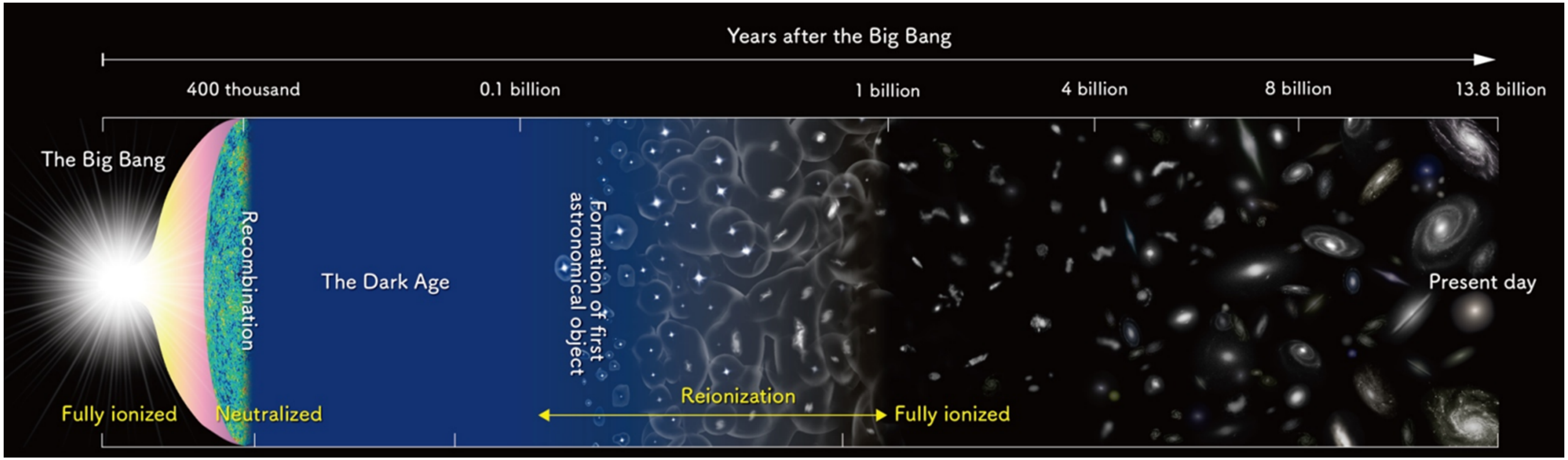
Probing the Epoch of Reionization with LAEs from deep Roman NIR Grism Surveys

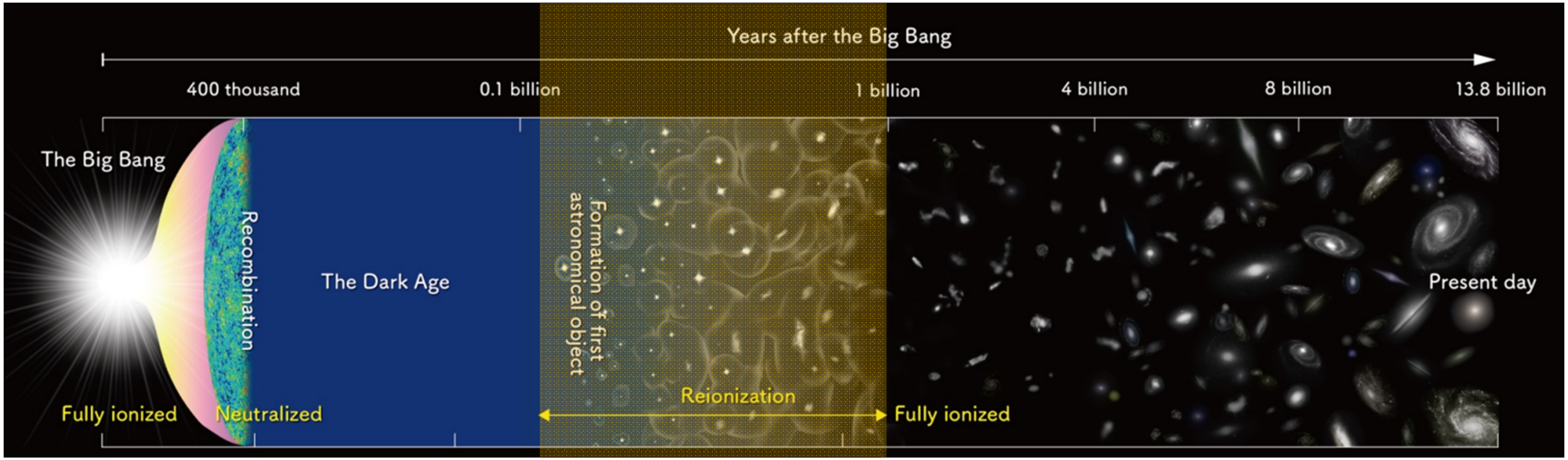
Fengshan Liu (NAOC)

21 cm Cosmology Workshop 2023 & Tianlai Collaboration Meeting @ NEU

Epoch of Reionization



Epoch of Reionization



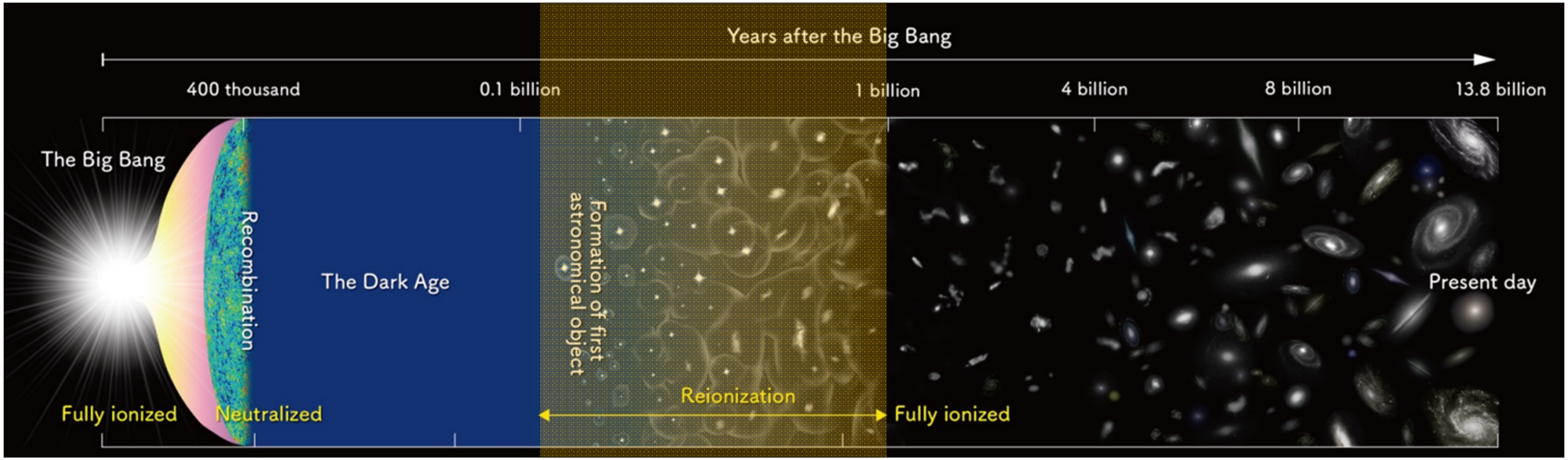
Understanding of reionization is still far from complete!

- When exactly did it happen?
- How did it develop over time?
- How long did the process take?
- What were the major sources of ionizing photons during this period?

Epoch of Reionization

Galaxies at z>7：

rare, bright, massive galaxies; first quasars, SMBH;
early star-forming galaxies (specially LAEs given their precise redshifts)



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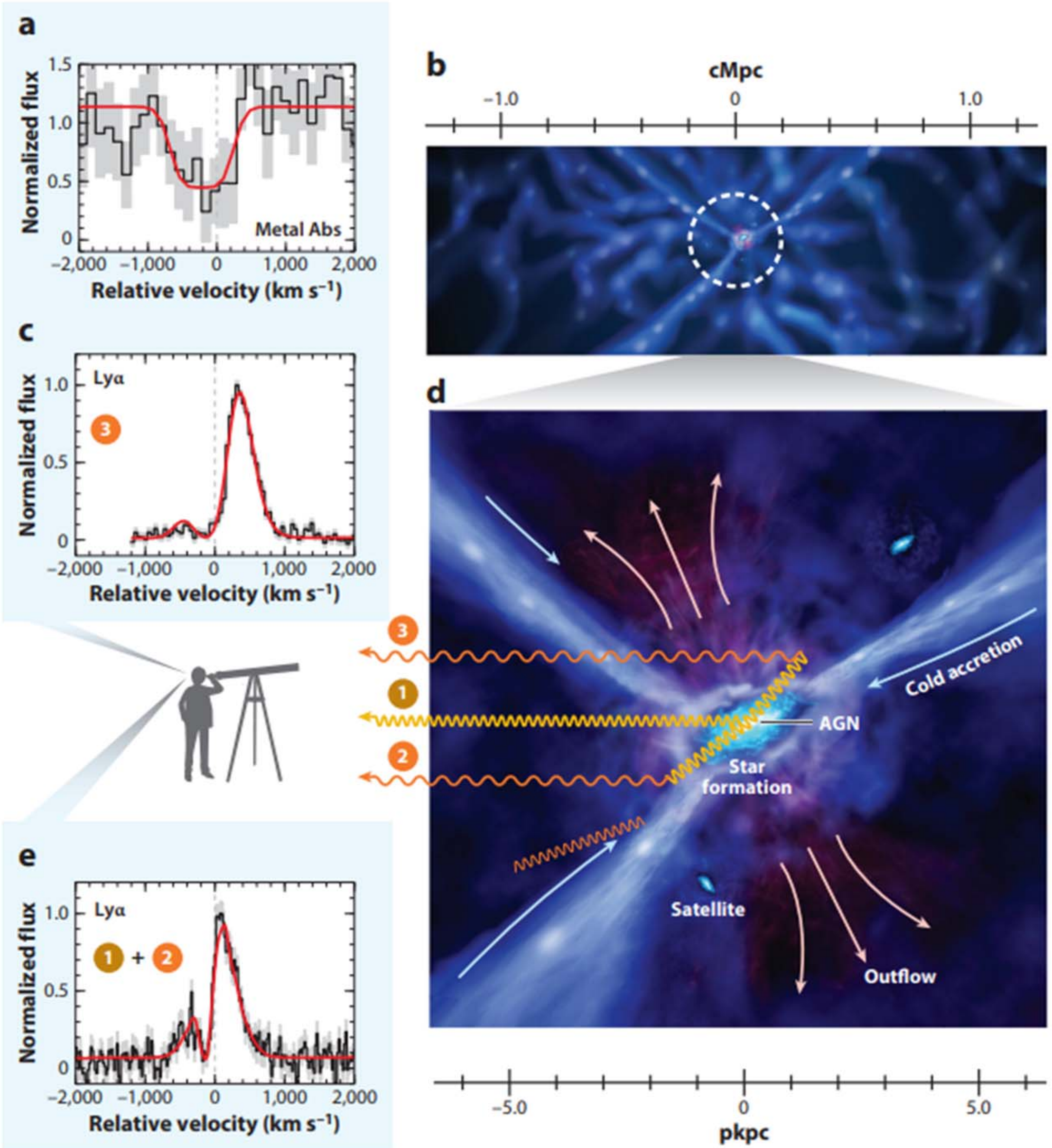
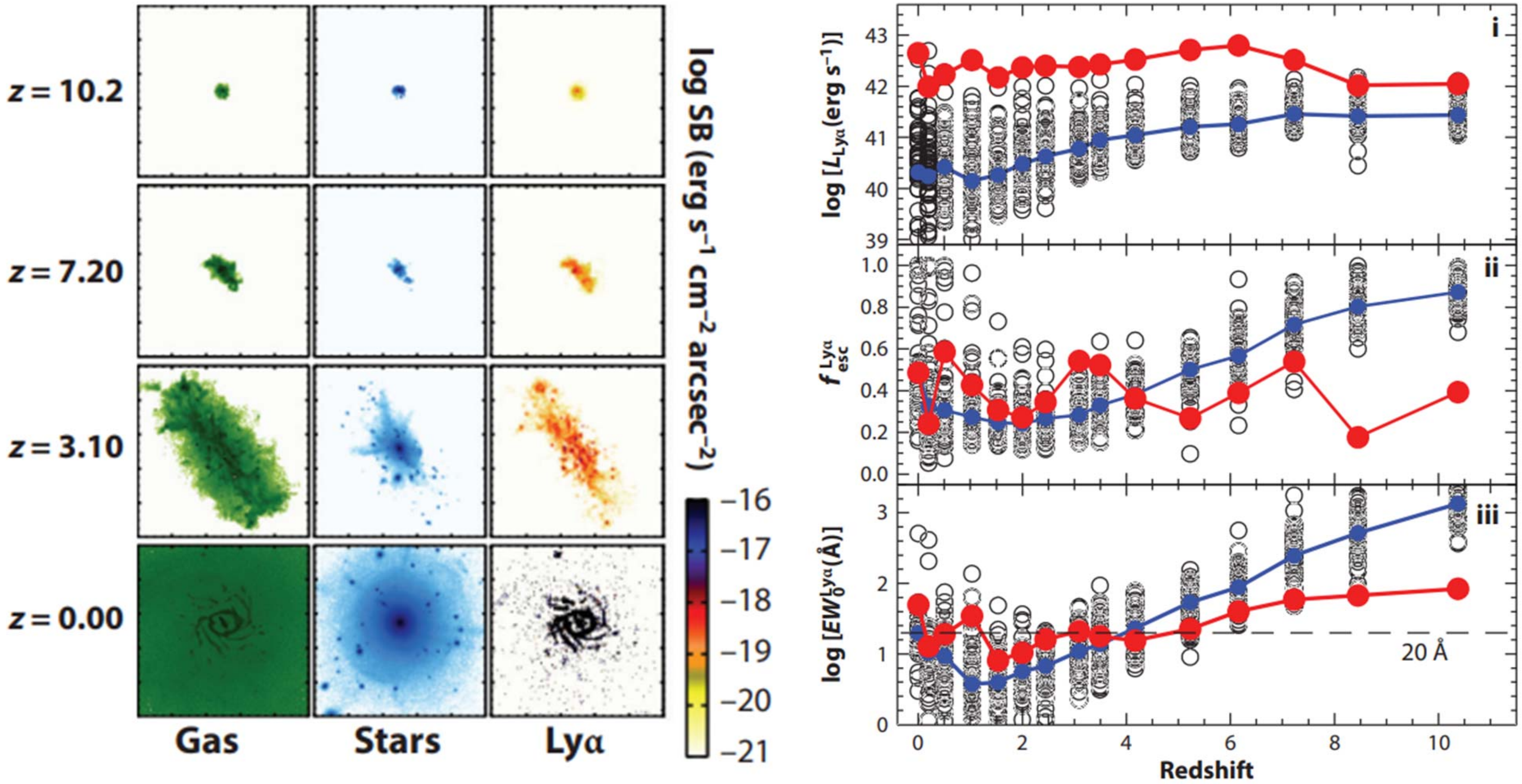
An illustration of a conceptual LAE



Ouchi et al. 2020
Hashimoto et al. 2015
Sugahara et al. 2019

Observations for LAEs at hi-z

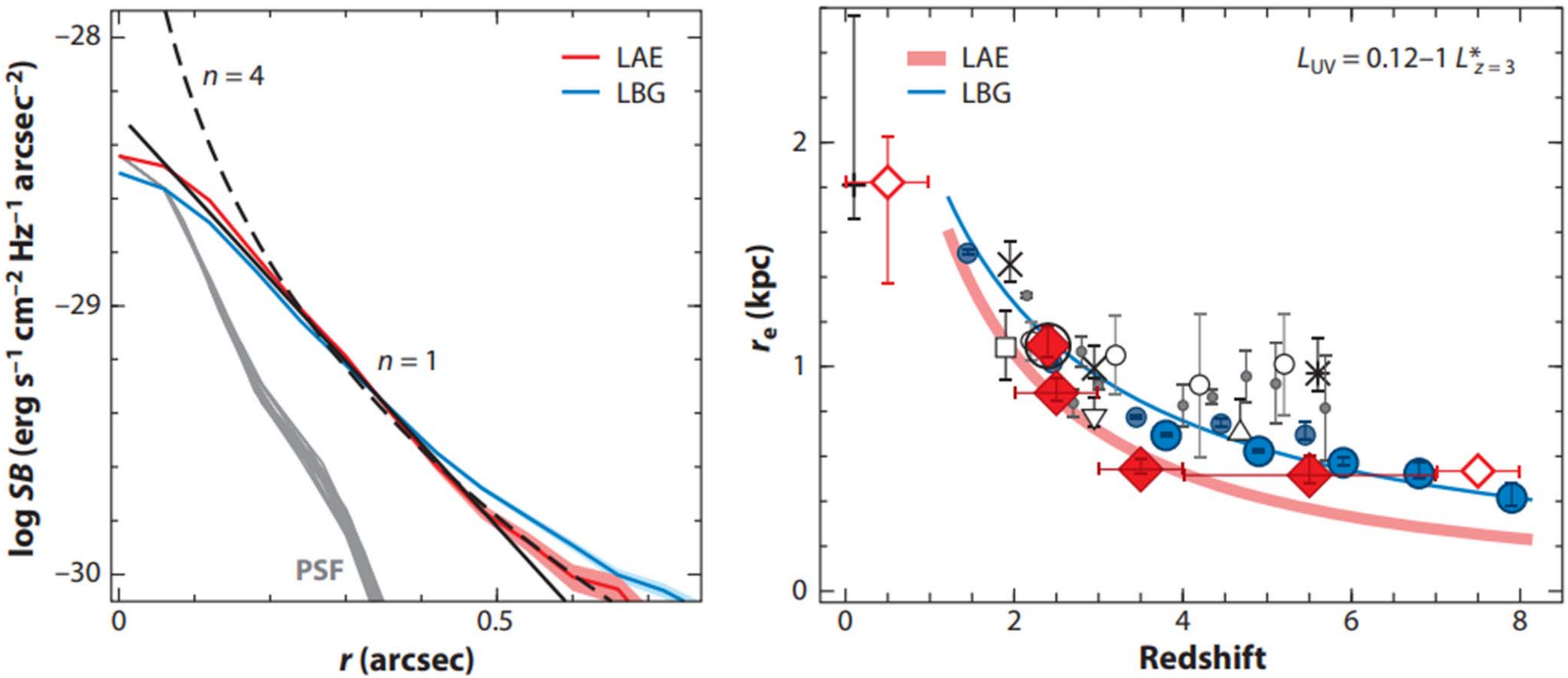
Progenitor of a present-day Milky Way–like galaxy



Yajima et al. (2012)

Morphological properties of LAEs

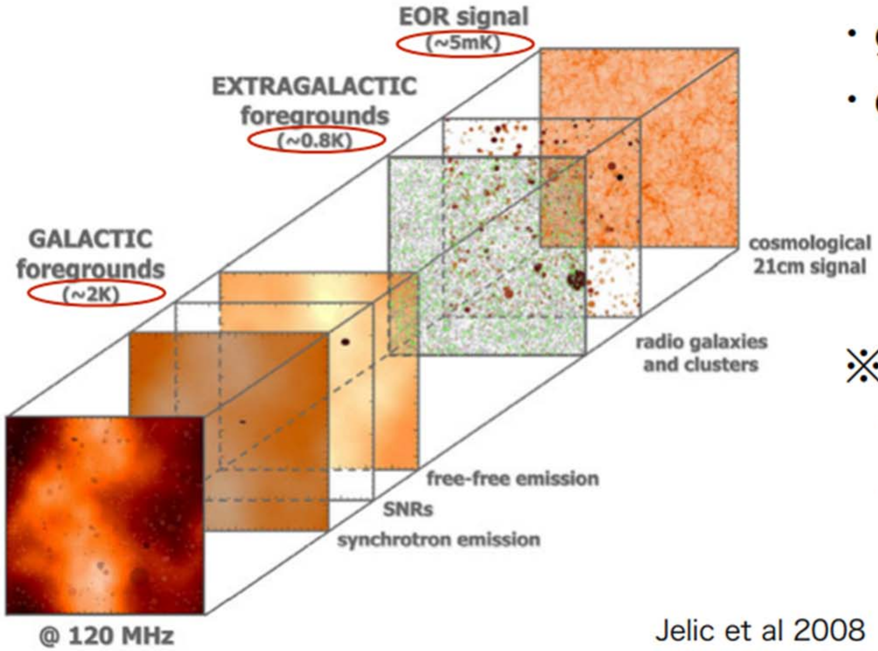
LAEs are small at all redshifts and have disk-like shape.



Malhotra et al. 2012; Ouchi et al. 2020

Problem of 21cm observation

The detection of 21cm-signal is very challenging!



<u>Foreground</u>

・galactic synchrotron

・extragalactic radio

etc…

※21cm signal : ~mK

foreground : ~K

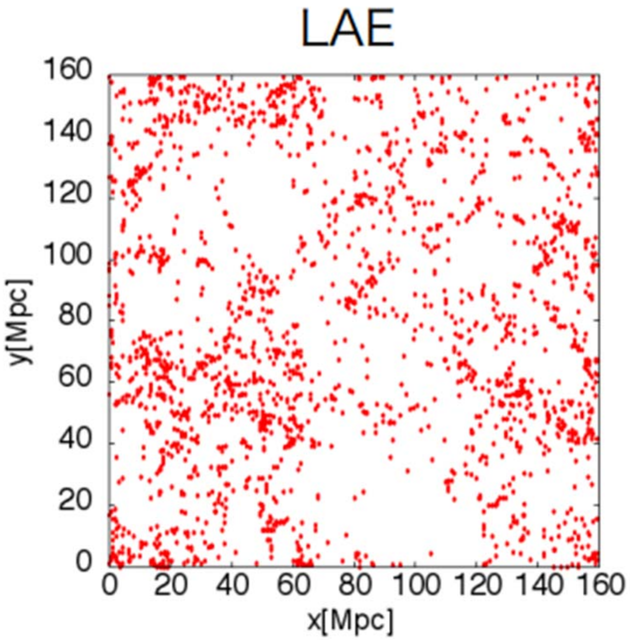
foreground >> 21cm

Jelic et al 2008

Kenji Kubota et al. 2018

21cm-signal from the EoR has not been detected.

LAE-21cm anti-correlation



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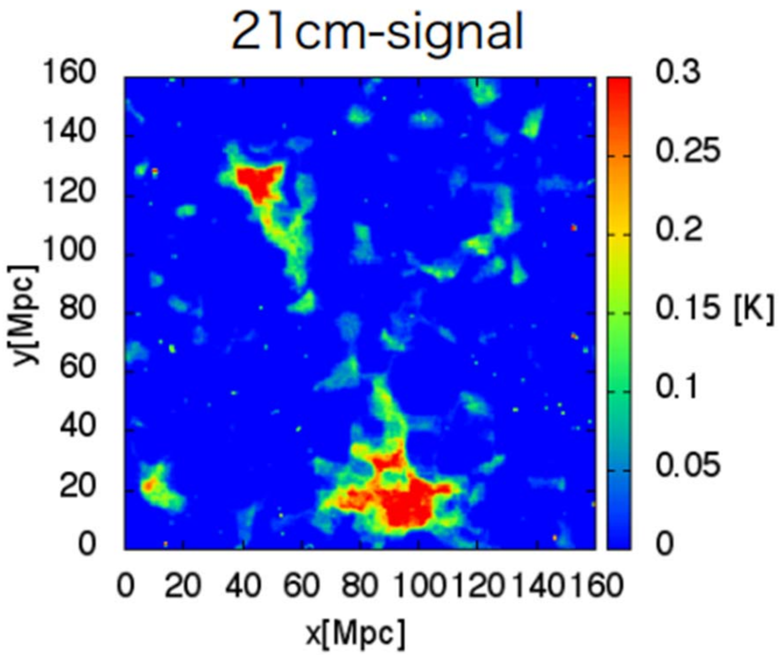
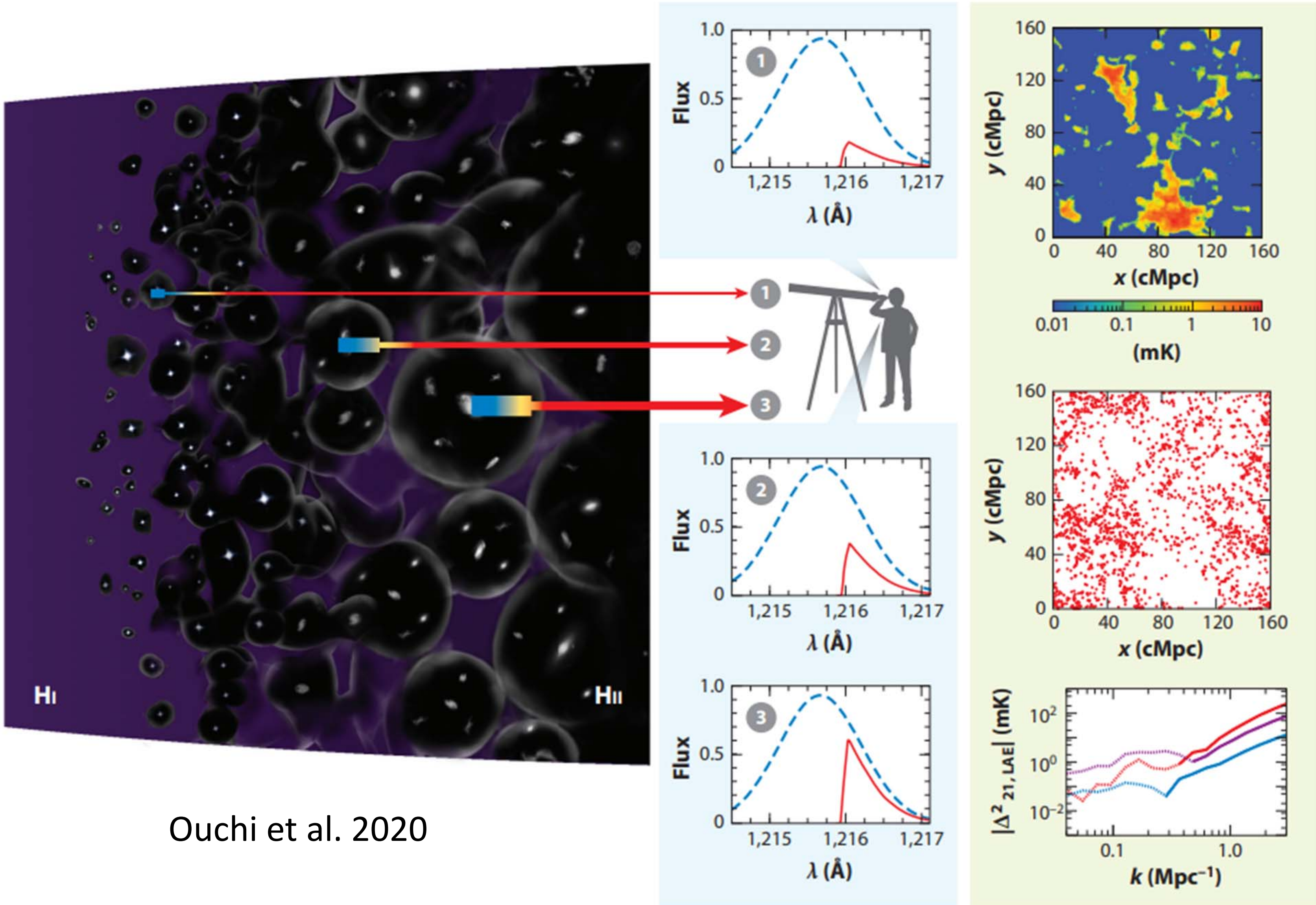


- The region around LAEs is dark in 21cm.
- The region far from LAEs is bright in 21cm.

Negative correlation!

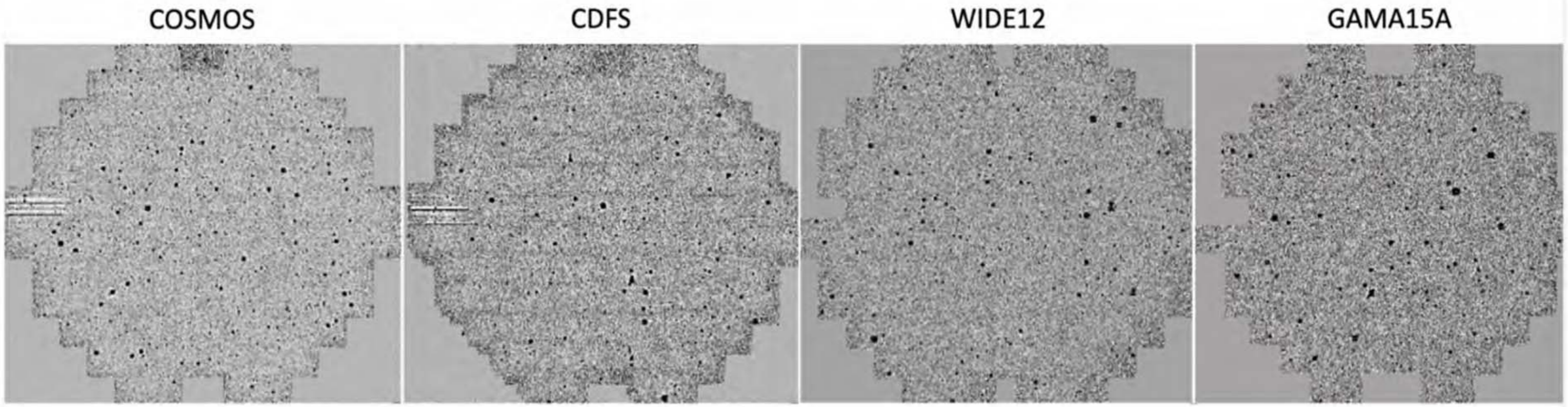
Conceptual diagram of Observations for LAEs at the EoR



Ouchi et al. 2020

The LAGER Survey for LAEs to z~7

Redshift ~6.9; 24 Square Degrees; 200 Lyα Galaxies already, 400-600 expected - 80% spectroscopic confirmations with > 50 spectroscopically confirmed - 13 papers - Luminosity functions, Bubbles, Structures, and more!

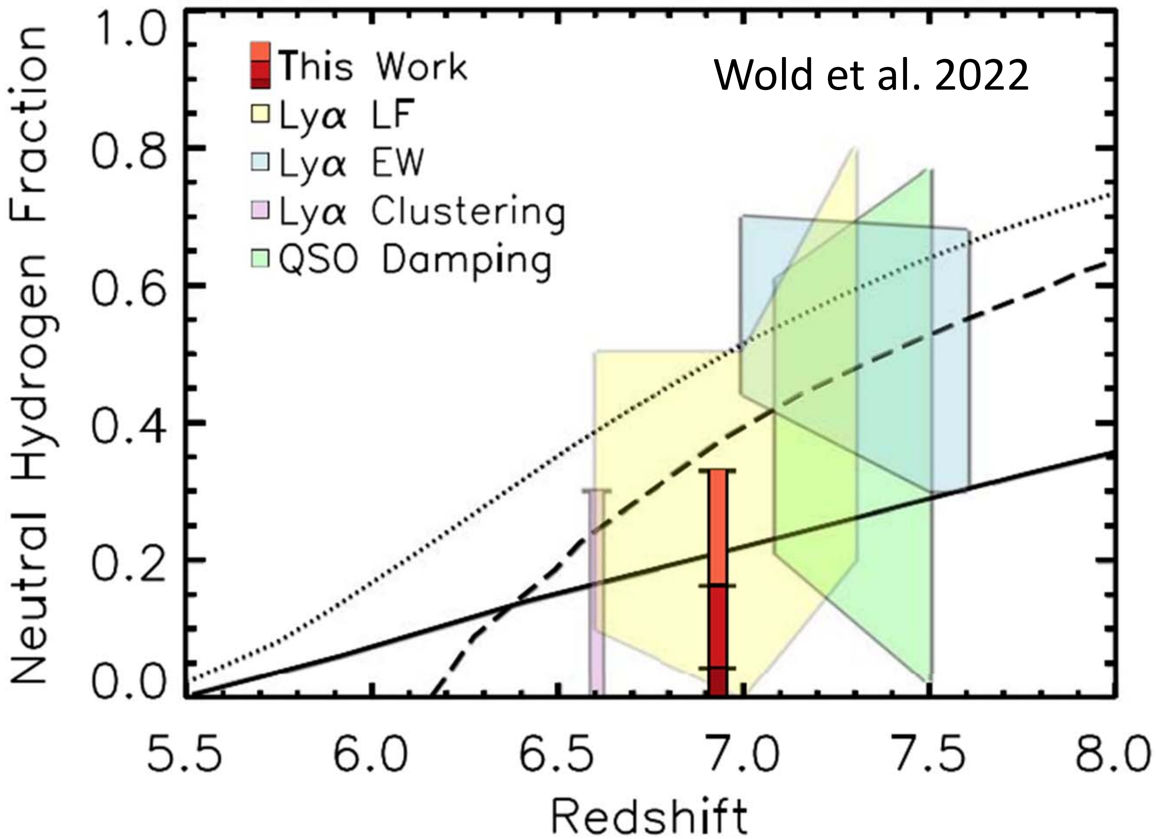


Lyman
Alpha
Galaxies in the
Epoch of
Reionization

The largest narrowband survey yet for LAEs at z~7,
(where reionization is thought to be mostly complete!)
using the Dark Energy Camera on the NOAO 4m Blanco telescope

Sangeeta Malhotra (PI), Junxian Wang (PI), Zhenya Zheng, Polo Infante (Co-PI), James Rhoads, Felipe Barrientos (Co-PI), Alistair Walker, Weida Hu, Isak Wold, Lucia Perez, Ali Khostovan, Santosh Harish, Jorge Gonzalez, Cristobal Moya, Franz Bauer, Wenyong Kang, Linhua Jiang, Chunyan Jiang, Alicia Gonzalez, Xu Kong, Pascale Hibon, Gaspar Galaz, Huan Yang

The LAGER Survey for LAEs to z~7

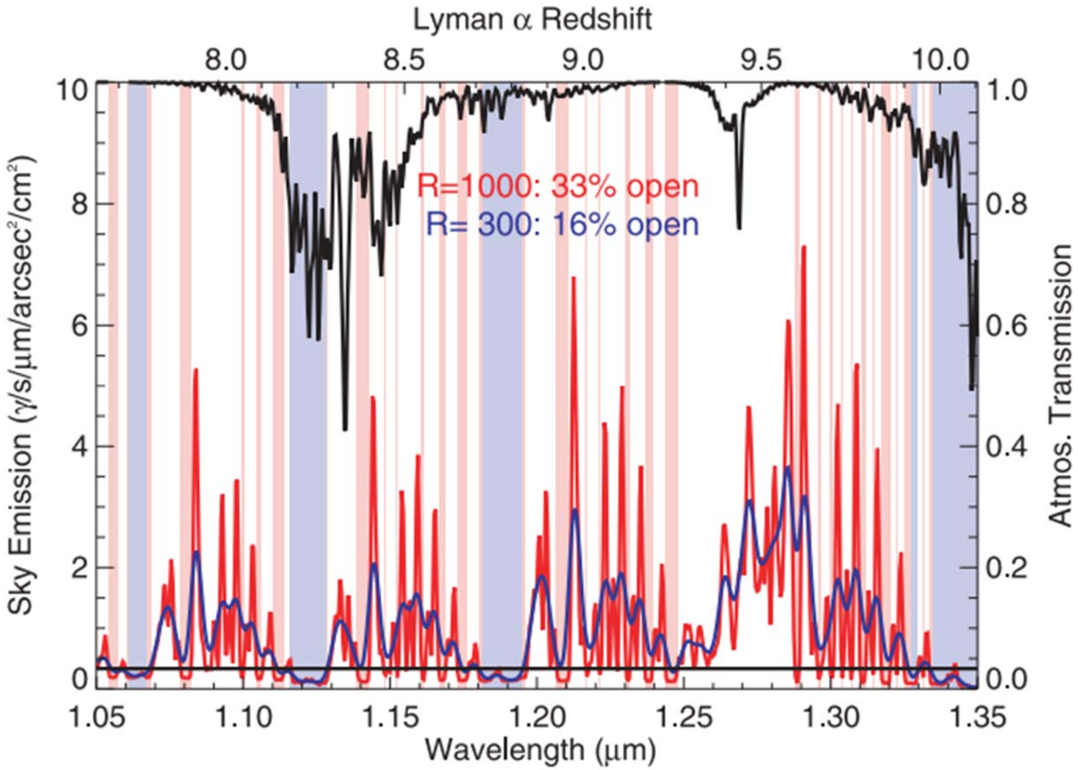


Recent results based on 150 LAEs found within 4 of the 8 planned LAGER fields find a neutral hydrogen fraction consistent with zero (red upper limit) at z~6.9.

Problem of ground-based searches for LAEs at z>7

In total, thanks to the successful selection techniques and intensive spectroscopic follow-up campaigns, to date >1,000 (>20,000) LAEs have been spectroscopically identified (photometrically selected) in the literature. But only a few tens of them have z>7.

'Windows' in the J-band night-sky spectrum (Barton et al. 2004)



Ground-based infrared surveys are increasingly impractical at redshifts beyond z ~7, both due to airglow OH emission and a steep drop in silicon detector response at 1μm

Spectroscopically identified galaxies at z>7

Object ID	Right ascension (J2000)	Declination (J2000)	Spectroscopic redshift z_{spec}	Intrinsic UV abs. magnit. M_{UV}	Lyα EW_0[a] (Å)	Probe	Other lines	Reference
GN-z11	12:36:25.46	+62:14:31.4	11.09	-22.1 ± 0.2	ND	Lyman break	ND	Oesch et al. 2016
MACS1149-JD	11:49:33.58	+22:24:45.7	9.1096	−19.0	11.4	[OIII] 88 μm	Lyα	Hashimoto et al. 2018, Hoag et al. 2018
EGSY-2008532660	14:20:08.50	+52:53:26.60	8.683	−22.0	28	Lyα	ND	Zitrin et al. 2015
A2744-YD4	00:14:24.9	−30:22:56.1	8.382	−20.3	10.7 ± 2.7	[OIII] 88 μm	Lyα	Laporte et al. 2017
MACS0416-Y1	04:16:09.40	−24:05:35.5	8.3118	−20.8	ND	[OIII] 88 μm	ND	Tamura et al. 2019
EGS-zs8-1	14:20:34.89	+53:00:15.4	7.7302	-22.06 ± 0.05	21 ± 4	Lyα	CIII] 1908	Oesch et al. 2015, Stark et al. 2017
z7-GSD-3811	03:32:32.03	−27:45:37.1	7.6637	$-21.22^{+0.06}_{-0.10}$	$15.6^{+5.9}_{-3.6}$	Lyα	ND	Song et al. 2016
MACS1423-z7p64	14:23:46.18	+24:04:10.76	7.640	-19.6 ± 0.2	9 ± 2	Lyα	ND	Hoag et al. 2017
z7-GND-16863	12:37:19.94	+62:15:26.05	7.599	−21.24	61.28 ± 5.85	Lyα	ND	Jung et al. 2019
z8-GND-5296	12:36:37.90	+62:18:08.5	7.506	−21.2	33.19 ± 3.20	Lyα	CIII]1908	Finkelstein et al. 2013, Hu et al. 2019, Jung et al. 2019
EGS-zs8-2	14:20:12.09	+53:00:26.97	7.4770	−21.9	20.2	Lyα	ND	Roberts-Borsani et al. 2016, Stark et al. 2017
GS2-1406	03:33:09.14	−27:51:55.47	7.452	−19.9	140.3 ± 19.0	Lyα	ND	Larson et al. 2018
SDF-NB1006-2	13:24:35.418	+27:27:27.81	7.288	-23.79 ± 0.04	1.99 ± 0.37	Lyα	ND	Shibuya et al. 2012
SXDF-NB1006-2	02:18:56.536	−05:19:58.87	7.215	-21.52 ± 0.18	32	Lyα	[OIII] 88 μm	Shibuya et al. 2012, Inoue et al. 2016
GN-108036	12:36:22.68	+62:08:07	7.213	−21.8	33	Lyα	ND	Ono et al. 2012

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z8-GND-5296						Lyα	CIII]1908	Finkelstein et al. 2013, Hu et al. 2019, Jung et al. 2019
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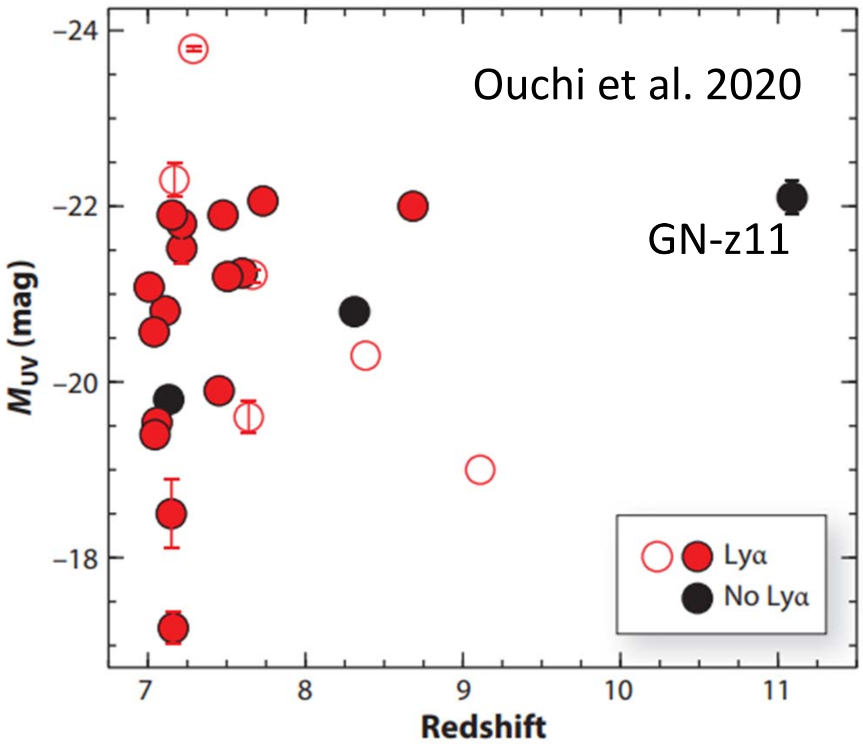
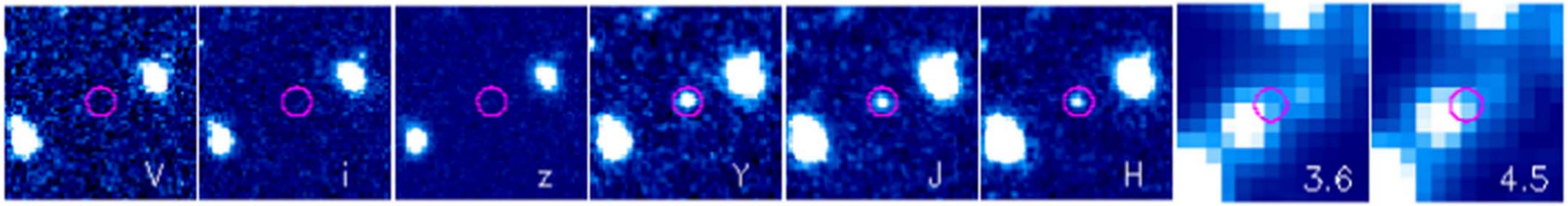
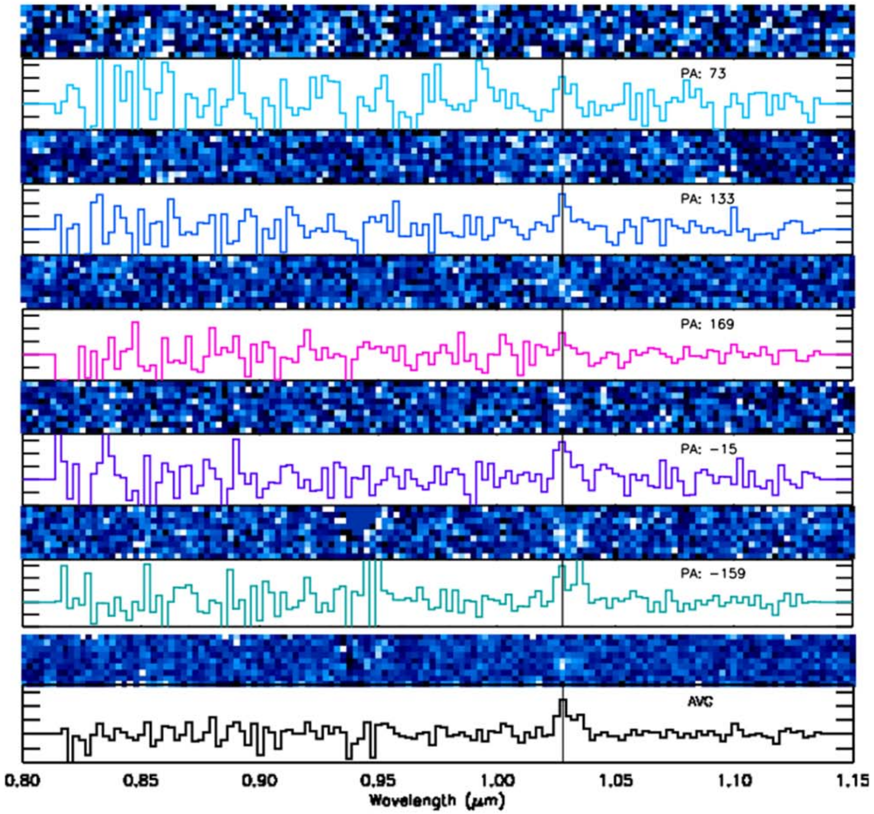


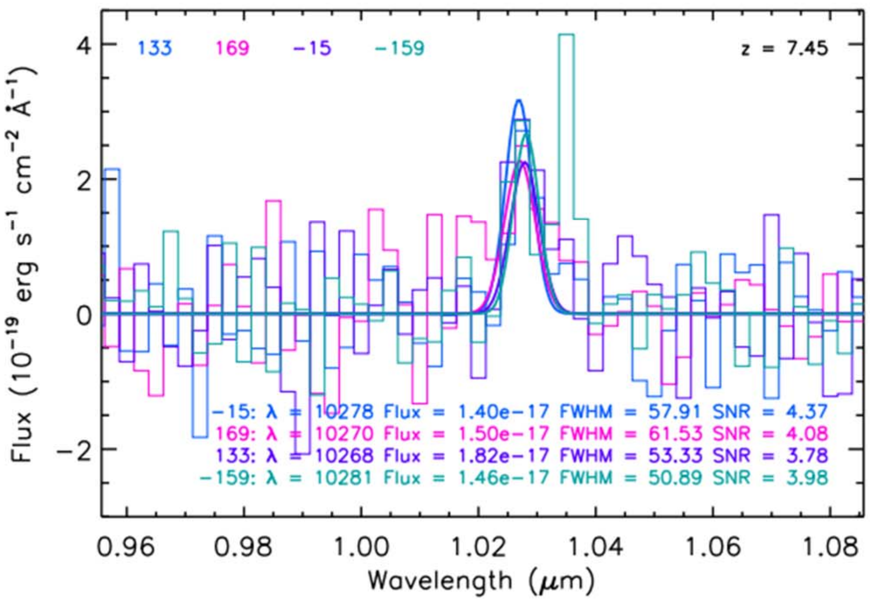
Space slitless spectroscopy for LAEs at z>7

This has been done before, by multiple Hubble programs.





LAE @ z=7.45 by HST/FIGS
Larson et al. 2018



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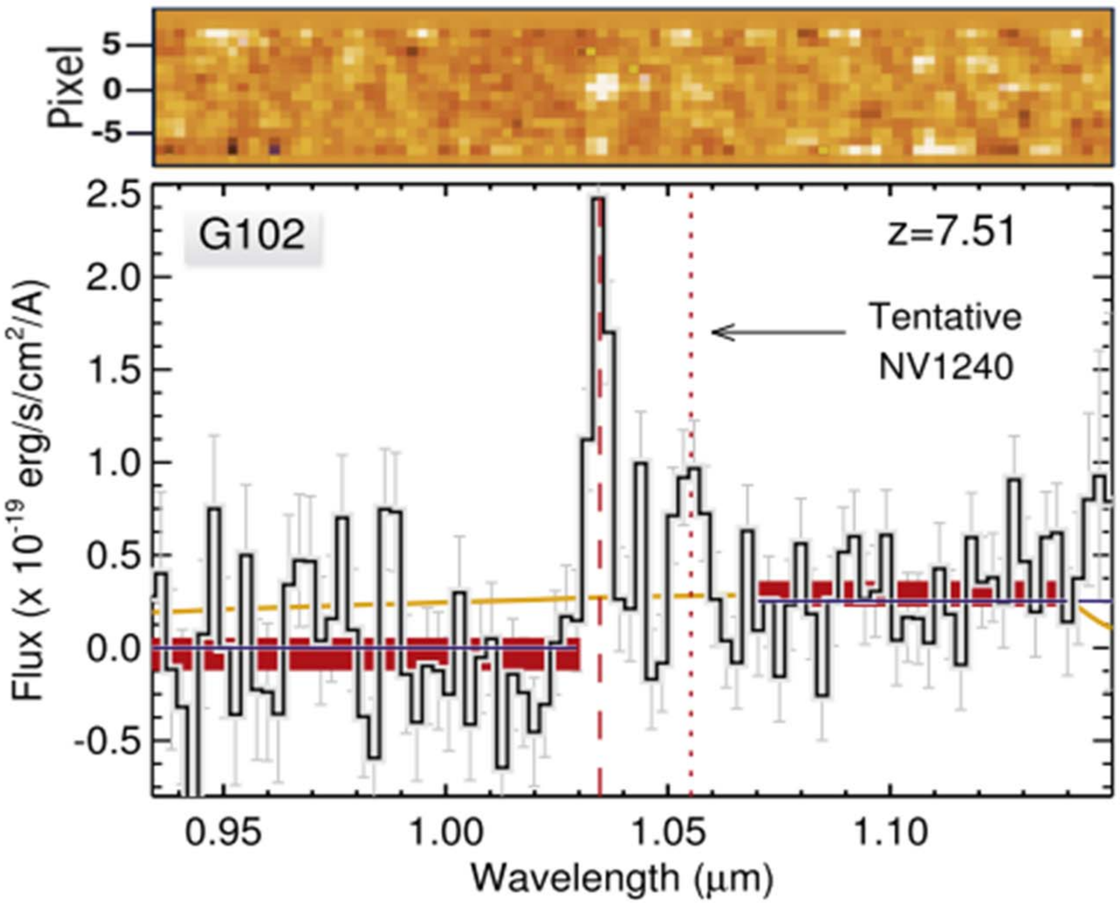
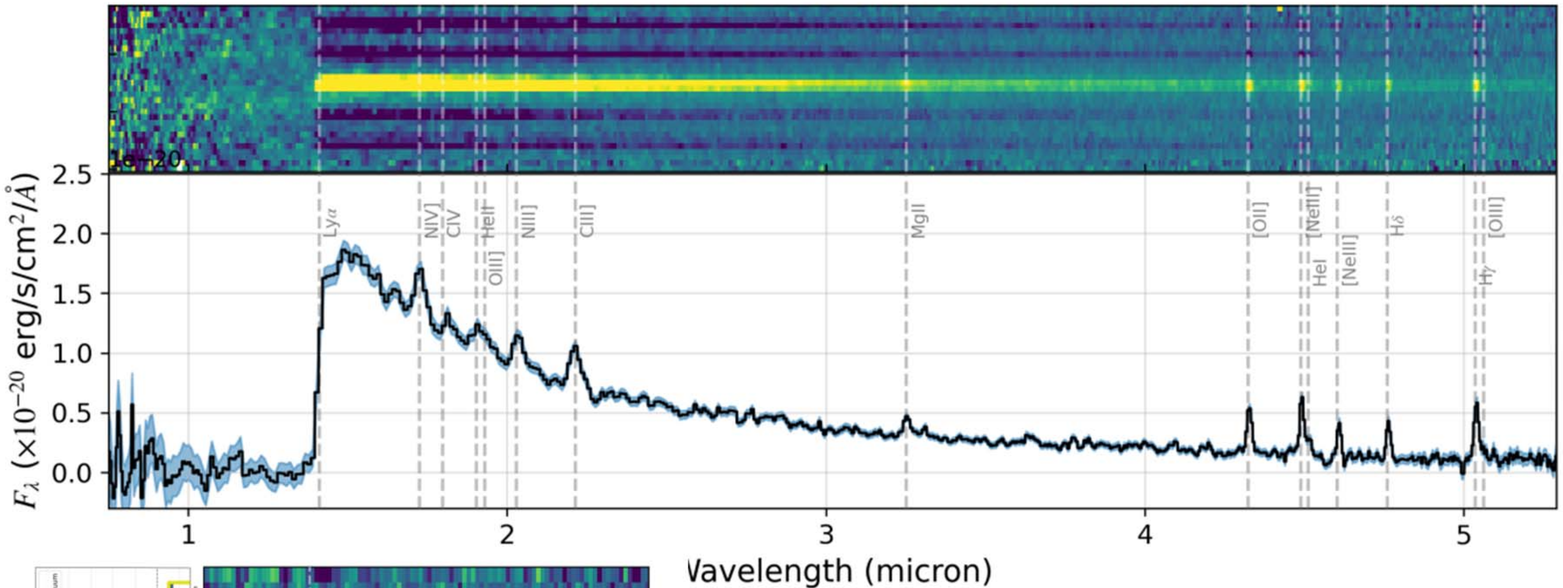
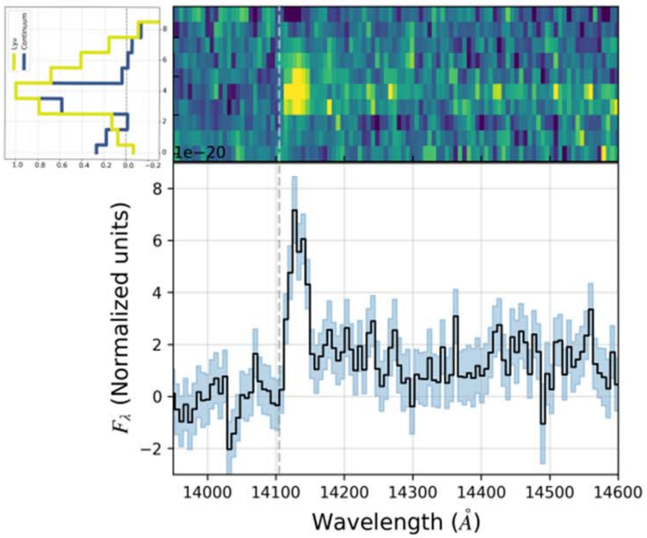


LAE @ z=7.51 by HST/FIGS
Tilvi et al. 2016

JWST/NIRSpec observations of LAEs at z>7

JADES NIRSpec Spectroscopy of GN-z11:



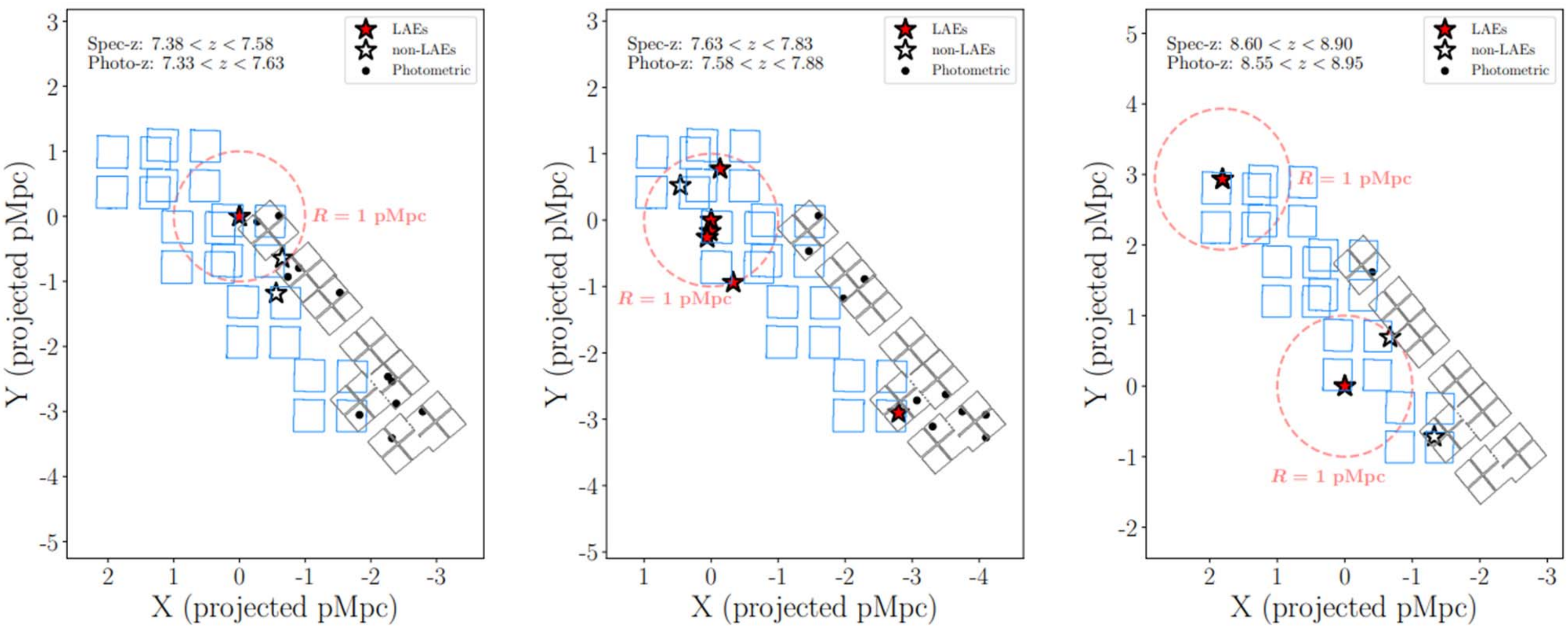


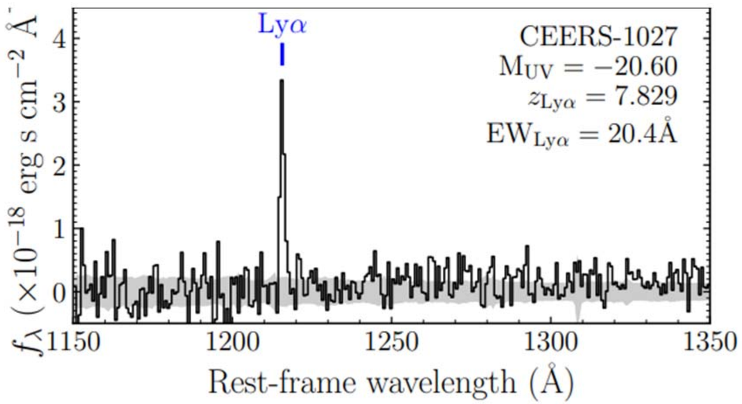
Spatially-extended Lyman-α emission was seen!

Bunker et al. 2023

JWST/NIRSpec observations of LAEs at z>7

ten newly-identified LAEs in the CEERS survey of the EGS field

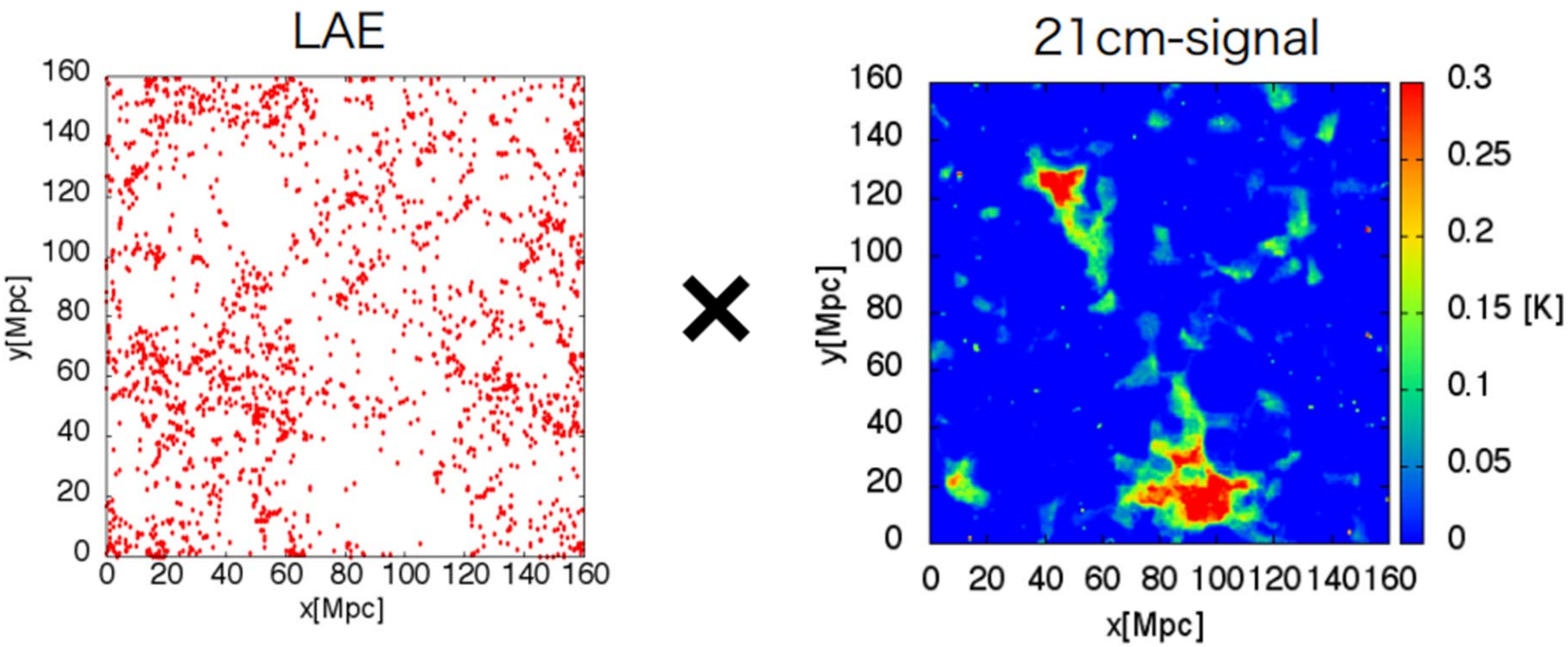




Tang et al. 2023

21cm-LAE synergies

A large and complete survey of LAEs at z>7 is needed to finally understand the physics of the EoR!



- The region around LAEs is dark in 21cm.
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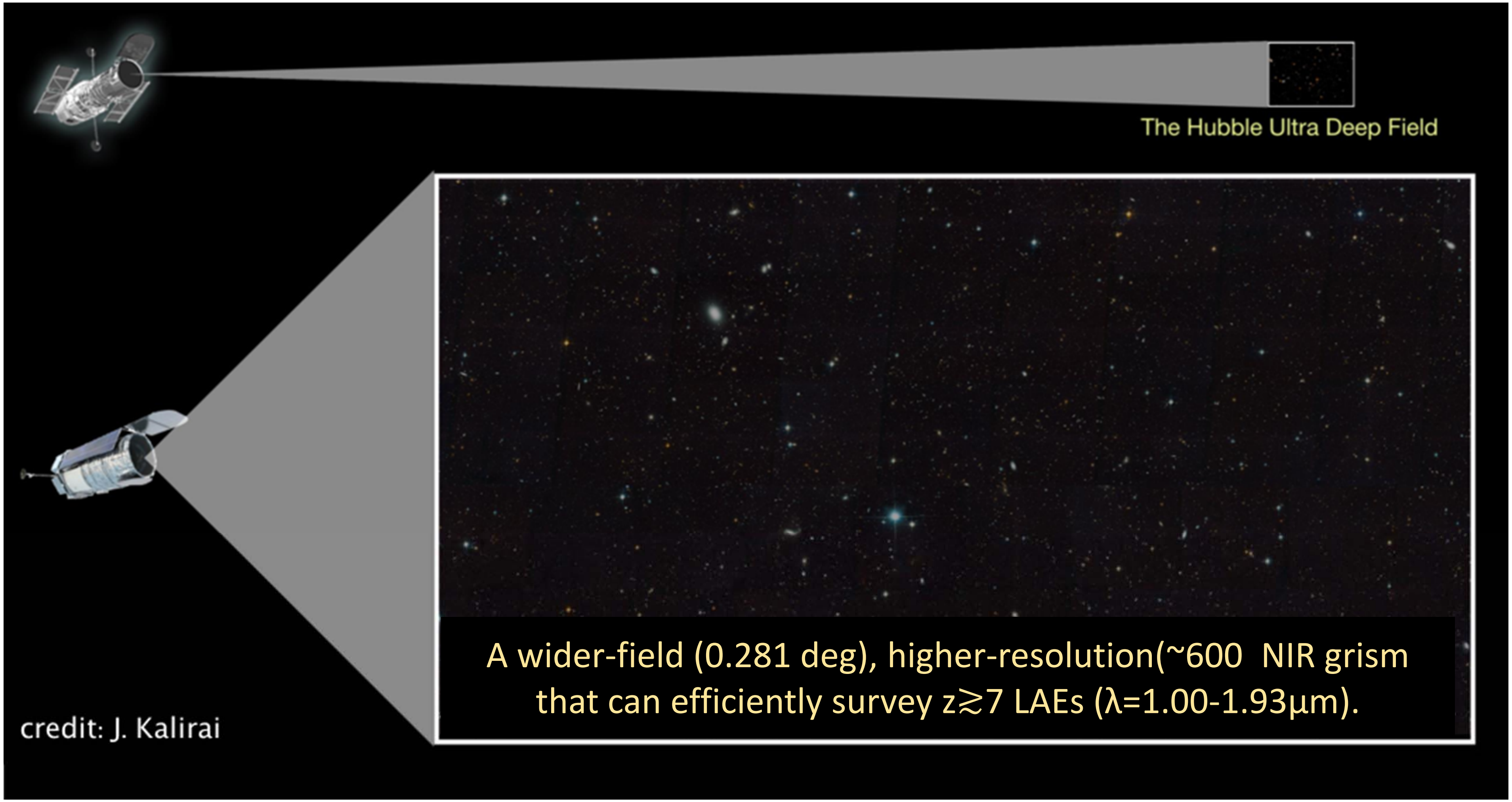
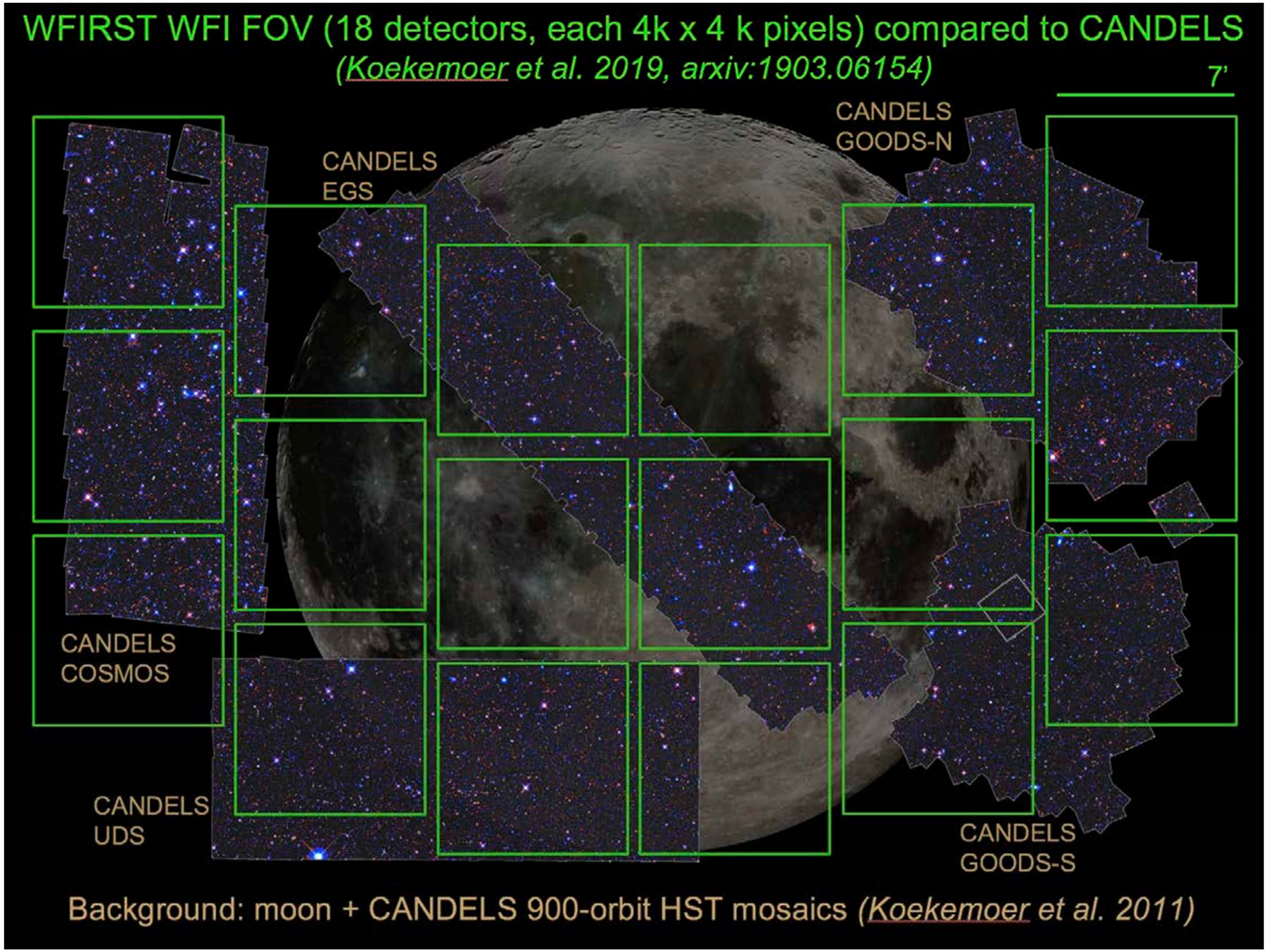
What Roman(WFIRST) Brings



What Roman(WFIRST) Brings

Roman/WFI FOV compared to HST CANDELS/UDF/XDF/HFF survey area



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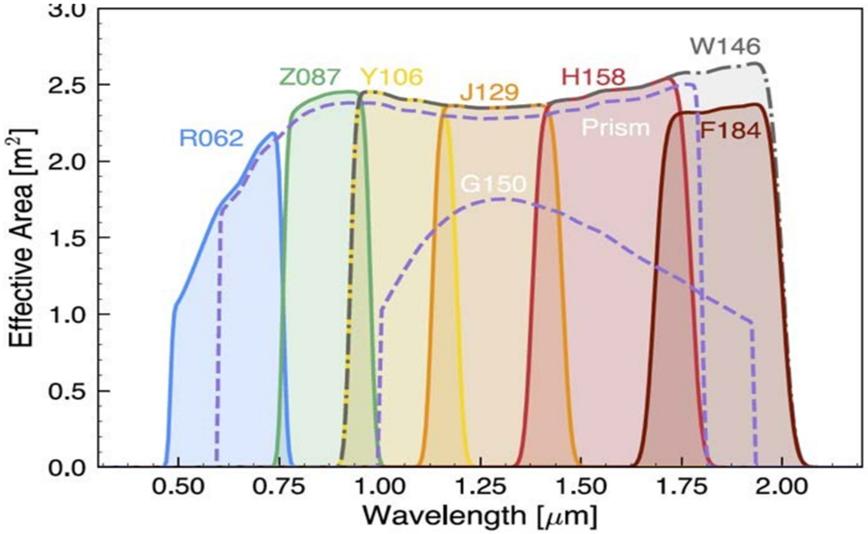
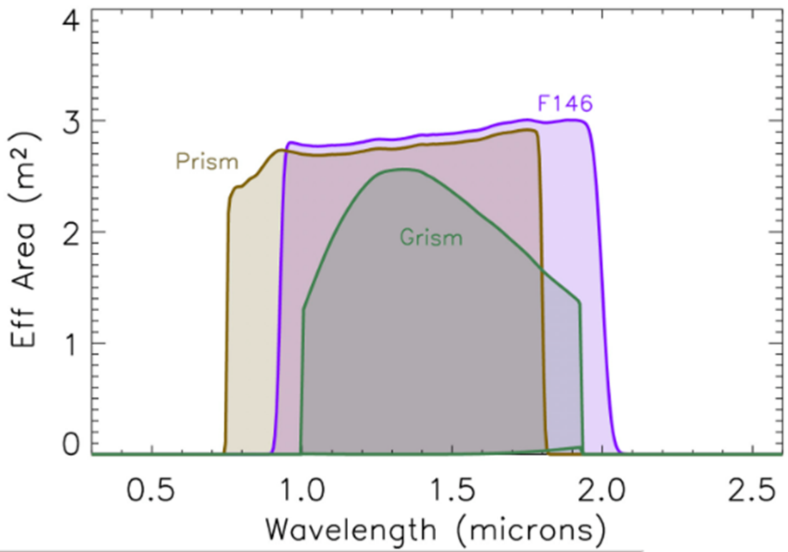




Roman Space Telescope Imaging Capabilities			
Telescope Aperture (2.4 meter)	**Field of View** (45′x23′; 0.28 sq deg)	**Pixel Scale** (0.11 arcsec)	**Wavelength Range** (0.5-2.0 μm)

Filters	**R062**	**Z087**	**Y106**	**J129**	**H158**	**F184**	**W146**
Wavelength (μm)	0.48-0.76	0.76-0.98	0.93-1.19	1.13-1.45	1.38-1.77	1.68-2.00	0.93-2.00
Sensitivity (5σ AB mag in 1 hr)	28.5	28.2	28.1	28.0	28.0	27.5	28.3

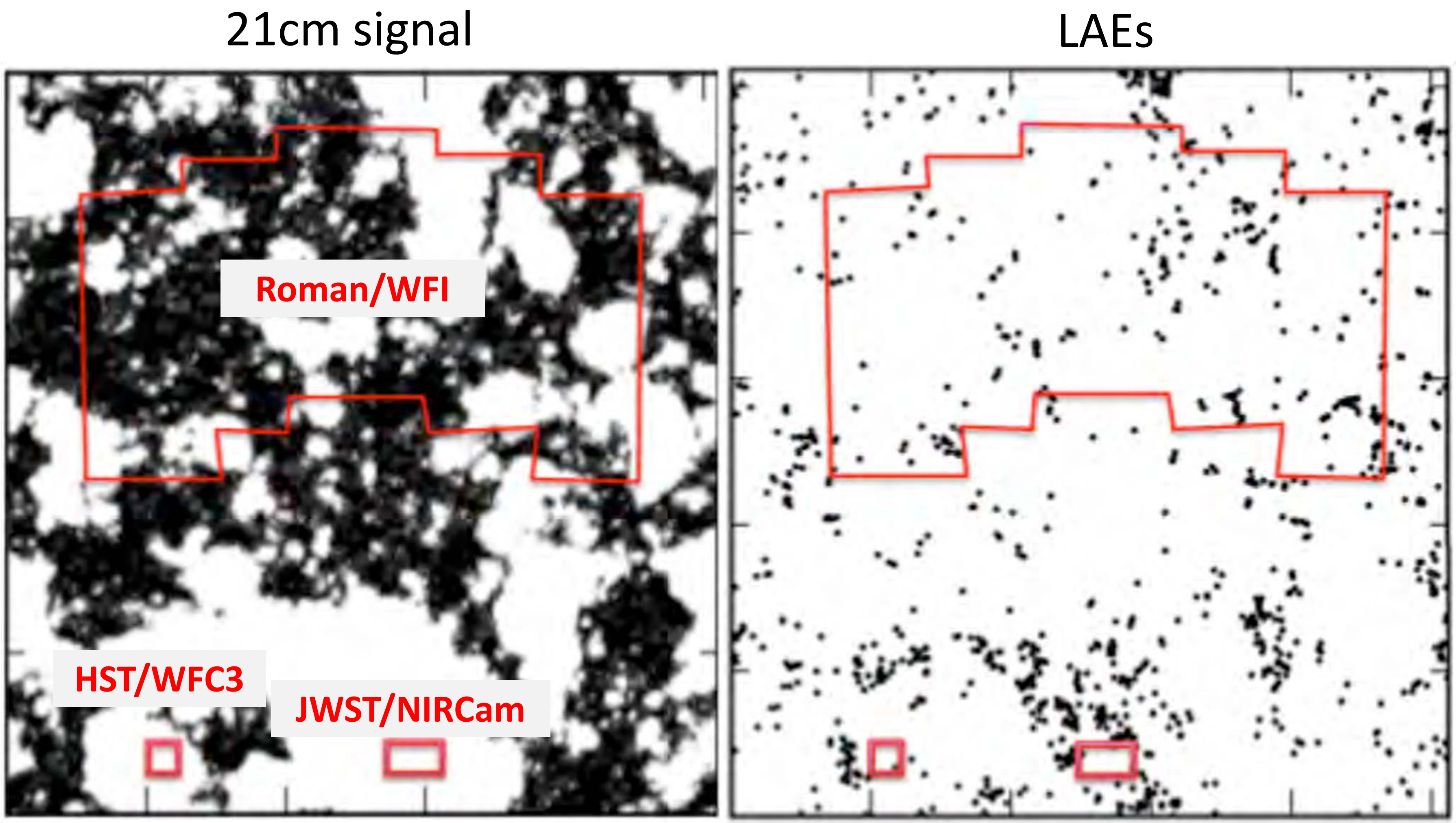
Roman Space Telescope Spectroscopic Capabilities				
	Field of View (sq deg)	**Wavelength (μm)**	**Resolution**	**Sensitivity (AB mag) (10σ per pixel in 1hr)**
Grism	0.28 sq deg	1.00-1.93	435-865	20.5 at 1.5 μm
Prism	0.28 sq deg	0.75-1.8	70-170	23.5 at 1.5 μm

What Roman(WFIRST) Brings

- Ground based surveys offer wide fields, but the atmosphere is a problem
  - Limited redshifts for sensitive narrowband work
- Space based surveys beat the atmosphere
  - No interference from bright sky lines which enables continuous redshift coverage.
  - Slitless spectroscopy [e.g. GRAPES, PEARS, 3dHST, FIGS] for emission lines
  - But HST, JWST have limited fields of view.
- Roman offers the best of both worlds, with its combined wide field and uninterrupted near-IR wavelength coverage.

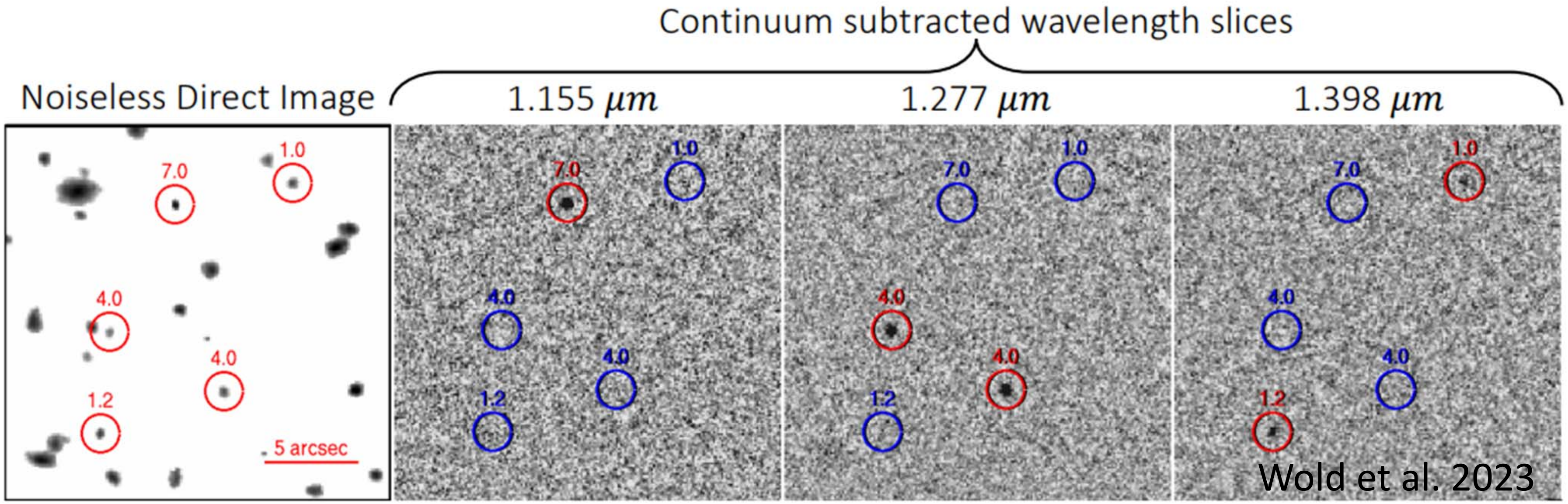
What Roman(WFIRST) Brings

Roman will find many more LAEs at z>7.



What Roman(WFIRST) Brings

- Vrbanec et al. (2020) predicted that Roman could observe spectroscopically about ~900 LAEs per deg^2 and unit redshift in the range 7.5 ≤ z ≤ 8.5.
- More recently, Wold et al. (2023) showed that a deep Roman grism survey with 25 PAs and a total exposure time of 70hrs can detect ∼ 450 deg^2 LAEs at z=8-9.



What Roman(WFIRST) Brings

LAEs-21cm synergies with Roman and SKA to shed light on the EoR

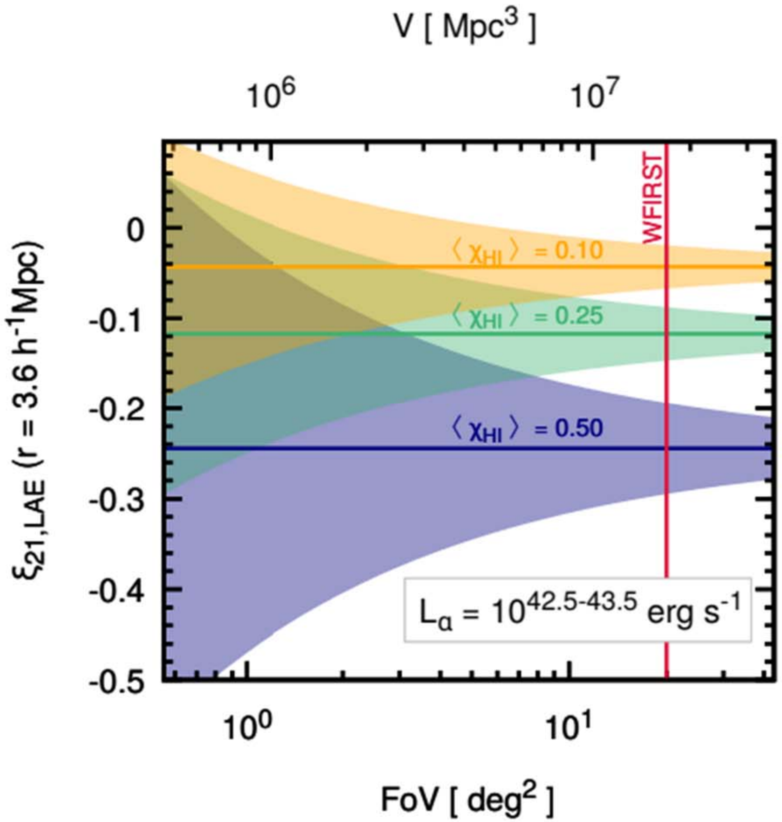
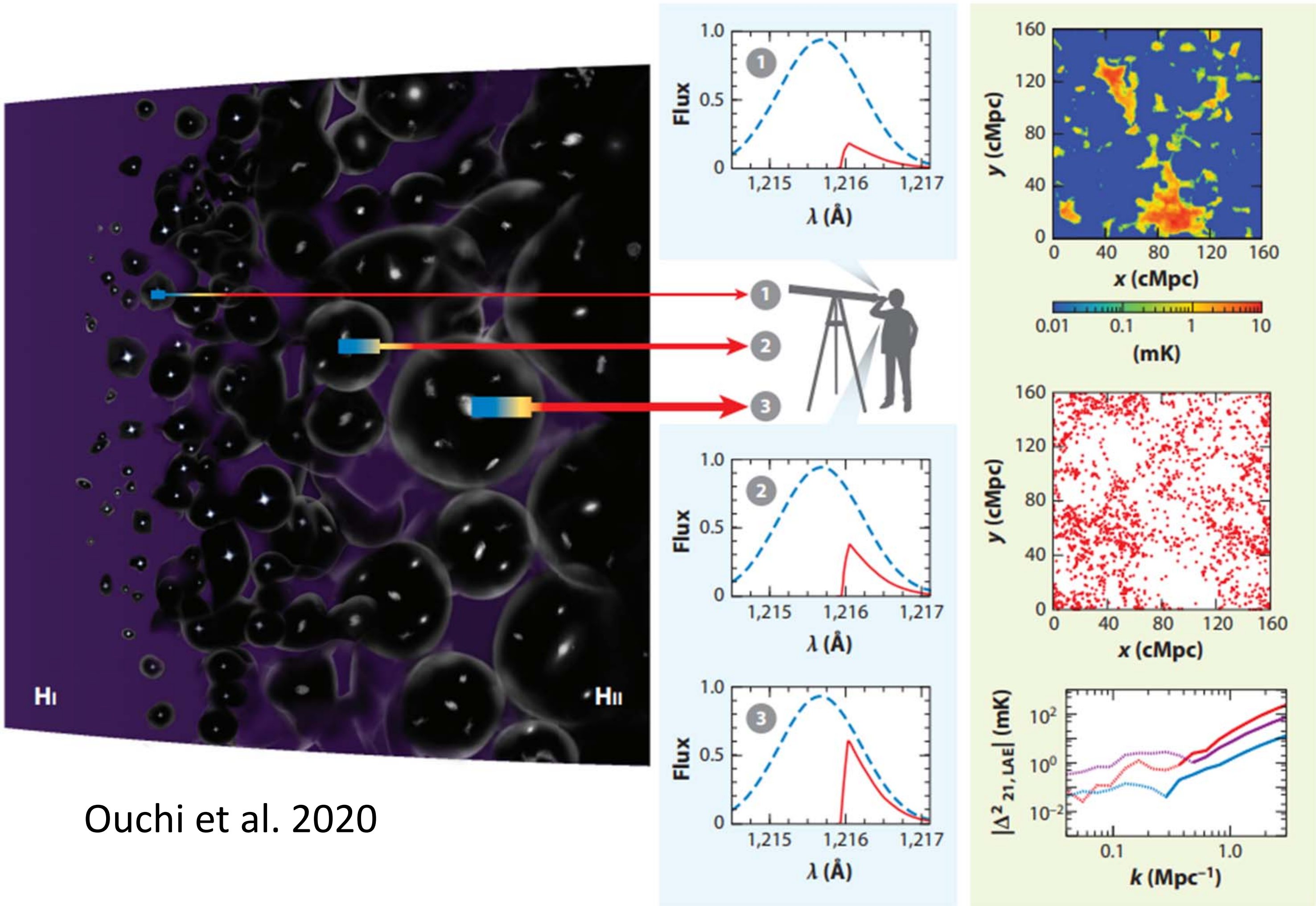


Figure 3: 21cm-LAE cross correlation function at $r = 3.6h^{-1}$cMpc for a survey Lyα luminosity limit of $L_\alpha = 10^{42.5}$erg s^{-1} for 1000h of SKA observations. The orange, green and blue lines represent results for $\langle \chi_{HI} \rangle \simeq 0.1$, 0.25 and 0.5, respectively. The shaded regions show the cross correlation function uncertainties as a function of the survey volume of the SKA and LAE observations. The vertical line shows the survey area for WFIRST. Surveying an area of 20 deg^2 to a depth of $L_\alpha = 10^{42.5}$erg s^{-1}, a correlation between WFIRST LAEs and SKA 21cm observations will be crucial in shedding light on the reionization state of the IGM.

Astro2020 White Paper by Hutter et al.

What Roman(WFIRST) Brings

Roman LAE and SKA 21cm observations to finally understand the physics of EoR over an uninterrupted redshift range spanning the end of the reionization era.



Ouchi et al. 2020

Summary

- LAEs are key sources for identifying signals of the 21-cm emission originated from neutral hydrogen at the EoR.
- to date, >1,000 (>20,000) LAEs have been spectroscopically identified (photometrically selected). However, only a few tens of them have z>7.
- Ground-based infrared surveys are increasingly impractical at redshifts beyond z ~7
- Roman's ability to obtain deep NIR spectra over a wide field of view will allow us to coherently measure the evolution of the LAEs at z>7. This will provide ionization measurements of the IGM at cosmic dawn.
- Roman LAE and SKA 21cm observations offer a unique opportunity to finally understand the physics of EoR over an uninterrupted redshift range spanning the end of the reionization era.

Thanks!

Backup slides

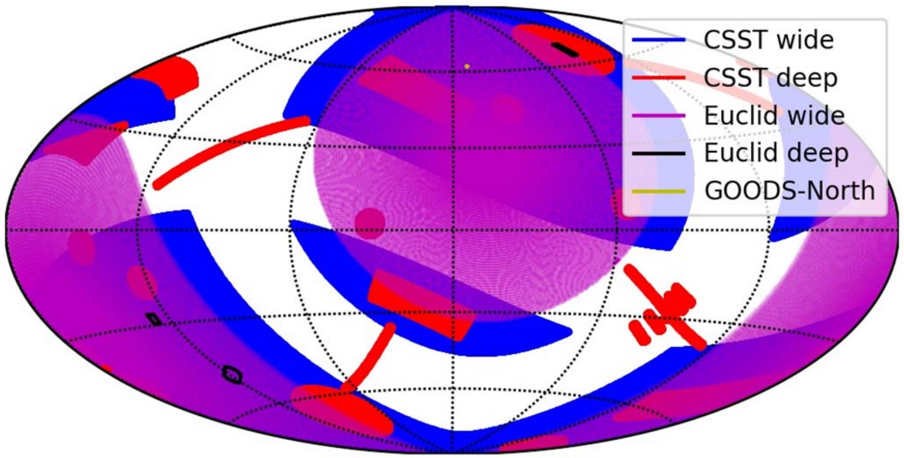
CSST-Euclid-Roman

overlap area (sqdeg)

Ultra-Deep(64*250s): 10

Deep(8*250s): 400

Wide(2*150s): 1000



Liu et al. 2023, in prep.

CSST-Euclid-Roman Realisti

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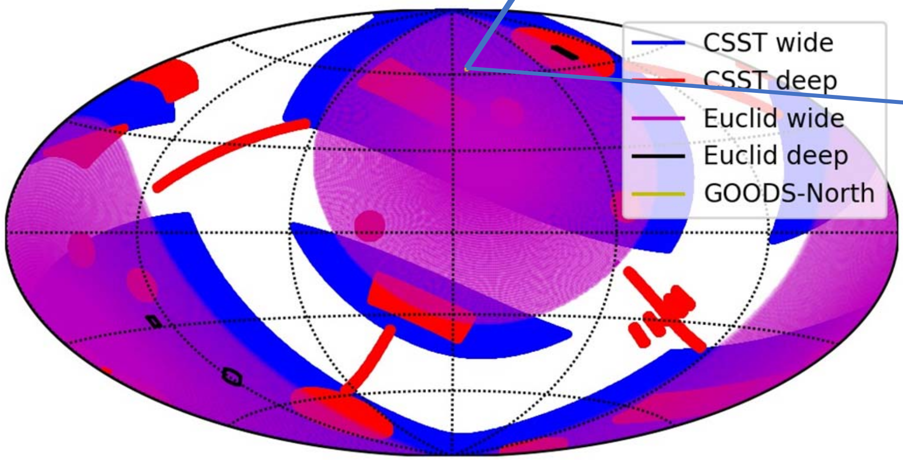

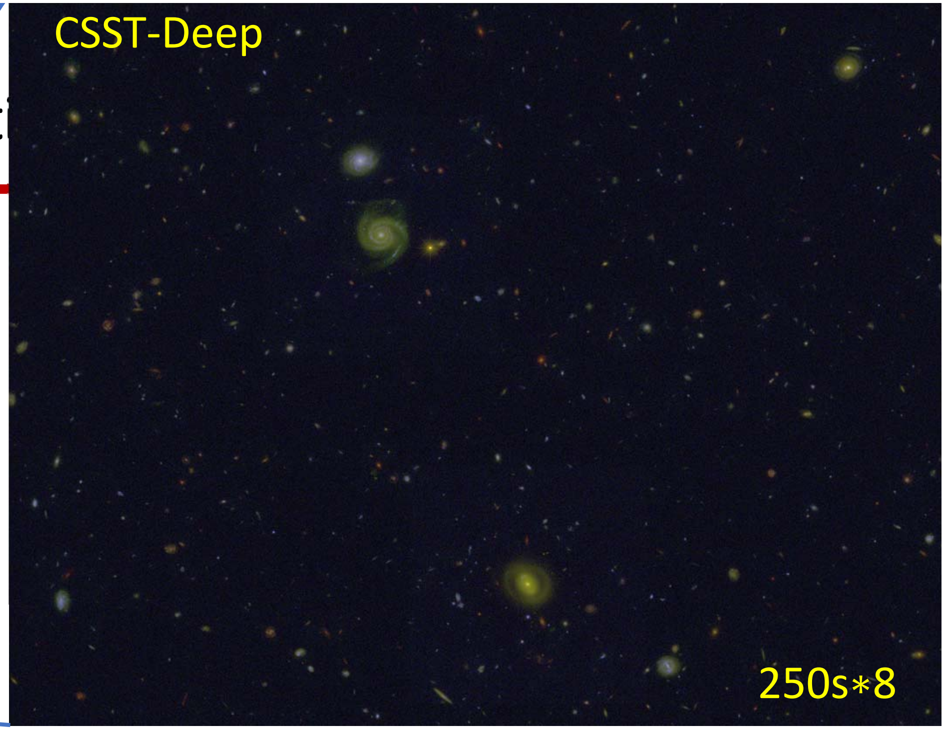

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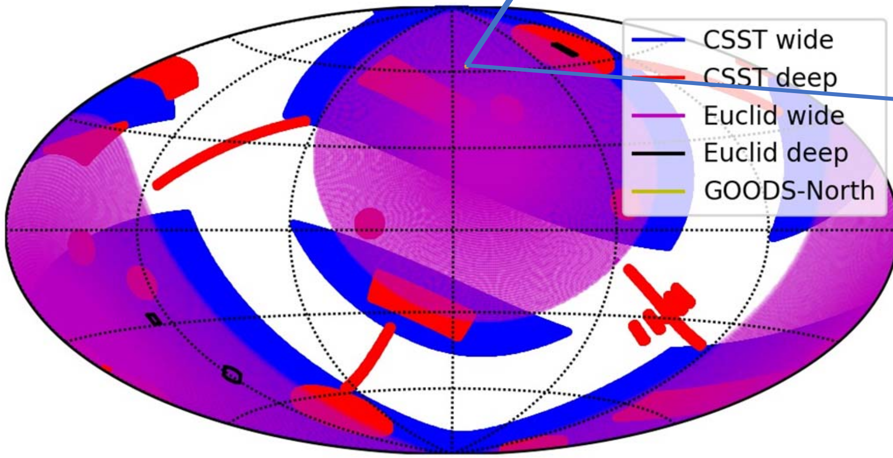

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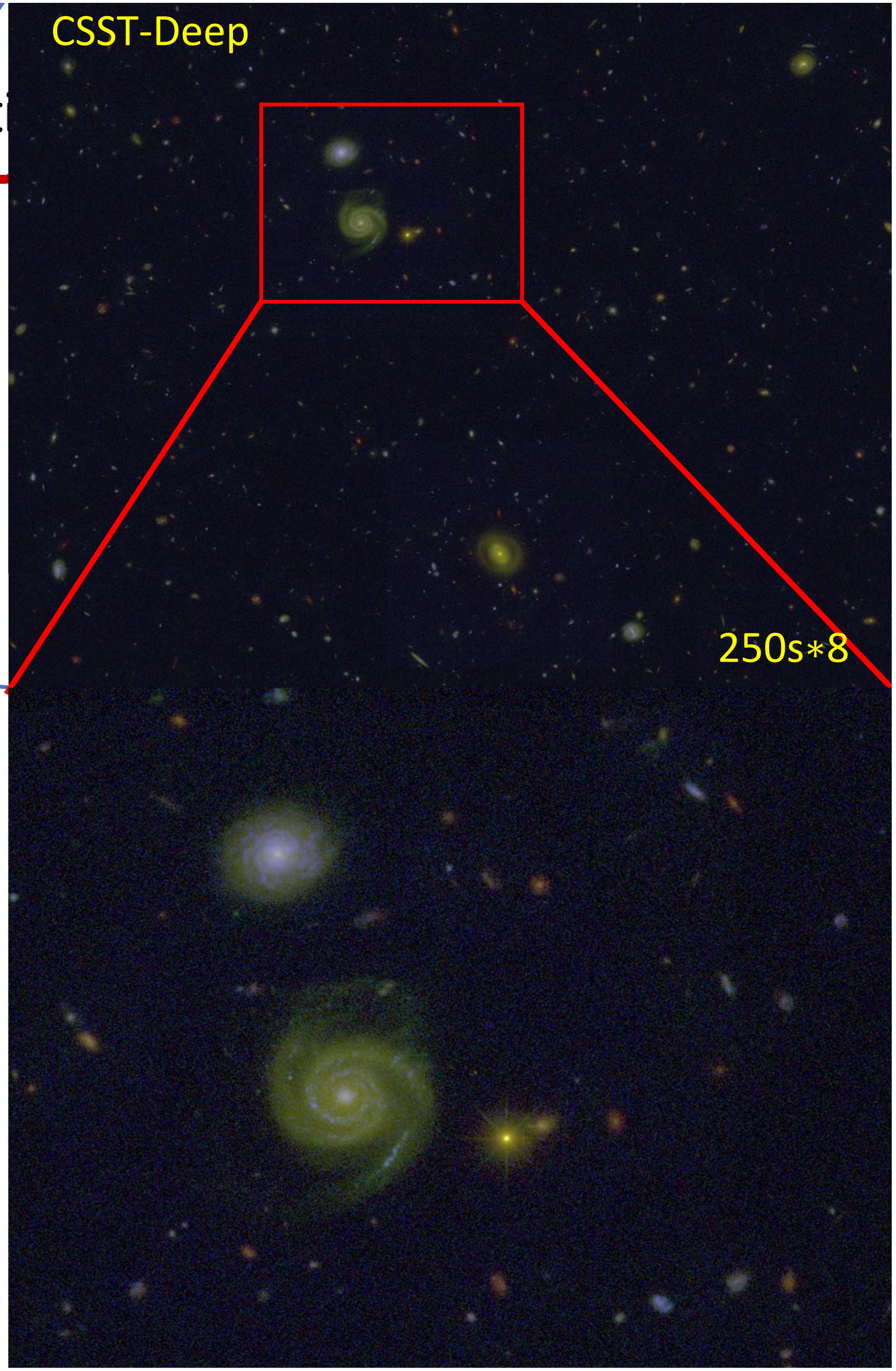

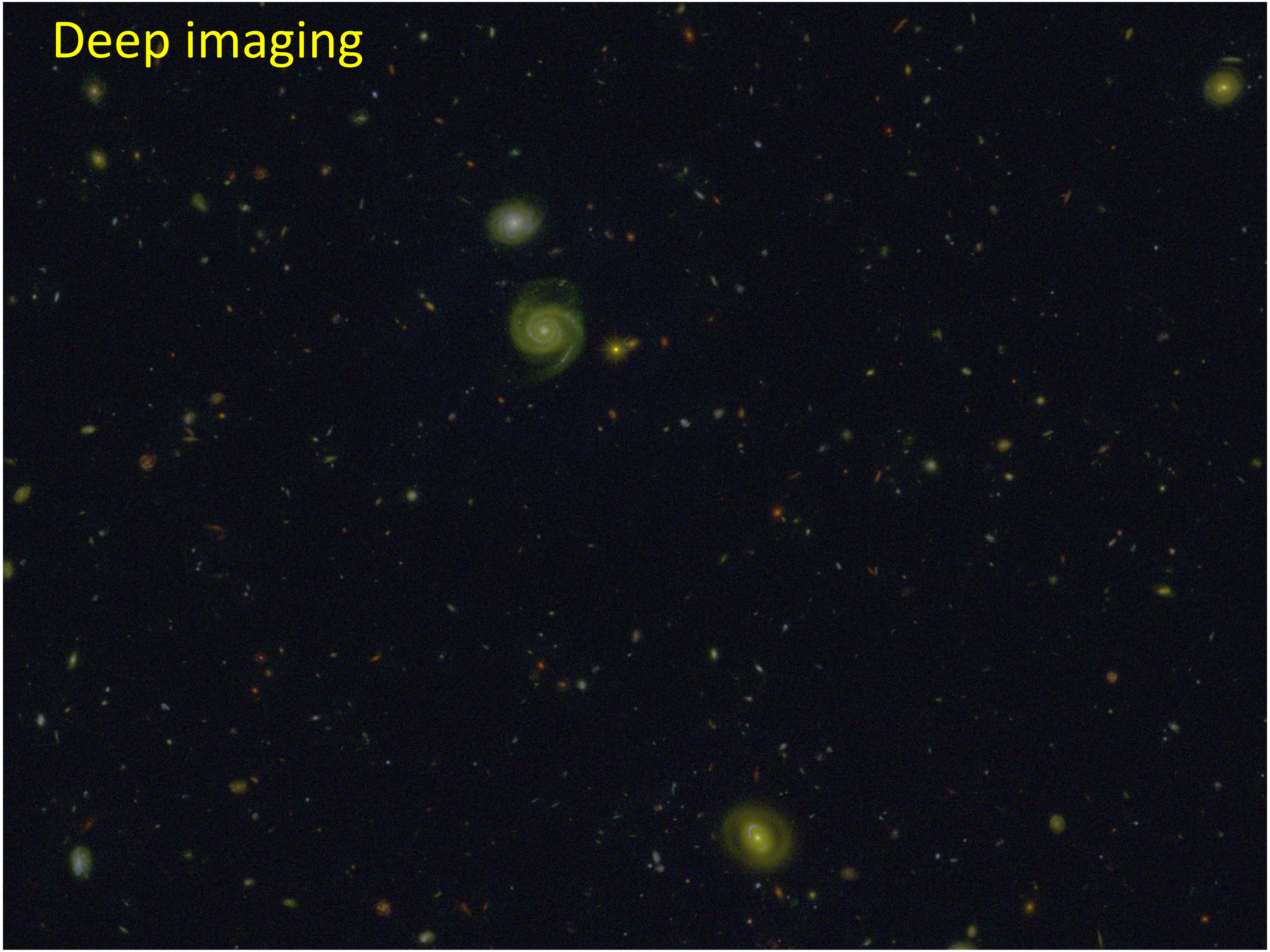
Deep imaging

Slitless spectroscopy