Measuring the Evolution of Reionization w/ Big-Glass Observations of Lyα emission

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Featuring work led by UT graduate students

Intae Jung *(-> NASA GSFC) and* ***Rebecca Larson***

<u>**Based on Astro2020 Science White Paper (https://arxiv.org/pdf/1903.04518) by:**</u>

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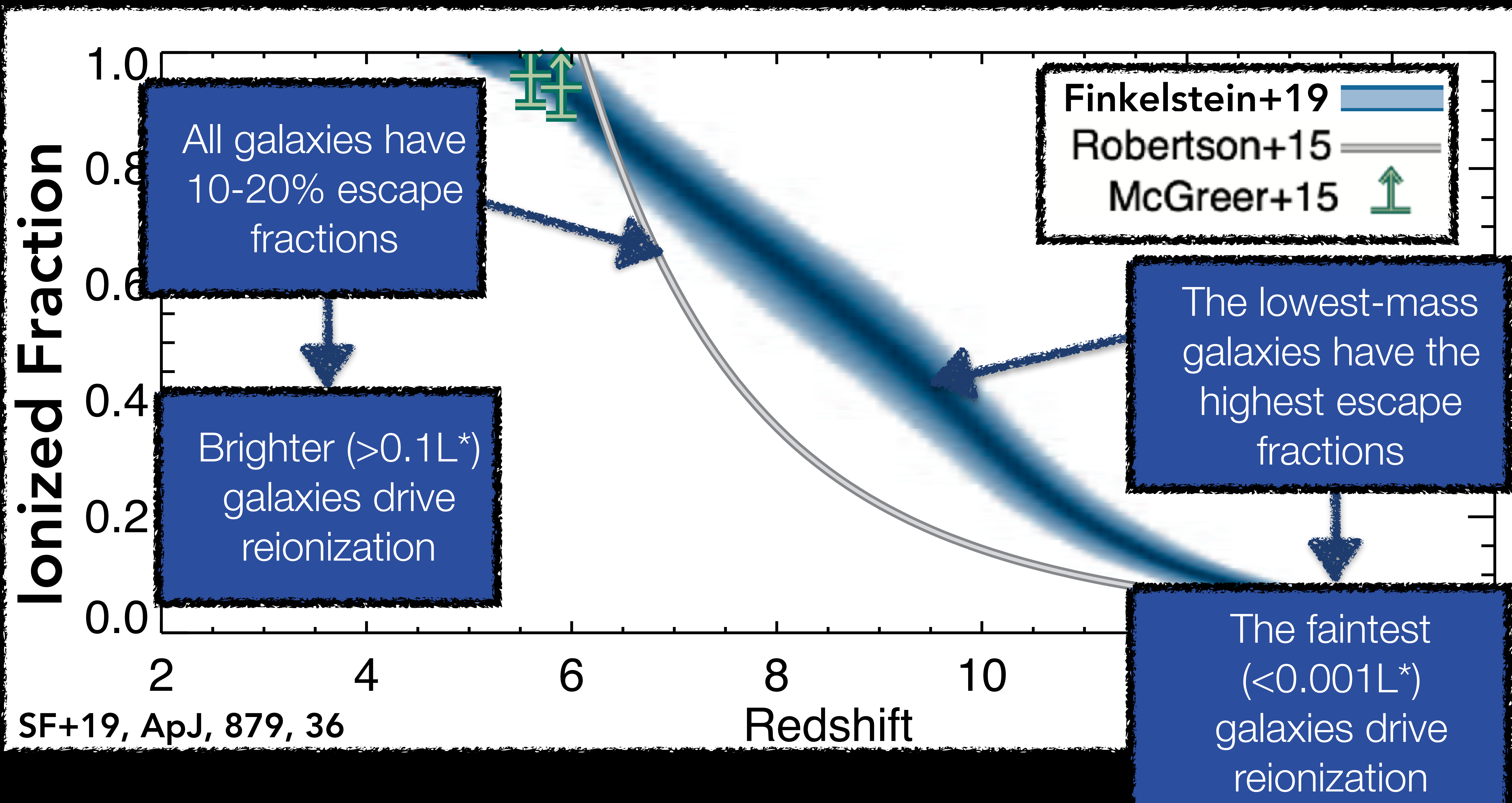
Image credit: Ocvirk+19

How rapidly does reionization end?

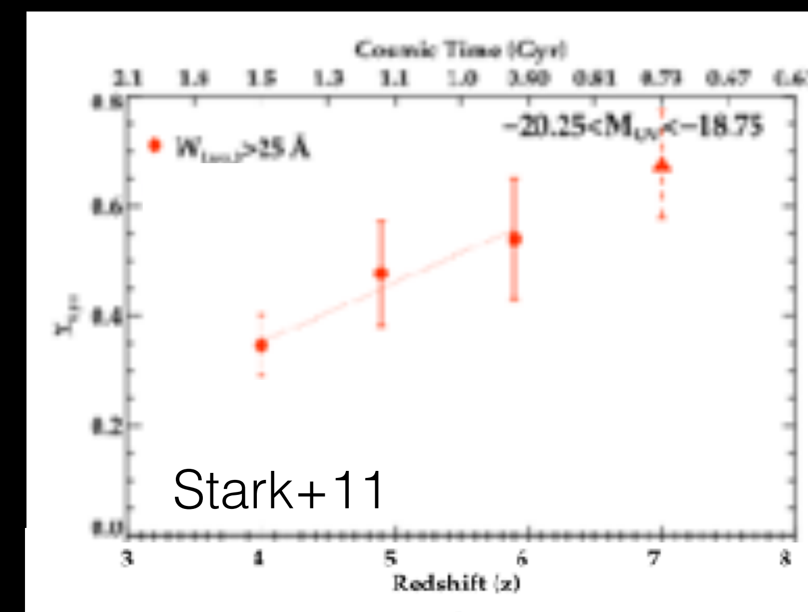
Understanding how reionization ends can tell us what drives it

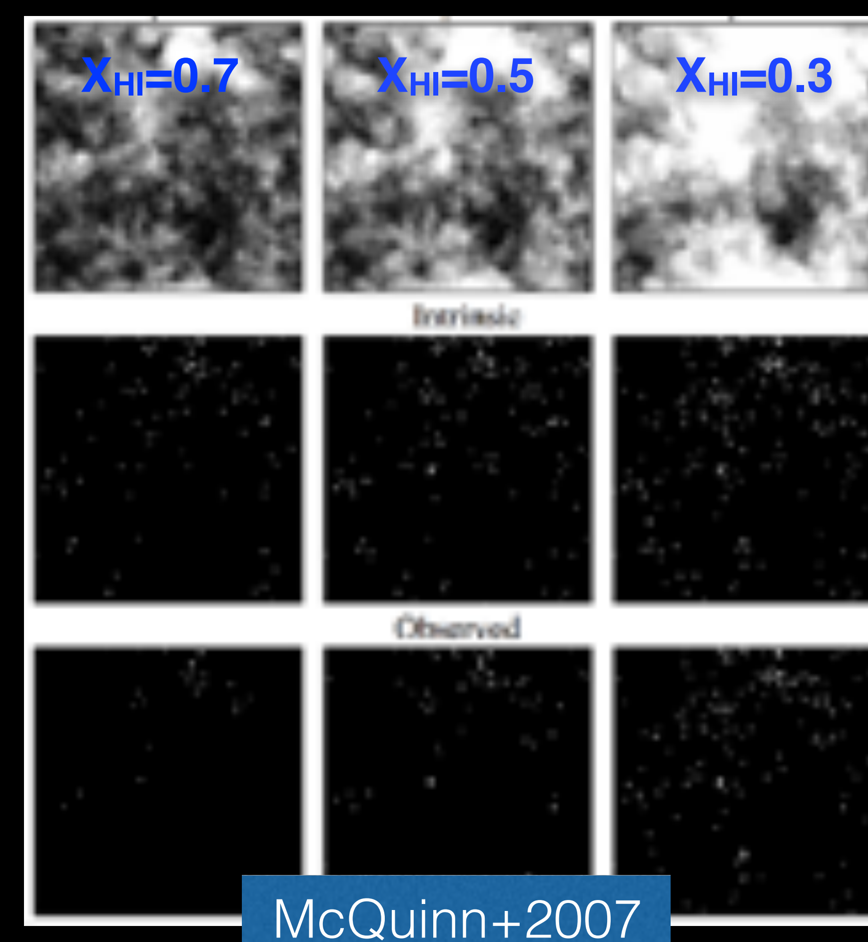


SF+19, ApJ, 879, 36

What is the ionized fraction at z~7-8?

- Lyα should be a sensitive tracer of reionization (e.g., Miralda-Escude+98, Malhotra & Rhoads 04, 06; Furlanetto+06; Dijkstra+07).
    - It is relatively “abundant” at z=6, just after the end of reionization, and is resonantly scattered by HI.
    - A patchy IGM should be directly traceable by the patchiness of Lya emission.

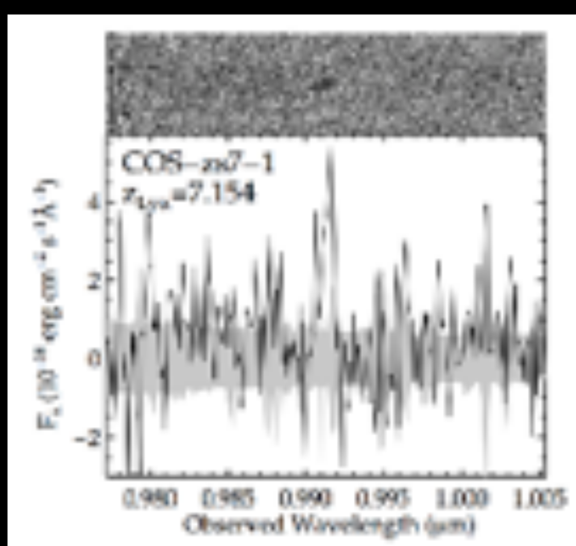




Is Lyman-alpha indicating a substantially neutral IGM?

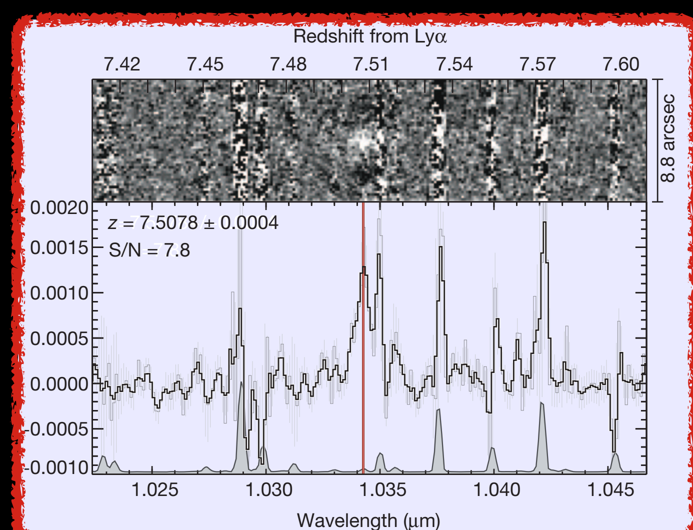
- This has led to a booming industry of attempted Lyα measurements at z > 6.5, with some notable successes (e.g., Shibuya+12, Finkelstein+13, Rhoads+13, Oesch+15, Zitrin+15, Roberts-Borsani+16, Song+16, Stark+16, Hoag+17, LaPorte+17).

z=7.17



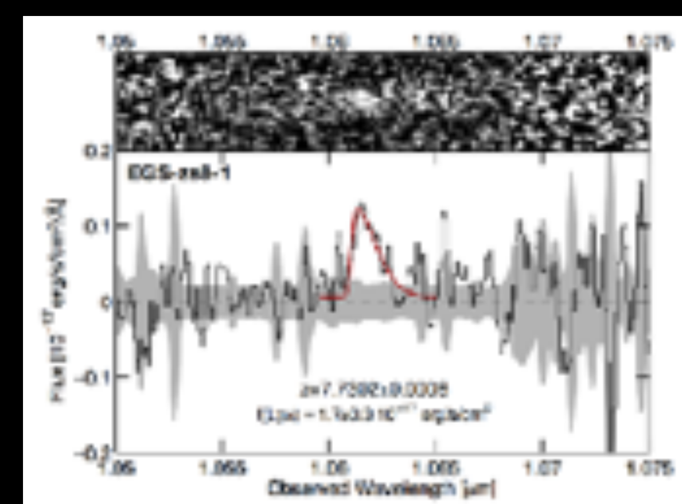
STARK+2016

z=7.51



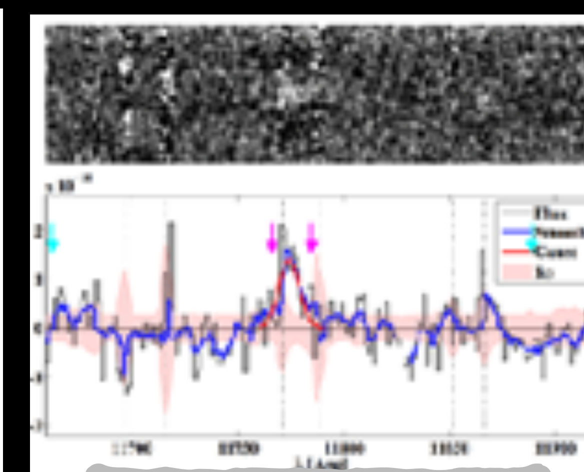
FINKELSTEIN+2013

z=7.73



OESCH+2015

z=8.68



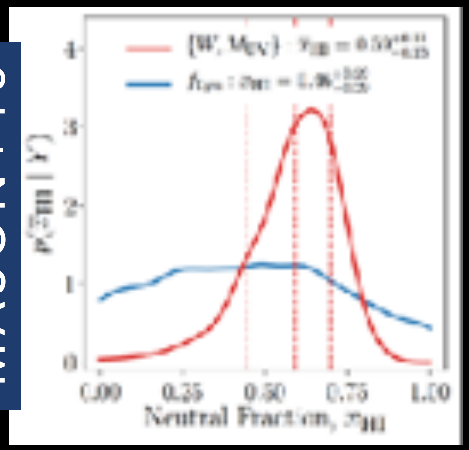
ZITRIN+2015

What is the ionized fraction at z~7-8?

- In spite of some detections (e.g., Shibuya+12, Finkelstein+13, Oesch+15, Zitrin+15, Song+16, Stark+16, Hoag+17, LaPorte+17, Hu+18), **the majority of z>7 galaxies go undetected with spectroscopic followup**.

- How high of a neutral fraction is needed?
  - The most recent studies infer X_{HI} = 60-90% at z=7-8 (Mason+18,19; Hoag+19).

MASON+18



- However, converting observed spectra to constraints on the neutral fraction has lots of <u>assumptions and potential for systematic uncertainties</u>, including:
    - Incomplete spectral coverage of the full P(z); copious telluric emission lines.
    - Limited spectroscopic depth
    - Small areas covered

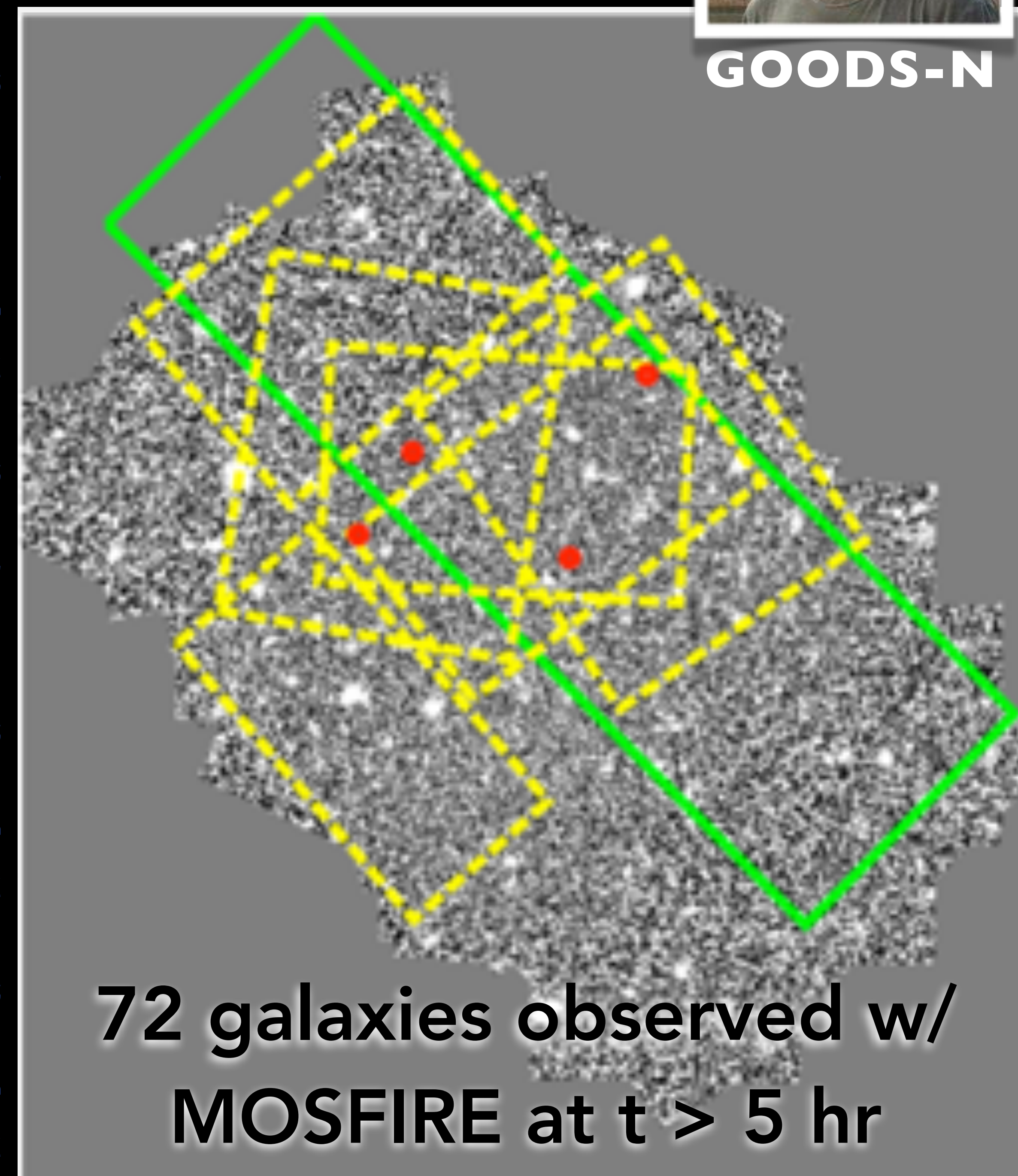
The Texas Spectroscopic Search for Lyα emission at the End of Reionization

In Intae Jung's thesis work, we used data taken over 18 nights from Keck with DEIMOS and MOSFIRE to try to overcome some of these systematics, specifically:

Depth: Our MOSFIRE integrations range from 5-20 hours.

Sample selection: Significant effort to improve the photo-z's (and minimize sample contamination) of the observed galaxies.

Wavelength: ~20 of our sources are covered by both DEIMOS and MOSFIRE



Nine z > 7 Lyα lines detected at >4σ @ $z_{Ly\alpha}$=7.1-7.9 (*five at >5σ @ z=7.1-7.6*)

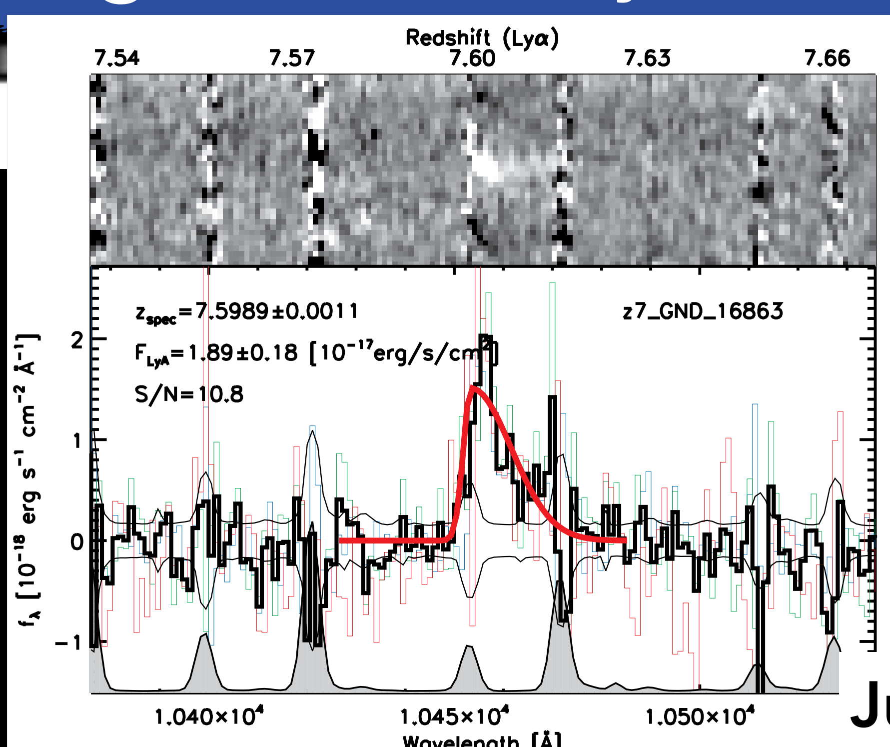
EW_0 ~ 20 - 200 Å (see also Larson+18)

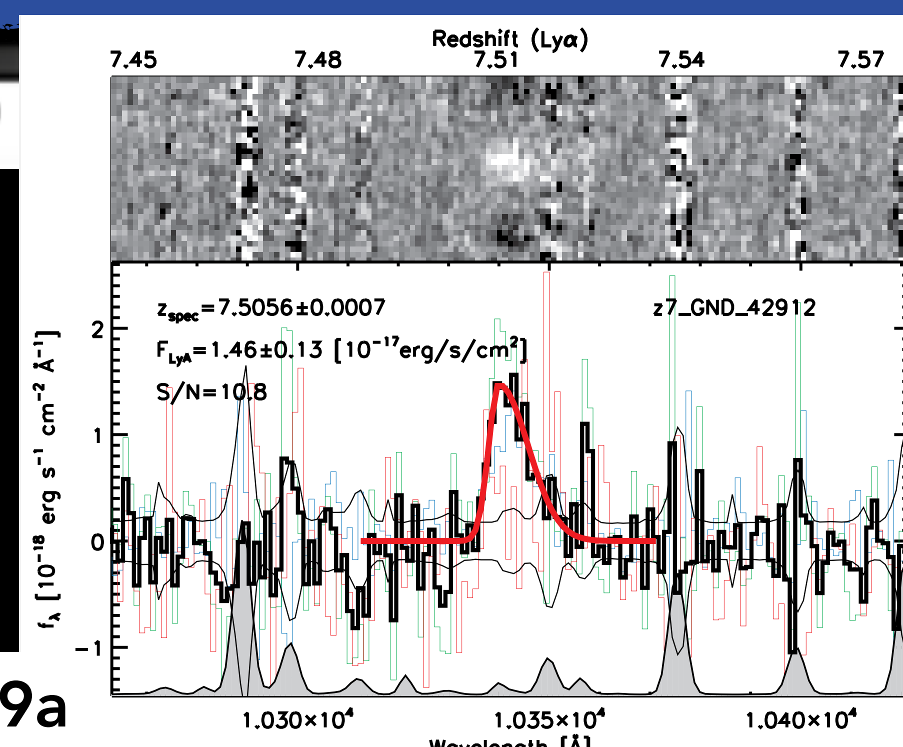
- ...d: S/N > 5
- Blue: 4 < S/N < 5
- Black: 3 < S/N < 4

(Finkelstein+13, Jung+19a)

(Jung+19a)

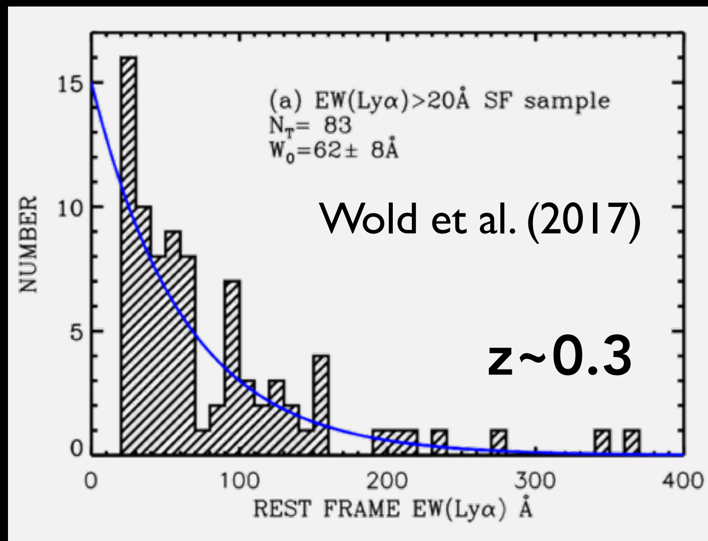
Significant asymmetry is seen when S/N > 10

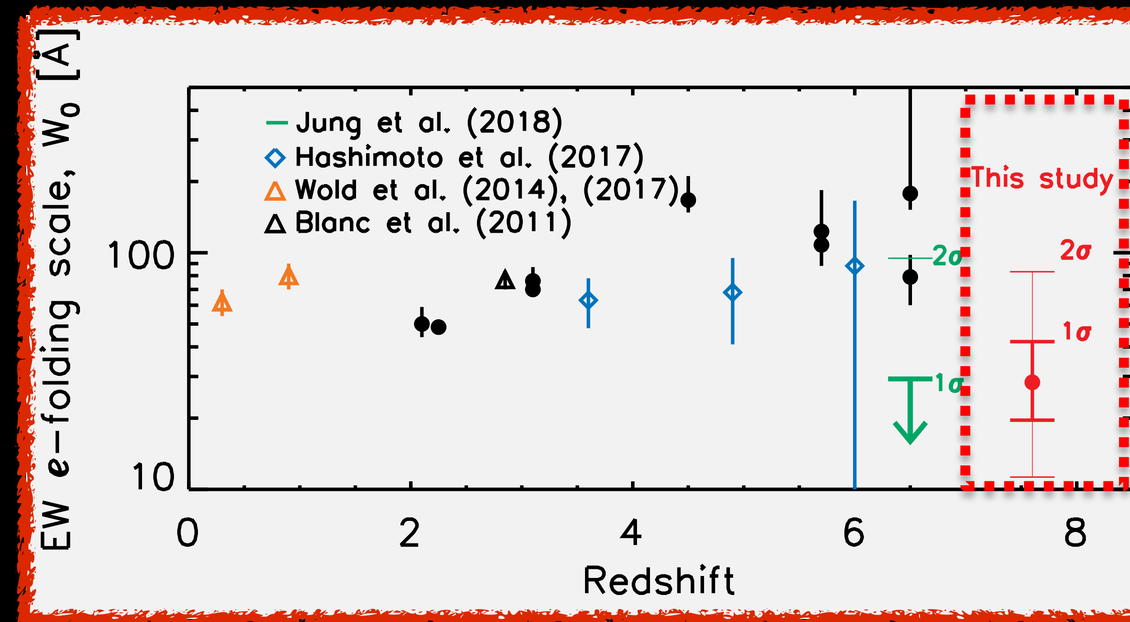




Jung,SF+19a

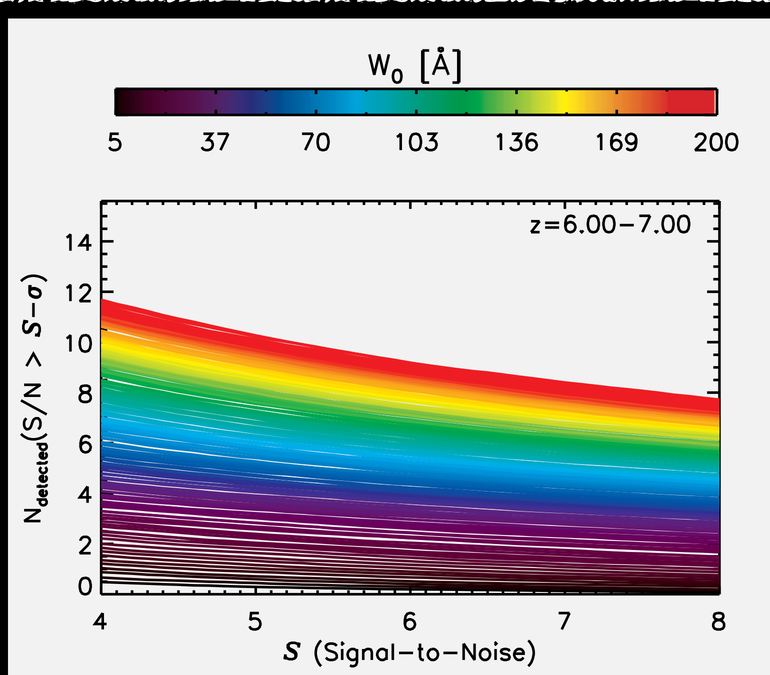
PARAMETERIZING EVOLUTION VIA THE EQUIVALENT WIDTH DISTRIBUTION

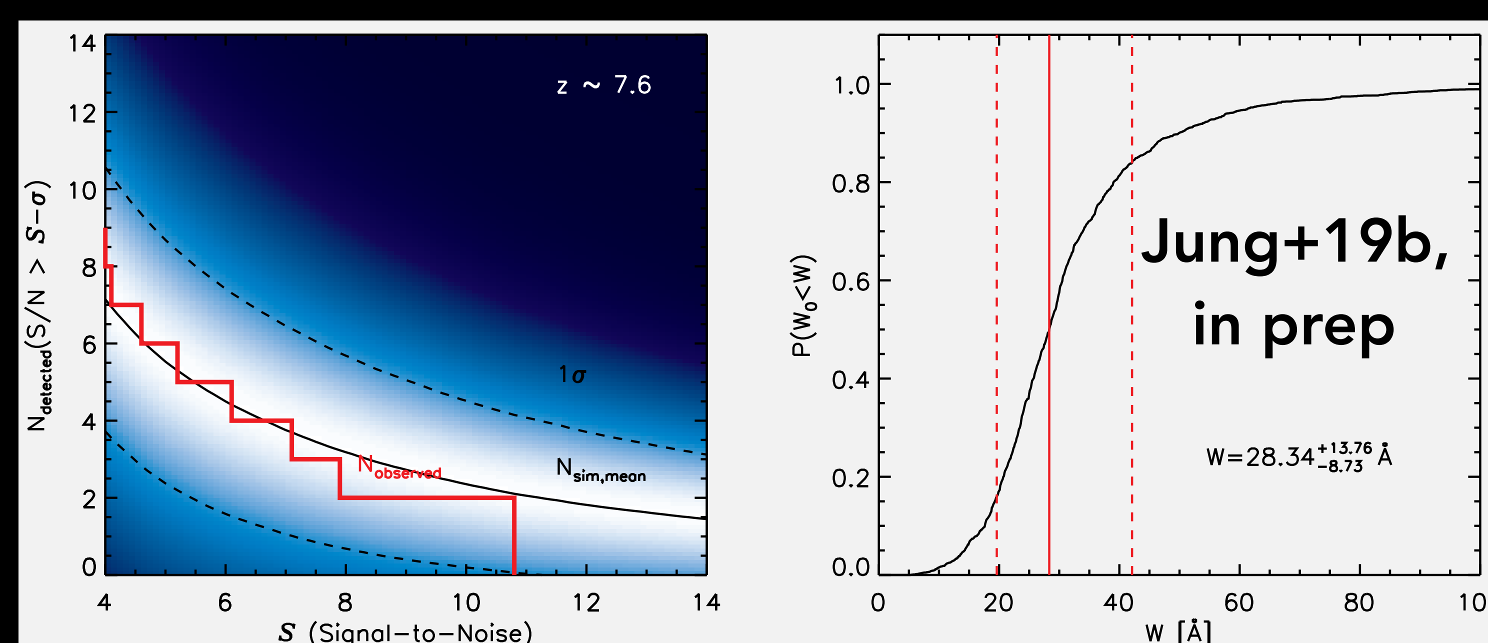




We use our observations to model the Lyα equivalent width (EW) distribution, accounting for all sources of incompleteness and uncertainty by implementing via MCMC (Jung+18, 19ab).

We constrain the characteristic scale-length of this distribution, predicting for a given value the number of lines we should detect at a given S/N in our data.





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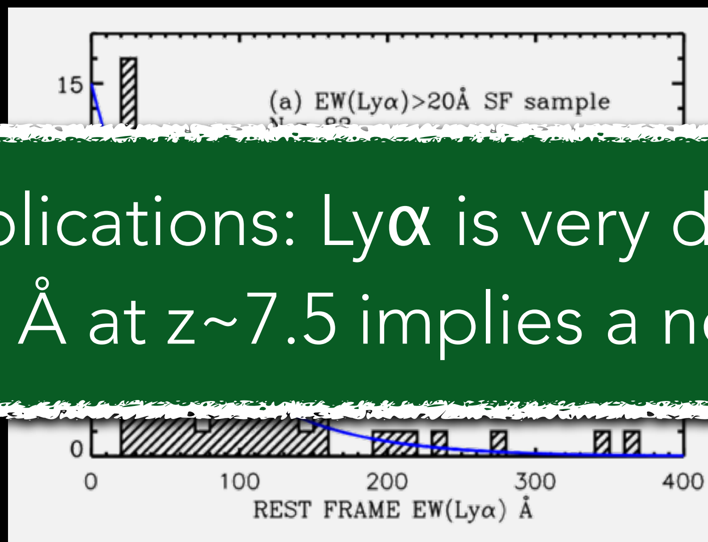

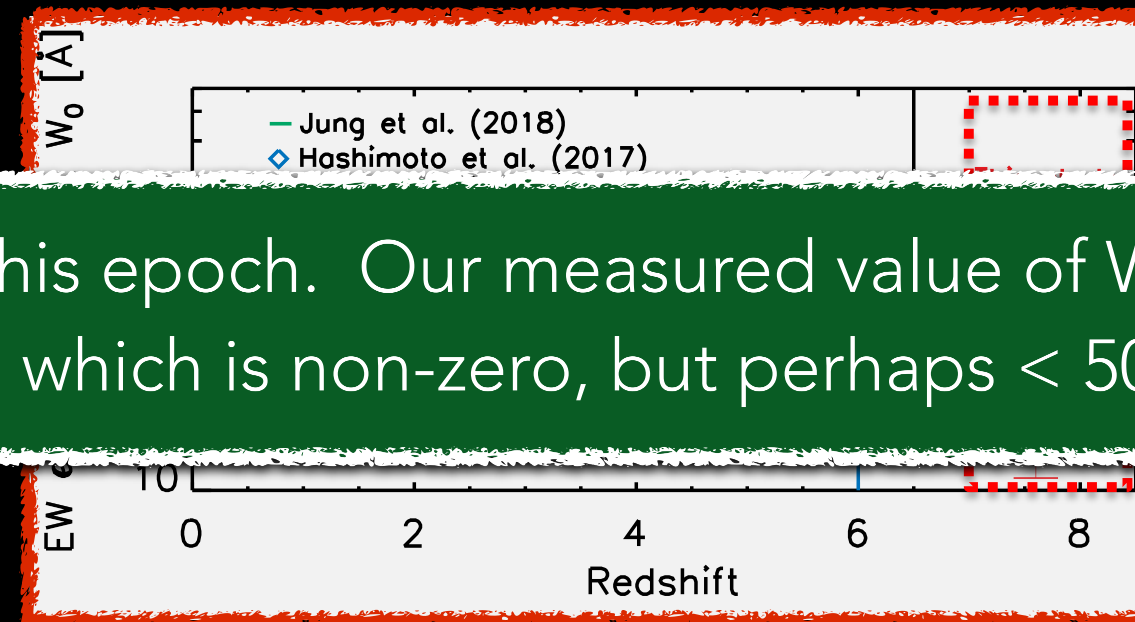

Implications: Lyα is very detectable in this epoch. Our measured value of W_0 ~ 30 Å at z~7.5 implies a neutral fraction which is non-zero, but perhaps < 50%.

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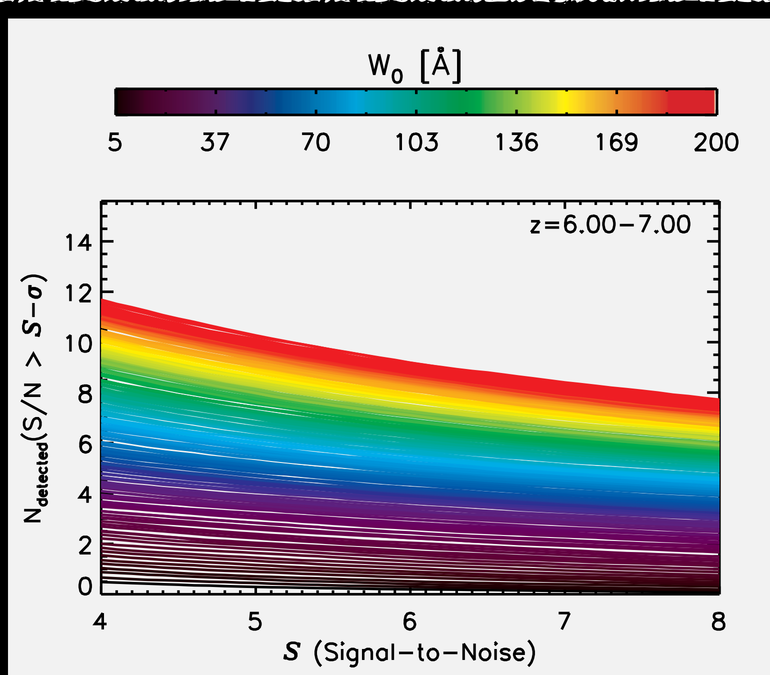
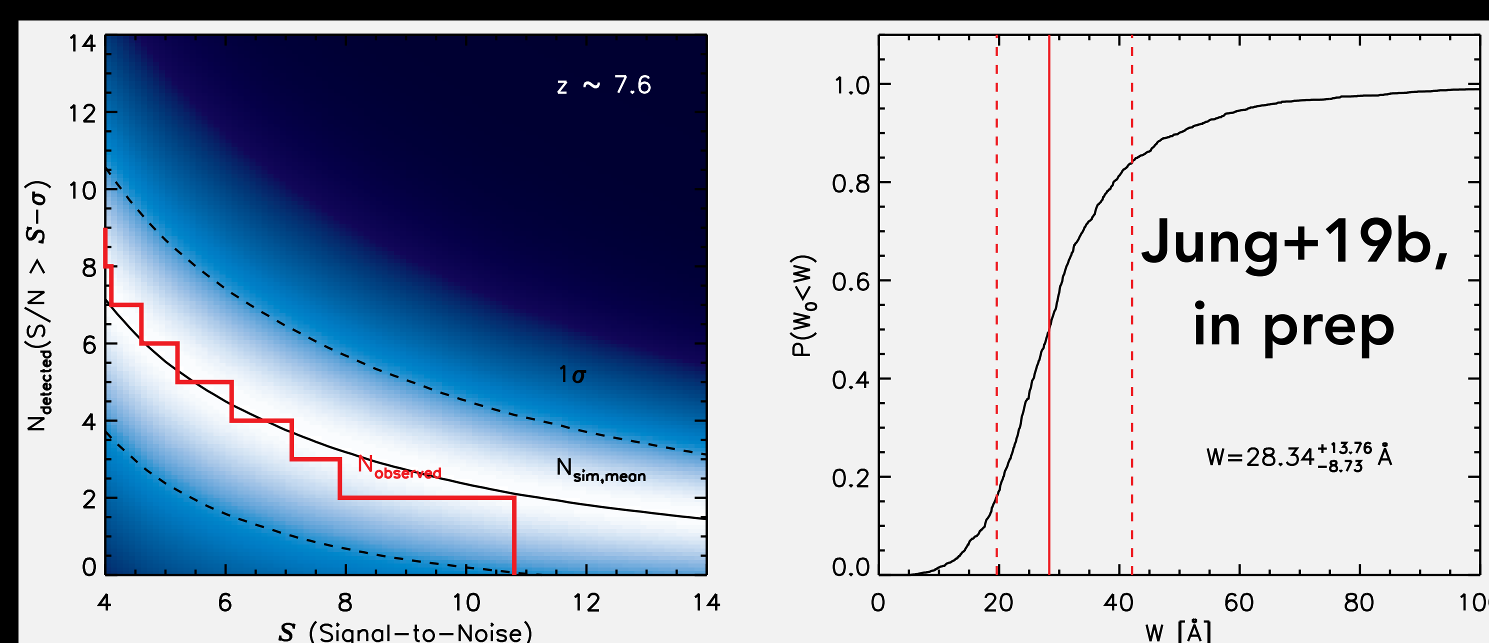
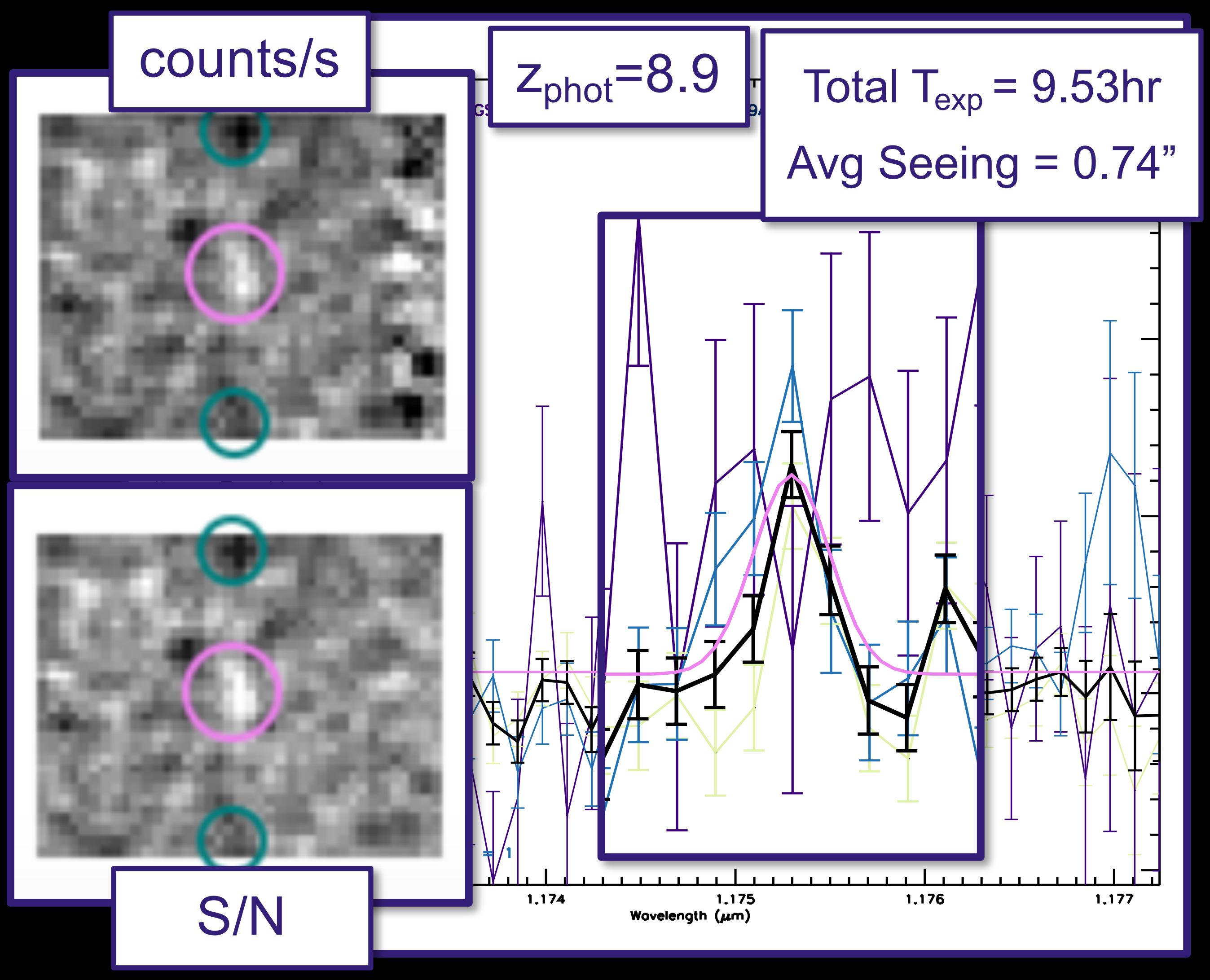




TRYING TO PUSH TO z=9

- We (PI Rebecca Larson) has been leading Keck/MOSFIRE followup of a larger sample of bright z~9-10 galaxies (SF+19b, in prep).
    - We have observed ~10 galaxies at t=5-10 hr depth in the J-band, which covers Lyα at z~8.5-10.1.
    - After a ***lot*** of hard work, accounting for drift along the slit, and differing slit positions between observations, we have a few potential detections.
    - How to best confirm these? ALMA can help, though many of these are in the north. Big glass would be great!



WHAT REMAINING PROBLEMS ARE THERE?

- Combing back to z~7-8, our sample is still small - an effective 10 nights of integration with Keck, and we were only able to observe ~20 galaxies to >10 hr.
- Most of these are bright (J < 26.5)
- The MOSFIRE FOV is small.
    - Large areas (1 deg^2+) need to be observed to overcome CV, and probe multiple ionized bubbles.
- The need: **<u>a wider field and larger aperture.</u>**

Scales of reionization

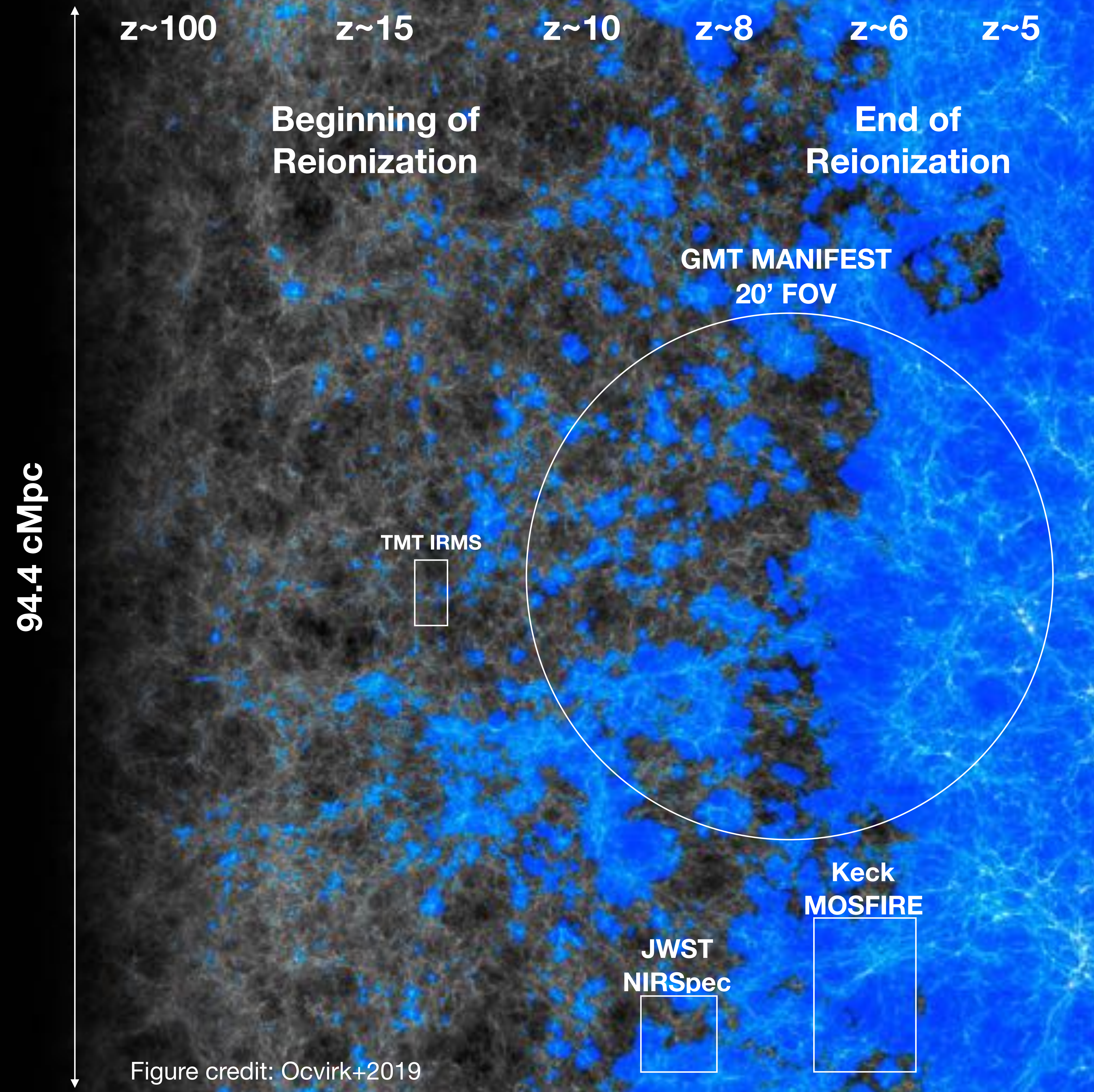
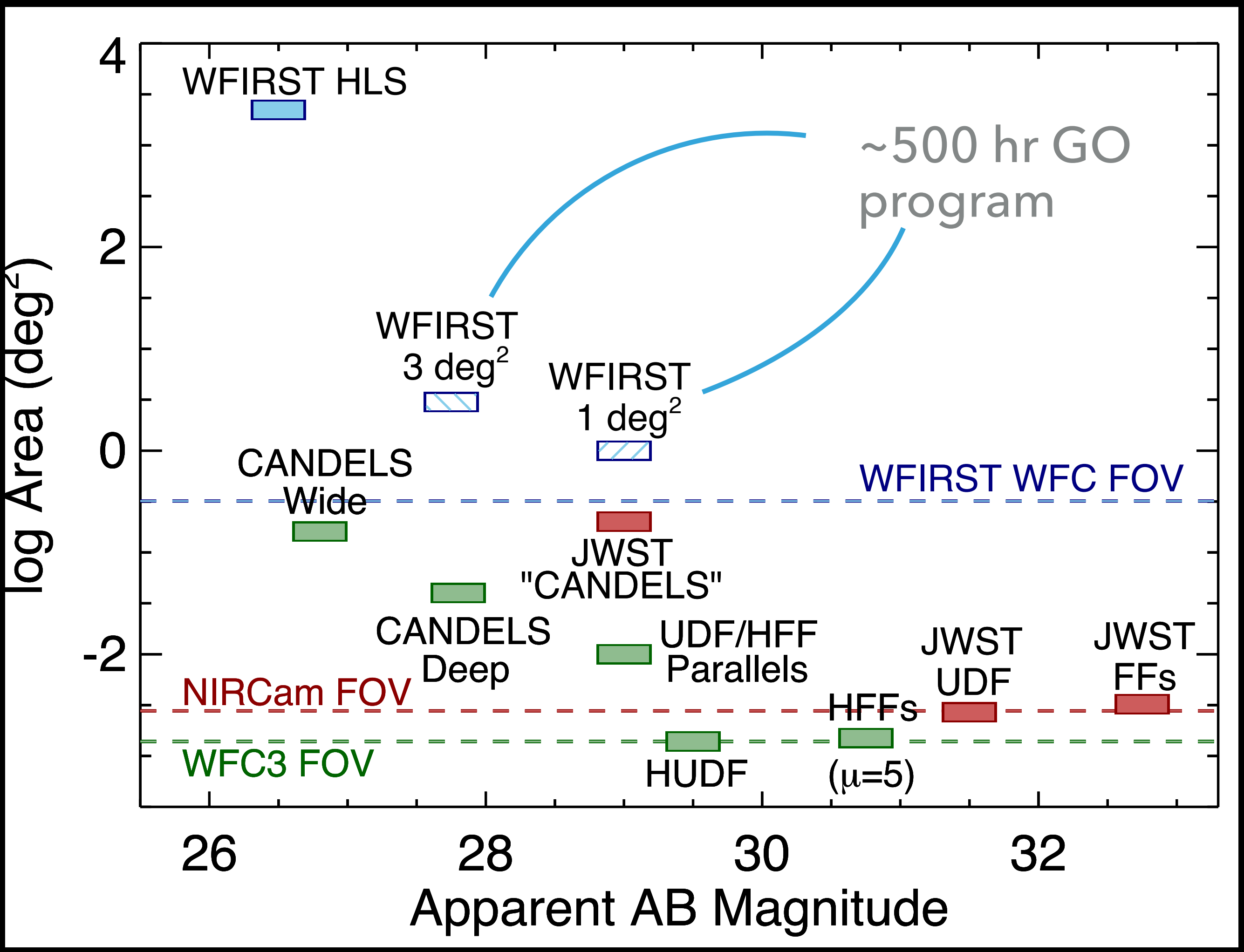


Figure credit: Ocvirk+2019

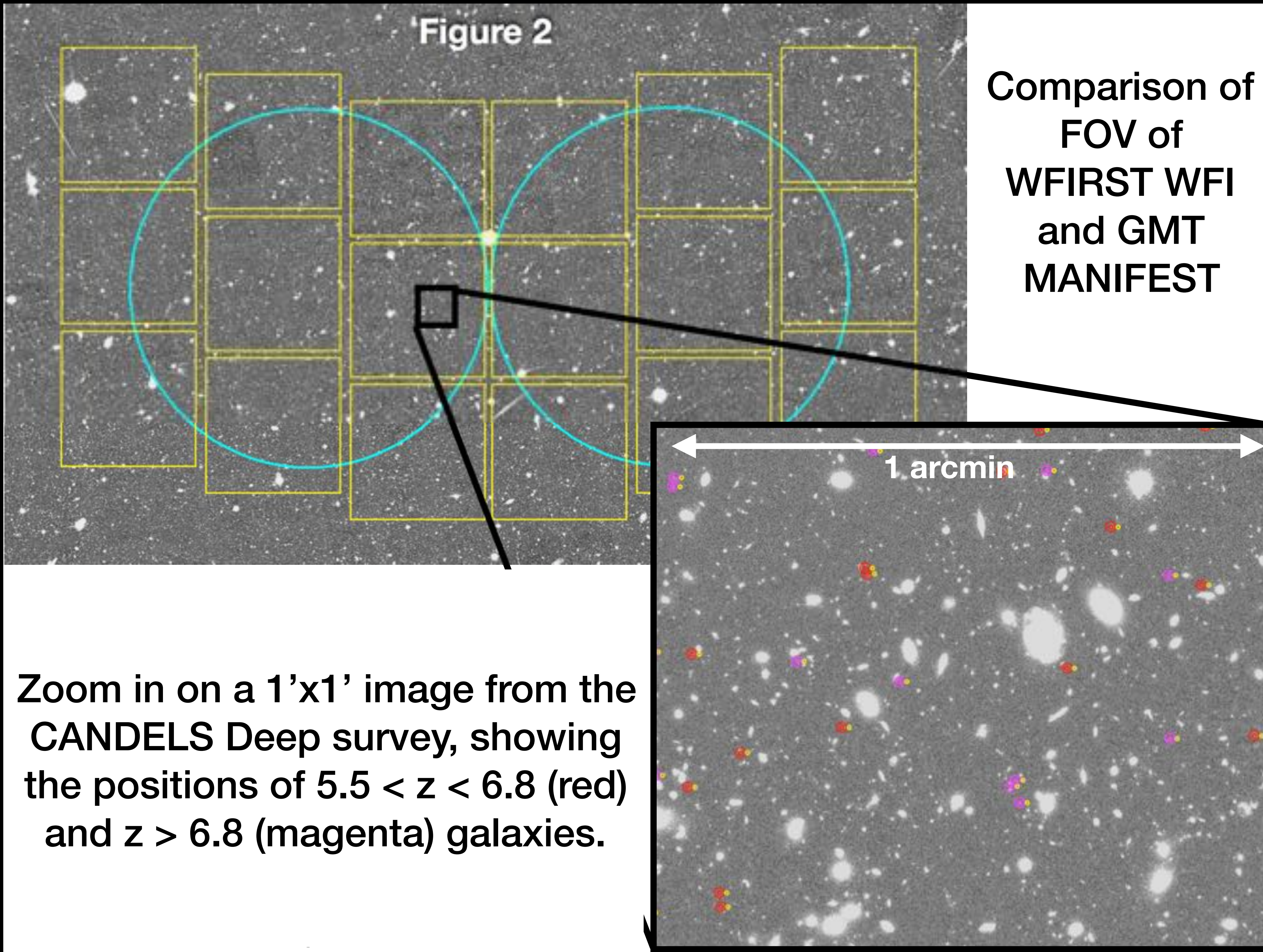
WHAT WILL PROVIDE THE GALAXY SAMPLE?
WFIRST



z	Expected # (HLS)	Expected # (deg² GO)	m~29 number per 20′ FOV
6	~3,300,000	~21,000	~2300
7	***~530,000***	~9200	~1000
8	~280,000	~4000	~450
9	~75,000	~1700	~200
10	~19,000	~700	~80

- Predictions assume smoothly evolving Schechter UV LF (Finkelstein 16), and limiting magnitudes = 26.5 for HLS (except for z=7, which is limited by z'_{LSST}=26.2 depth), with empirically derived (from HST) magnitude-dependent completeness applied.
- GO deg² survey is a roughly 500 hr survey observing one square degree to m~29.

WFIRST+GMT MOCK LAYOUT



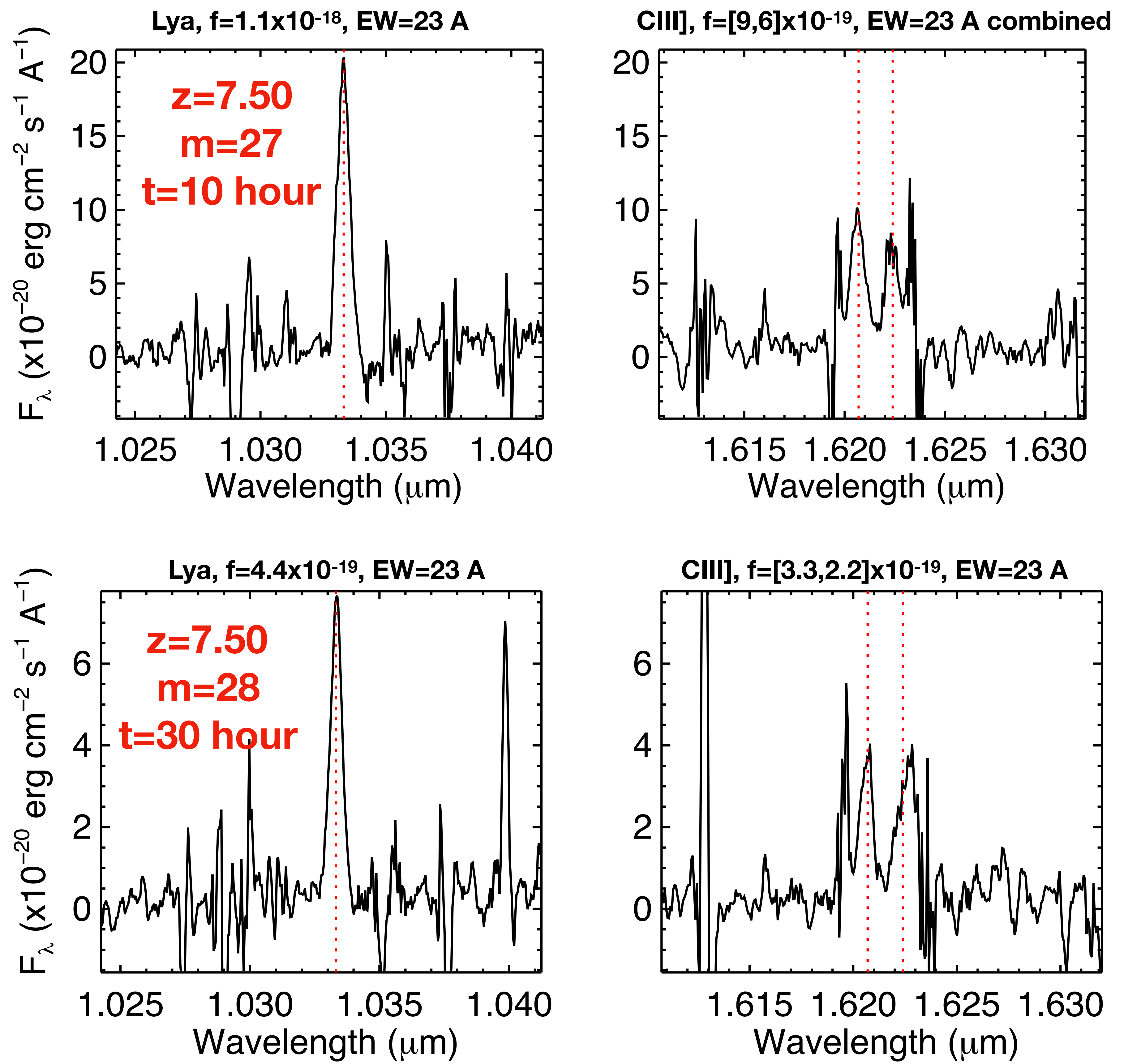
Comparison of FOV of WFIRST WFI and GMT MANIFEST

Zoom in on a 1'x1' image from the CANDELS Deep survey, showing the positions of $5.5 < z < 6.8$ (red) and $z > 6.8$ (magenta) galaxies.

Simulated GMT observations of WFIRST deep GO pointings.

30 hr should reach limiting emission line fluxes of ~2-3 x 10^{-19} cgs.

Significant science can also be done with other rest-UV lines, primarily CIII] 1907,1909, which probes the systemic redshift, and can constrain the metallicity and ionizing properties of the stellar populations.



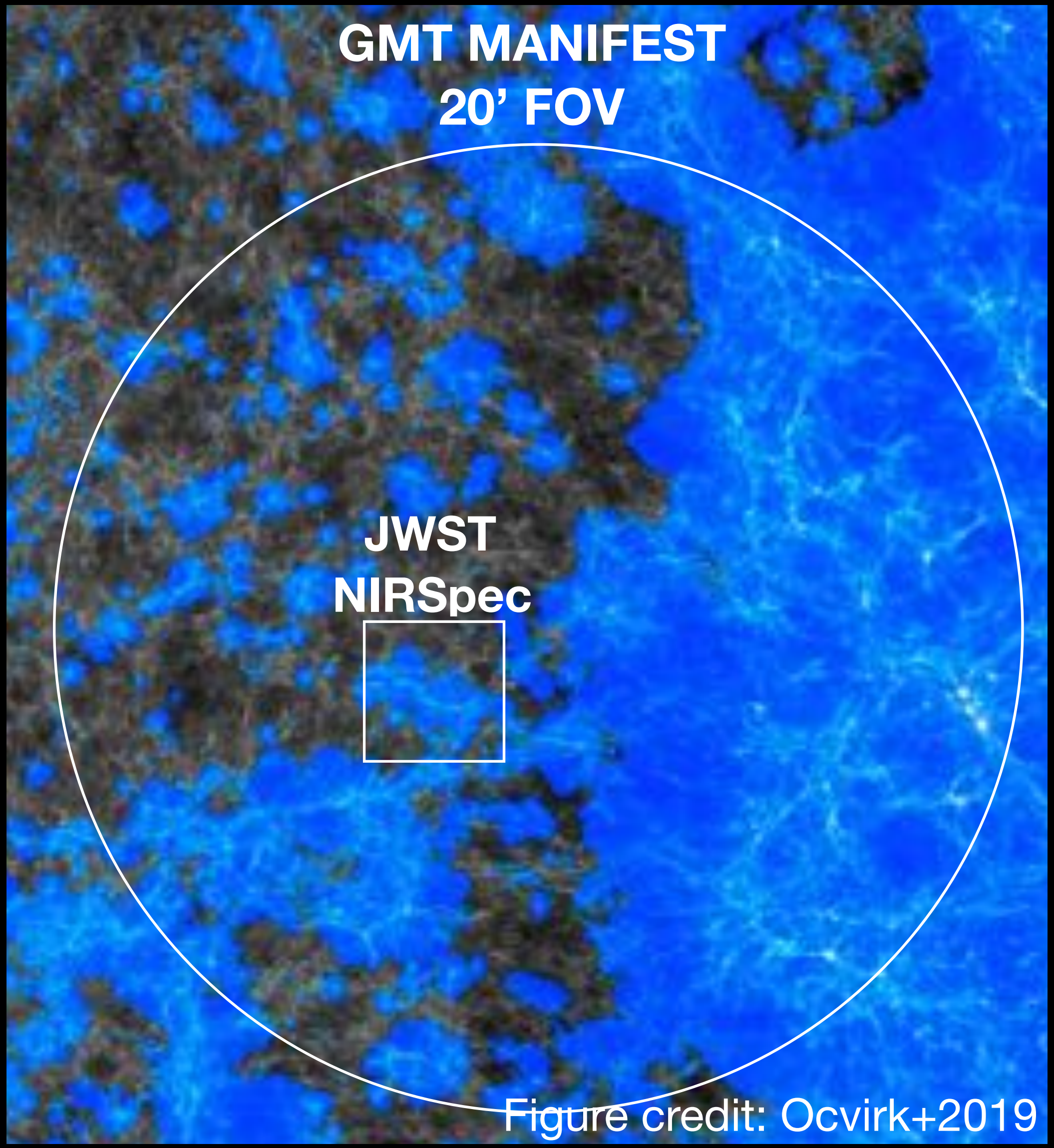
WHY NOT *JWST*?

Immense Gain in Multiplexing

The *JWST* NIRSpec FOV is only 3'x3'. The area probed by a single MANIFEST pointing is ~40X larger. The most efficient NIRSpec R~1000 or 2700 configurations net ~60 targets per observation, compared to up to 1000 objects observed per MANIFEST pointing.

Throughput

The NIRSPEC throughput begins to decline at $\lambda < 1.2\mu m$.



These two factors combined imply that JWST will *not* perform the deep and wide-field spectroscopic surveys necessary for Lyα probes of reionization at z~6-10 (though it will certainly provide guidance for such future studies).

TAKE-HOME POINTS

- Pinning down the detailed evolution of the reionization process places constraints on the nature of the earliest galaxies in the universe.
- Lyman-alpha emission is currently the best diagnostic to measure the neutral fraction (and even in the SKA-era, is very complementary).
- "Heroic" integrations with 10m-class telescopes show that Lyman-alpha is still detectable to z~9, but bigger glass and a wider field-of-view are needed to gain a clear picture of reionization.
- Combining the wide-field galaxy sample from WFIRST with the wide-field spectroscopic capabilities of GMT provide a clear path forward.

See more in our Astro2020 White Paper: https://arxiv.org/pdf/1903.04518