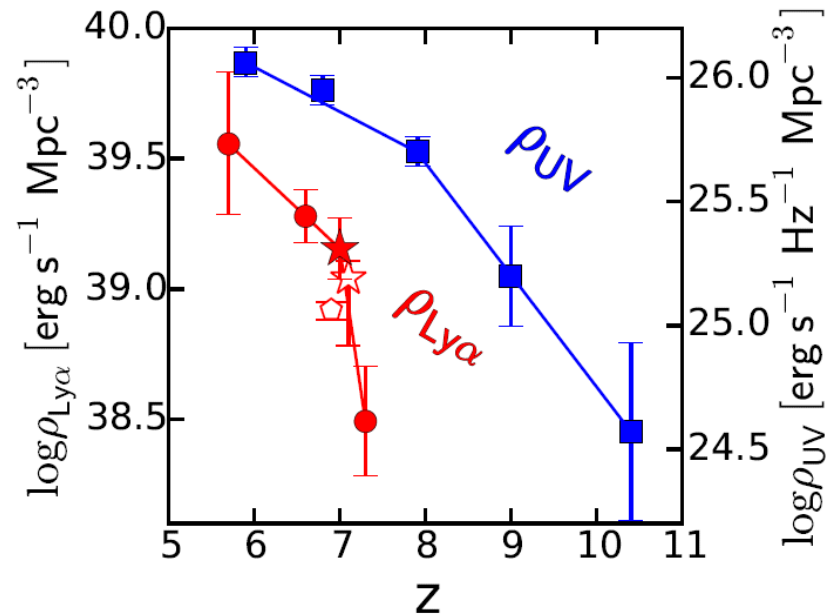
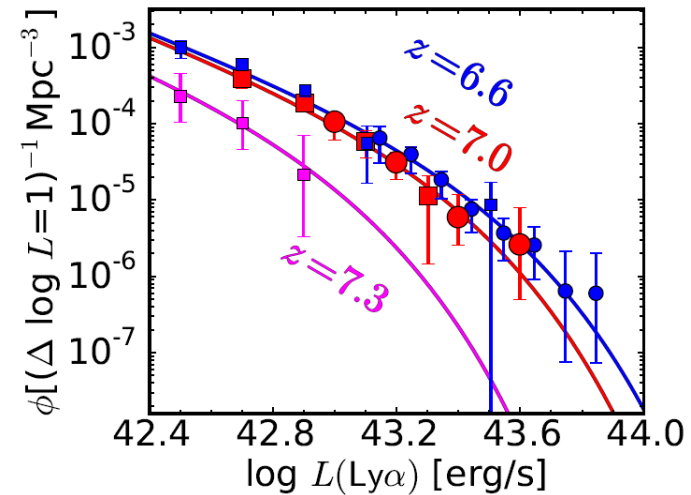
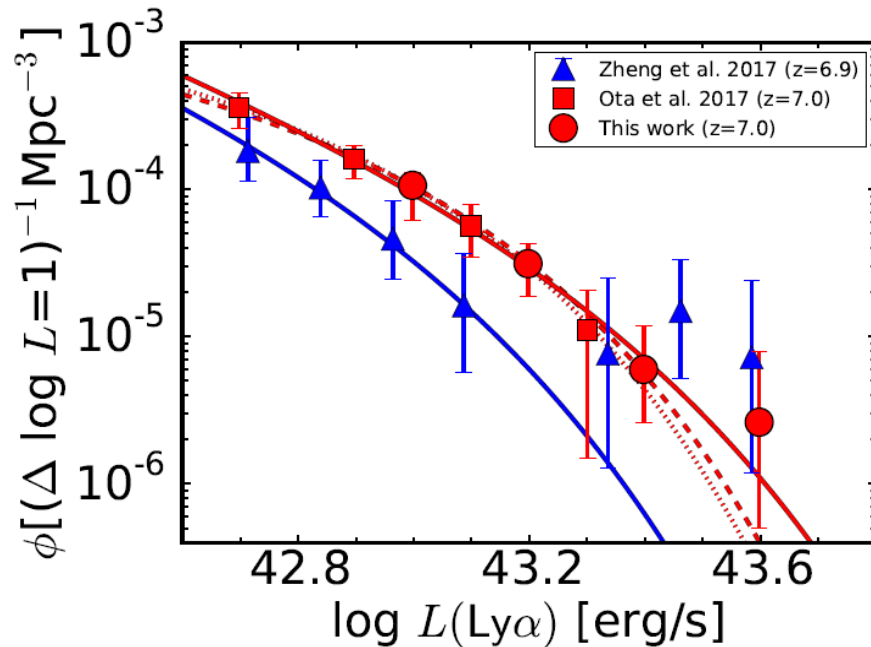
*1) Dark, transparency 0.9, seeing 0.7'', point source
(The seeing value does not change the ETC results, why?)

- 1 mag shallower than ETC.
 - M1 reflectivity degrade was ~40% ?
 - Sky model in ETC is too optimistic ?

SCIENCE RESULTS #1

R. Itoh et al. in prep.

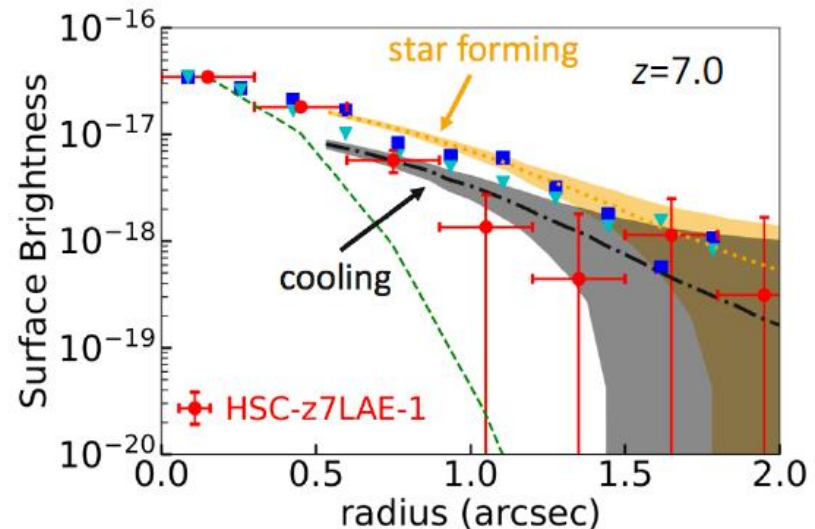
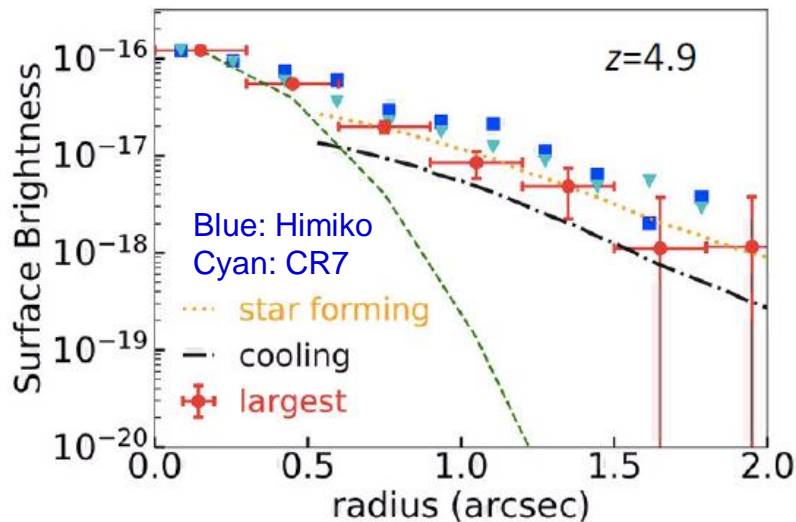
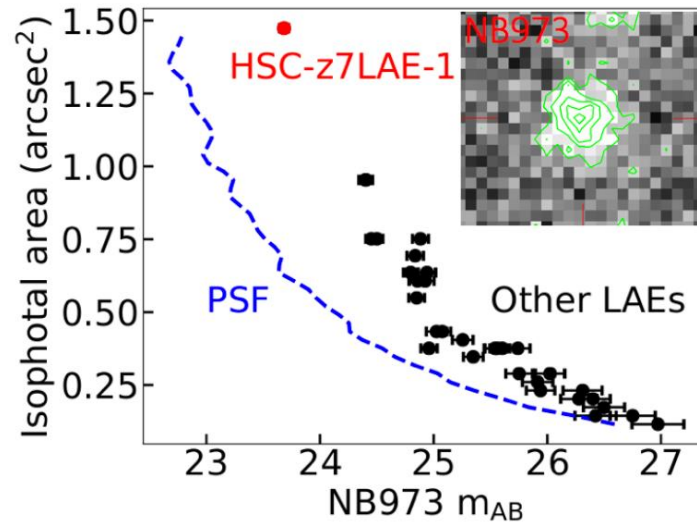
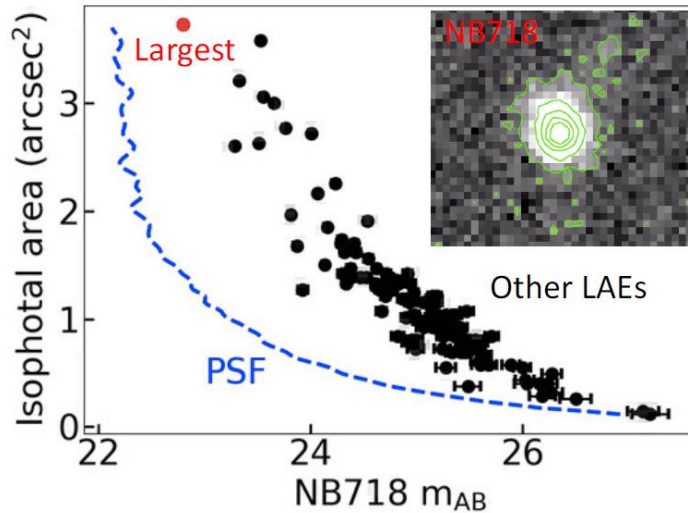
- LAE luminosity function at $z=7.0$
- A rapid decline of the LAE LF and Ly α luminosity density between $z=7.0$ and $z=7.3$.



SCIENCE RESULTS #2

H. Zhang et al. in prep.

- LyA blobs at $z=4.9$ and $z=7.0$.

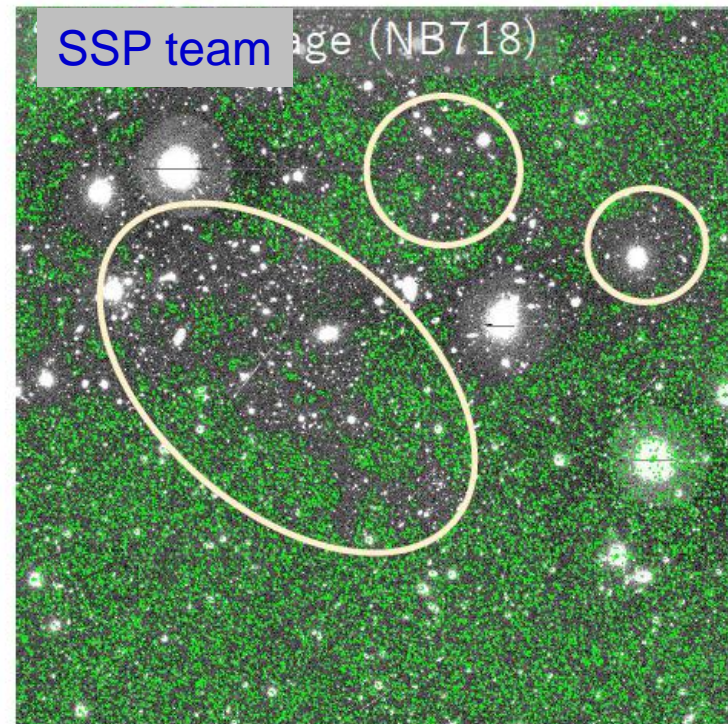
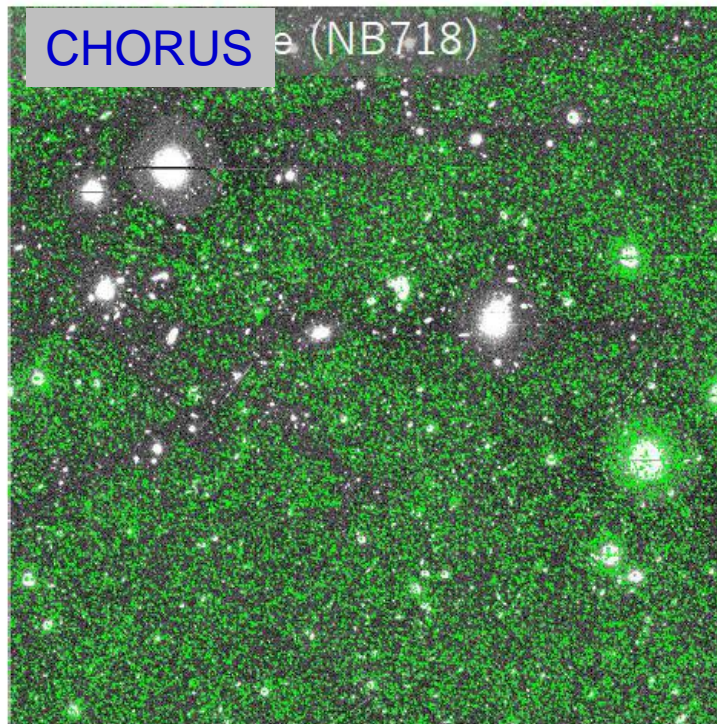


ISSUE IN HSC PIPELINE

- The latest (S17A) pipeline has a problem in source detections.
- The problem is caused by artifact rejections ?

Source detection problem in hscPipe 5.4

- hscPipe 5.4 source detections are strange in some areas!



SUMMARY

- **CHORUS is on-going.**
 - 2 filters (NB973, NB718) were completed and 3 filters remain.
 - Weather was not good so far and there will be no sufficient time for IB945.
 - We hope to submit a NORMAL program for the filter.
 - The achieved limiting magnitudes are 1 mag shallower than those expected by ETC.
 - M1 reflectivity ? and/or optimistic sky ?
 - Early science results are coming up:
 - LAE luminosity functions at $z=7.0$
 - LABs at $z=4.9$ and $z=7.0$
 - Source catalogs made by SSP team (S17A version) were released in the SSP collaboration.
 - Source detection problem in some areas (~15%).
 - CHORUS original catalogs (S16A version) will be also released in the SSP collaboration soon.

BACKUP

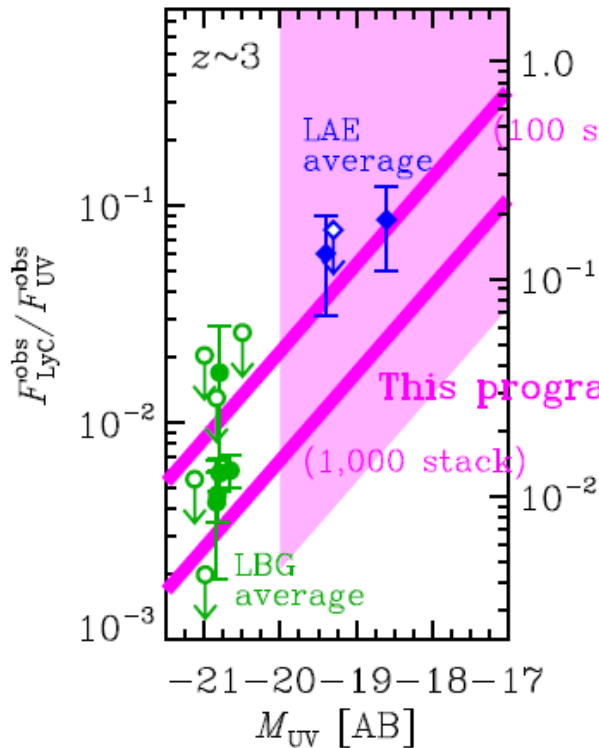
LYC EMISSIVITY OF GALAXIES

JWST
target

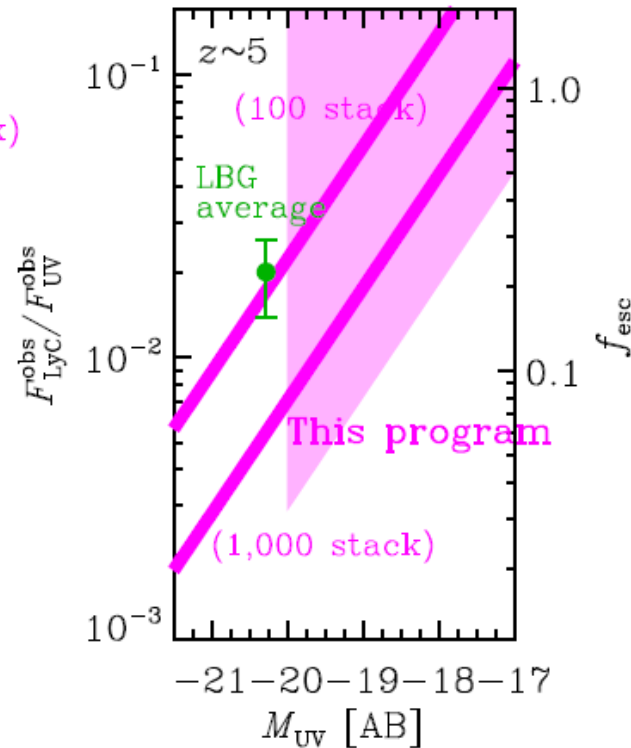
Redshift	LyC	Ly α	# of obj.
3.3	NB387	NB527	~10k
4.9	NB527	NB718	~6k

Individual detections (~ 40 @ $z \sim 3$, ~ 10 @ $z \sim 5$) \rightarrow Characterize of LyC emitters
 Average LyC emissivity of LAEs \rightarrow Galaxies' role in reionization

LyC(900A)/UV(1500A)
observed ratio



UV absolute mag.



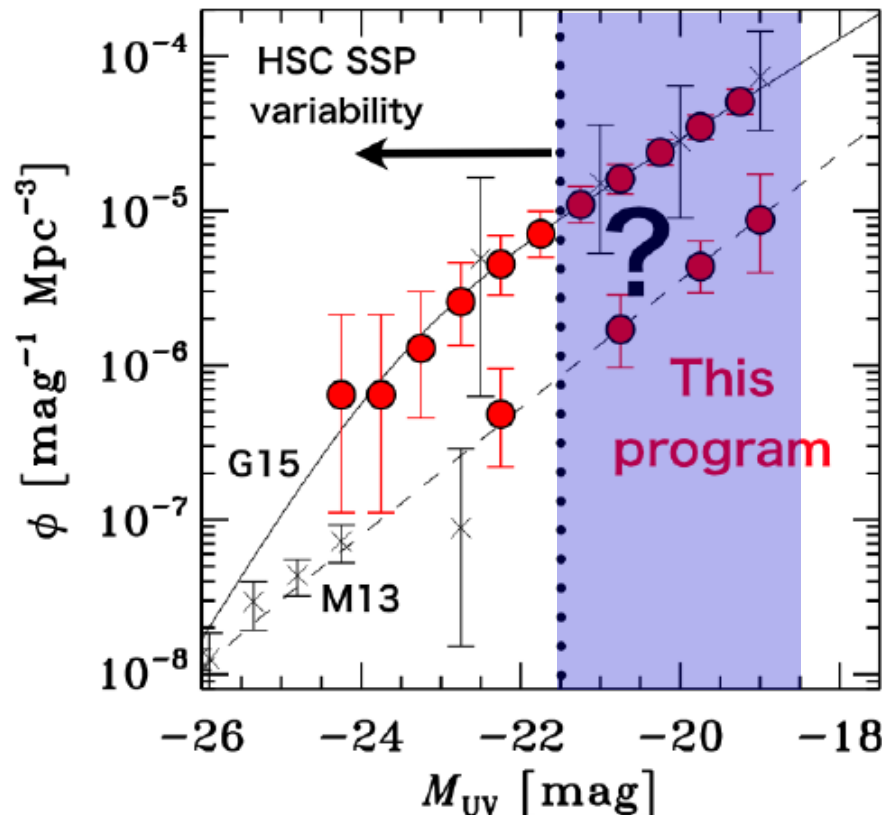
UV absolute mag.

Average escape fraction

FAINT-AGN LF

Faint-AGN = Ly α -CIV dual emitters

Redshift	LyC	Ly α	CIV	Offband	Hell
4.9	NB527	NB718	NB921	IB945	NB973



If Giallongo+15 LF is correct, only AGN can complete reionization.

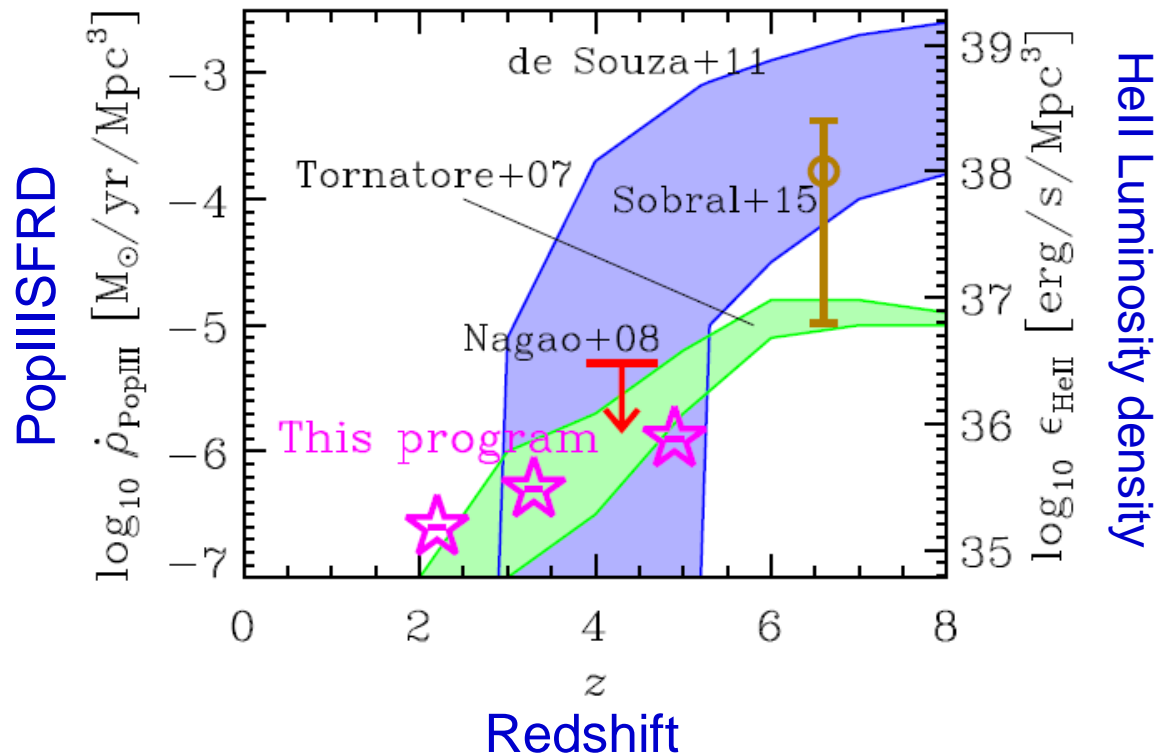
- 2.5 mag fainter AGNs than the SSP's variability survey can be detected.
- Direct measure of LyC from AGNs

⇒ Revealing the role of faint-AGNs in reionization.

POP-III ABUNDANCE

Pop-III galaxy candidates = Ly α -HeII dual emitters

Redshift	Ly α	Offband	HeII	SFR lim.[Mo/yr]
2.2	NB387		NB527	0.15
3.3	NB527		NB718	0.48
4.9	NB718	IB945	NB973	1.7

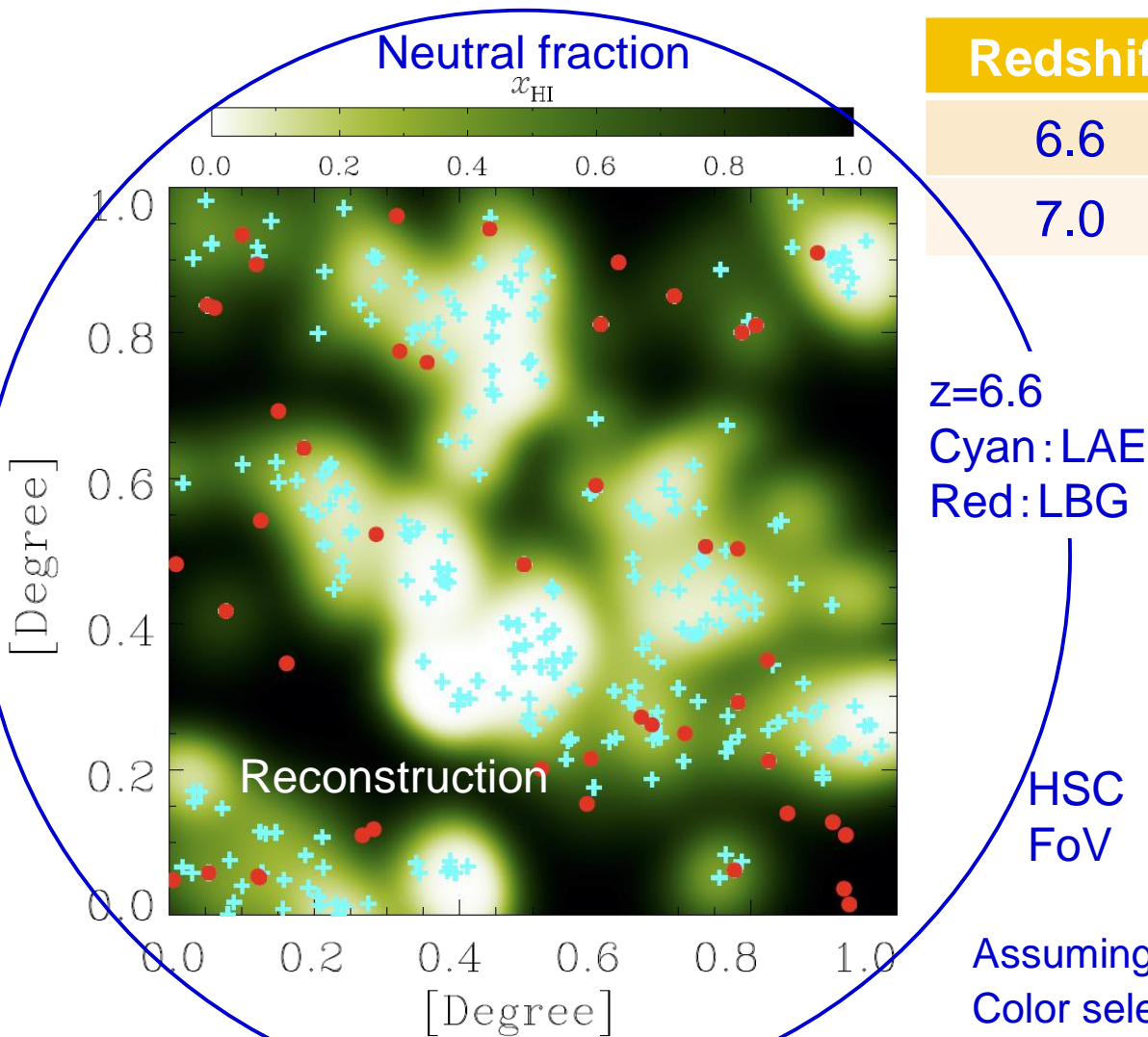


JWST spectroscopy
for candidate objects
→ Pop-III IMF

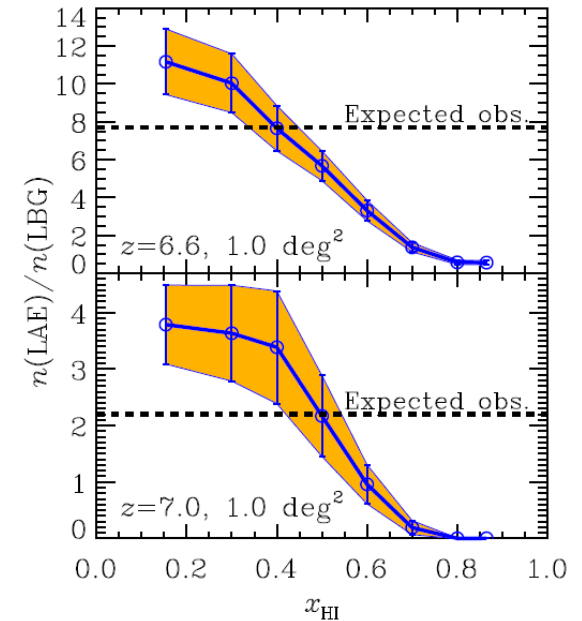
There are contamination
of AGN and WR stars in
the detected Ly α -HeII dual
emitters.

VISUALIZATION OF HI DIST.

- LAE/LBG number ratio well correlates with the neutral hydrogen fraction.
- By using IB945, LBG selection tailored to LAE redshift can be realized.



Redshift	LAE selec.	LBG selec.
6.6	NB921	IB945, z , Y
7.0	NB973	IB945, z , Y



Assuming $x_{\text{HI}} - T_{\text{Ly}\alpha}^{\text{IGM}}$ (Jensen+13)
Color selection with photometric errors