GALAXY EVOLUTION IN THE EARLY UNIVERSE WITH THE WFIRST HLS

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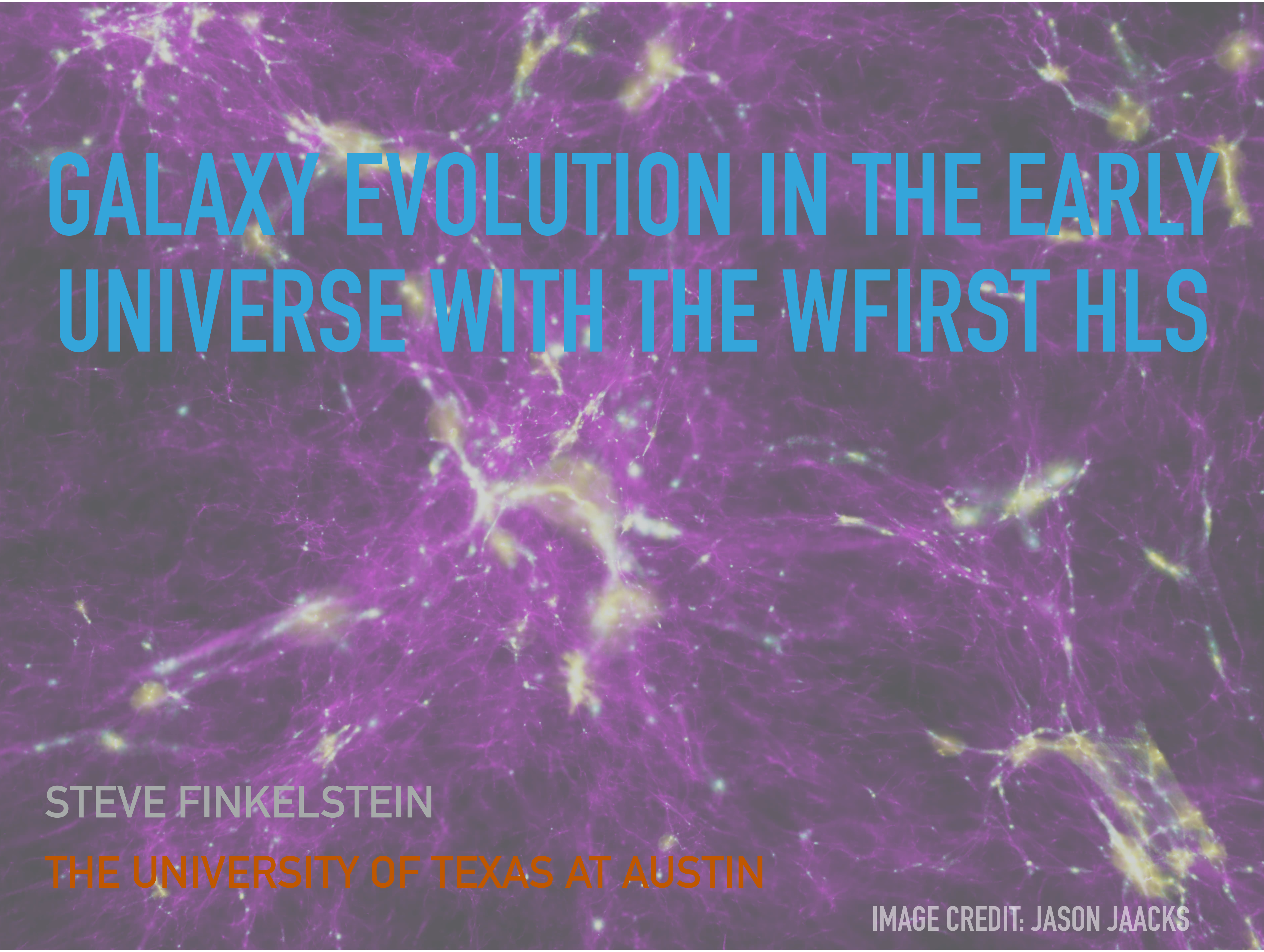
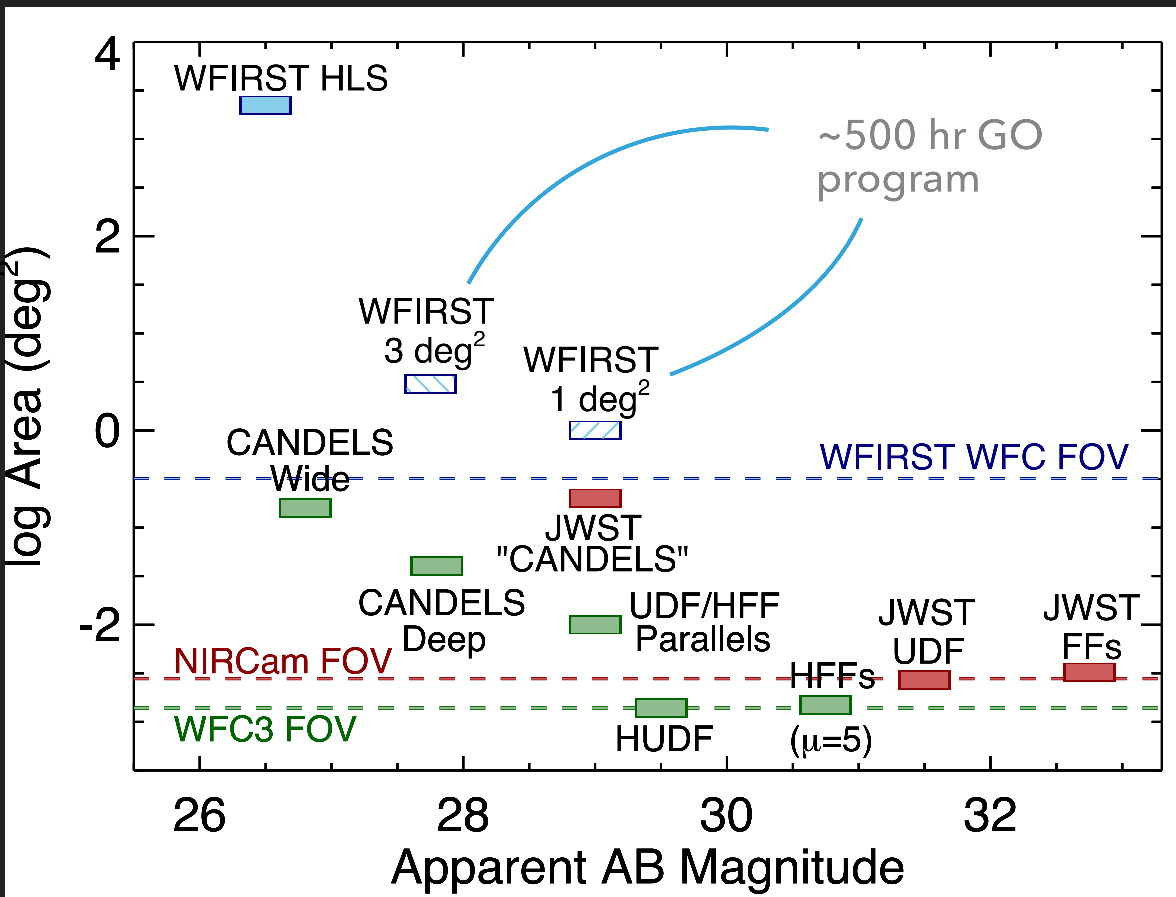


IMAGE CREDIT: JASON JAACKS

OPEN QUESTIONS FOR WFIRST

- HST and JWST are severely limited in volumes that they can simultaneously probe. The following are some high priority questions likely to remain open in ~a decade:
  - How do the physics which regulate star-formation evolve with cosmic time?
  - How has cosmic variance affected our current results, particularly at faint luminosities?
  - What is the large-scale distribution of the detectability of Lyα emission in the epoch of reionization?
  - What can UV emission lines tell us about the evolution of the physics of star formation, and AGN activity?

WHAT WFIRST BRINGS TO THE TABLE: SCIENCE ENABLED BY A ~100X INCREASE IN FOV

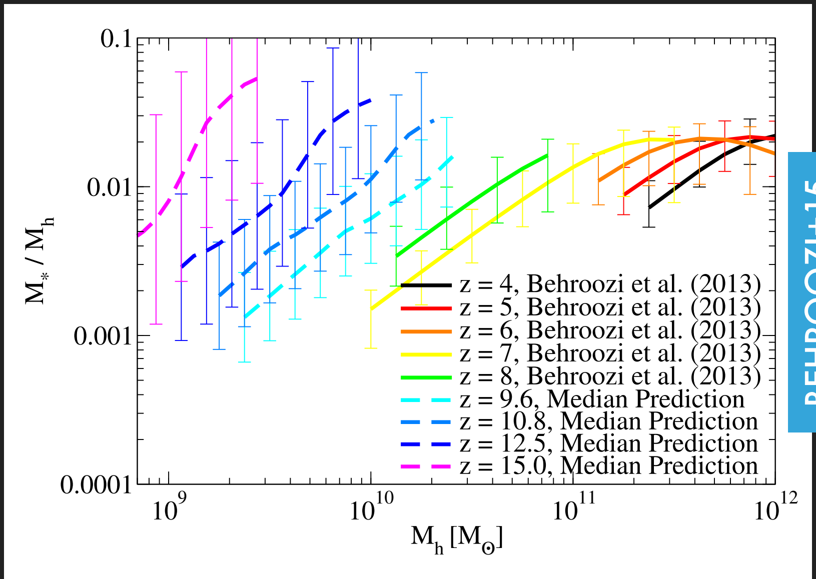


z	Expected # (HLS)	Expected # (deg² GO)
6	~3,300,000	~21,000
7	**~530,000**	~9200
8	~280,000	~4000
9	~75,000	~1700
10	~19,000	~700

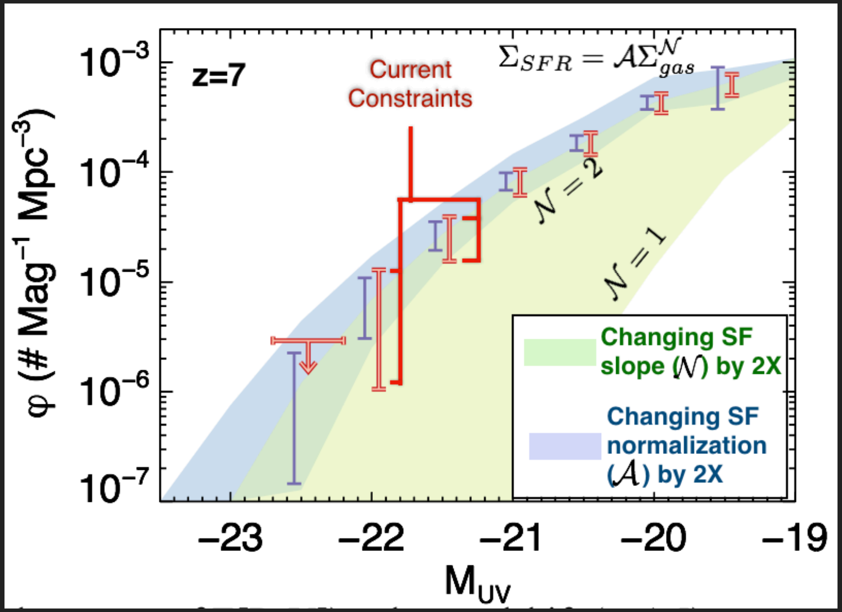
- Predictions assume smoothly evolving Schechter UV LF (Finkelstein 16), and limiting magnitudes = 26.5 for HLS (except for z=7, which is limited by z'_{LSST}=26.2 depth), with empirically derived (from HST) magnitude-dependent completeness applied.
- GO deg² survey is a roughly 500 hr survey observing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

HOW DO THE PHYSICS WHICH REGULATE STAR-FORMATION EVOLVE WITH COSMIC TIME?

- A phenomenological model which assumes that the star-formation rate tracks the halo mass accretion rate predict that the ratio of stellar-mass formed to halo mass (SMHM) increases with increasing redshift at z > 4 (Behroozi+13, Behroozi & Silk+15).
- This implies that galaxies are perhaps better at converting gas into stars at higher redshifts, counter to a variety of theoretical predictions (e.g., lower-Z *should* reduce SF efficiency). Other factors, such as reduced negative feedback effects, could be at play.
- One example - changing the star-formation law slope or normalization by a factor of two results in large changes at the bright end!
  - ***Current volumes probed do not contain enough galaxies to constrain these physics!***



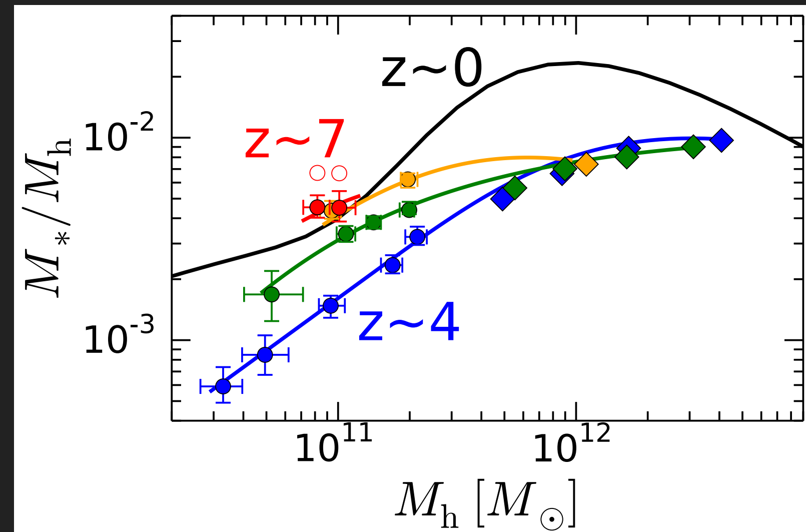
BEHROOZI+15



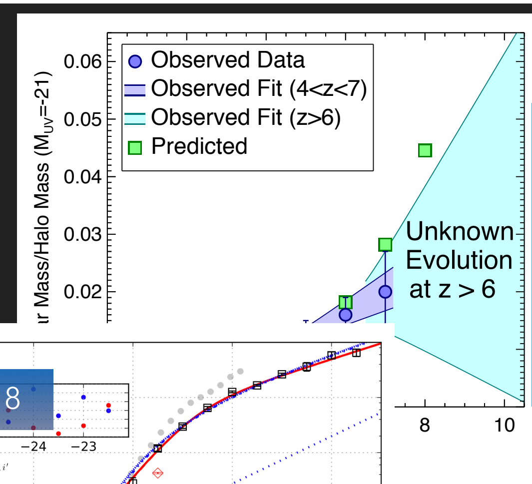
OBSERVATIONAL EVIDENCE?

- Galaxy clustering results have observationally found a similar trend - higher SMHM at fixed halo mass (Harikane+16,17).
- A similar result was found via abundance matching the UV luminosity function, and looking at evolution at fixed UV magnitude (~fixed stellar mass; Finkelstein+15b), though this is subject to UV scatter, and nebular contamination in M* estimates.
- There is now some evidence that the bright end of the UV luminosity function may be "super"-Schechter, e.g., a double power law (e.g., Bowler+14, 15; Finkelstein+15a, Ono+17, Stefanon+17, Stevans+18).

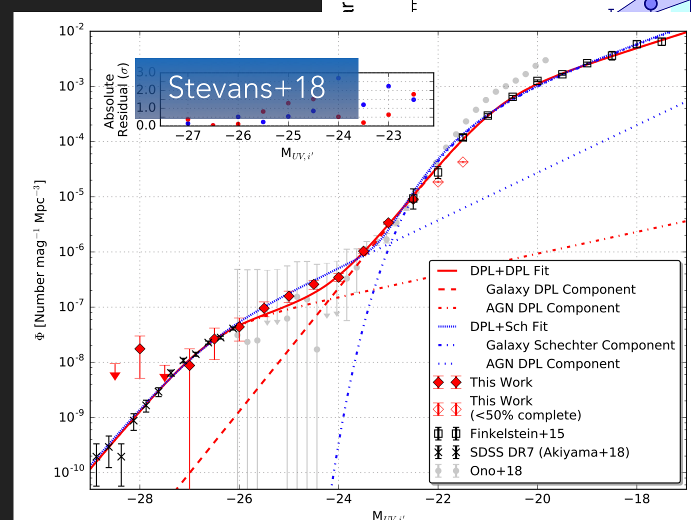
- Most of these studies are limited by small sample sizes, so conclusions remain difficult.



HARIKANE+17

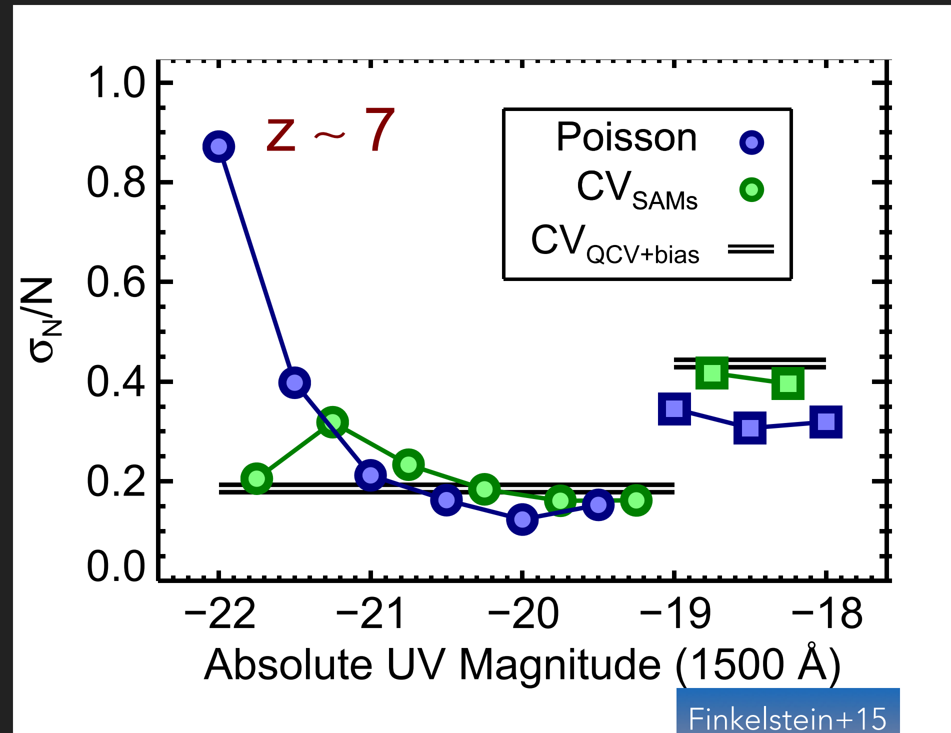


FINKELSTEIN+15B

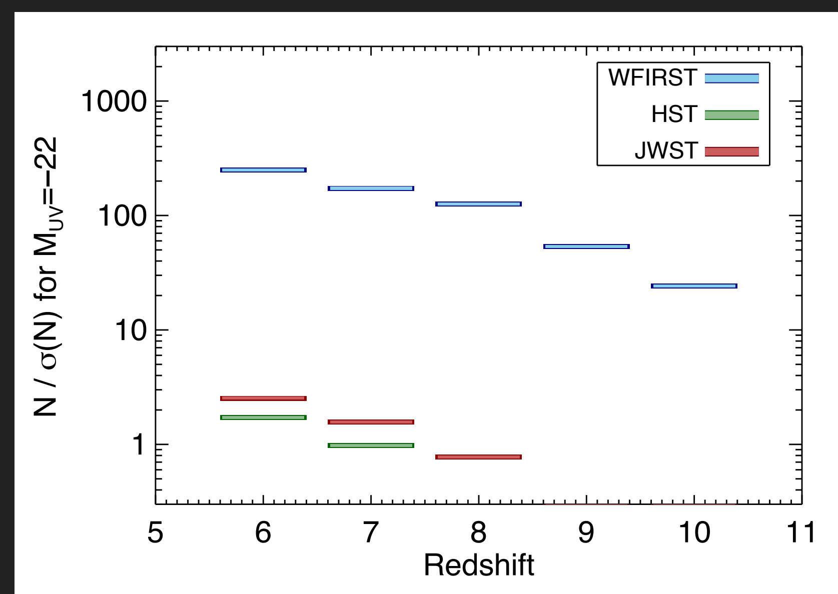


COSMIC VARIANCE

- Fractional uncertainty due to cosmic variance is ~40% in the HUDF.
    - Will be similar in a JWST UDF-style observation due to small volume probed.
  - How much are our conclusions on faint galaxies biased by cosmic variance?
- WFIRST HLS will allow measurements of the abundance of bright galaxies at z=6-8 with S/N > 100 (S/N > 10 at z=9-10).

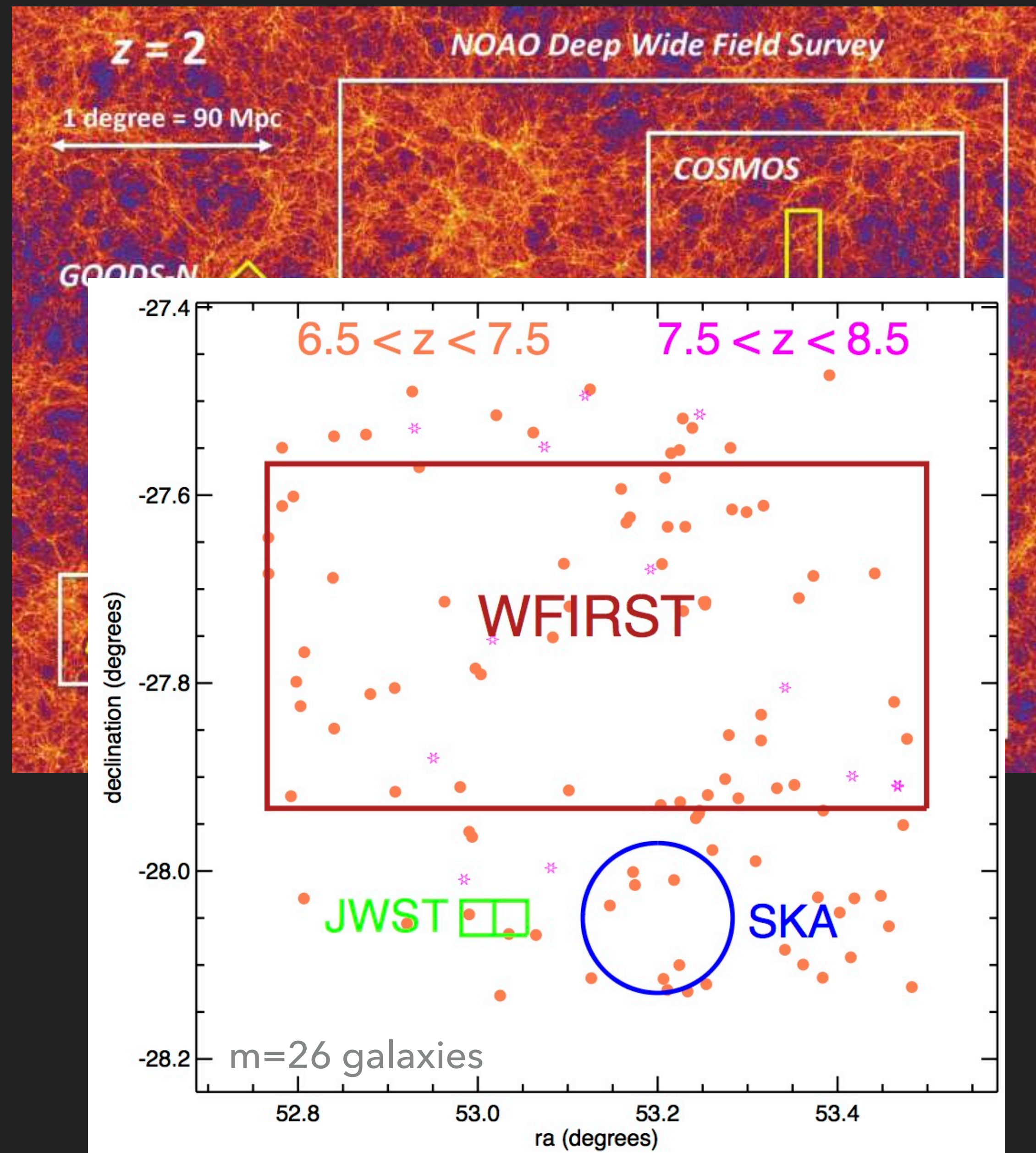


Finkelstein+15



HOW DO ENVIRONMENTAL FACTORS AFFECT STAR-FORMATION IN THE EPOCH OF REIONIZATION?

- Current volumes probed at z > 6 do not yet allow robust measures of environment to be made.
- The WFIRST HLS will probe 10-20 cGpc^3 volumes in unit-redshift bins at z=10-6, observing galaxies in the full range of cosmic environments.
  - Will also allow measurements of the cosmic SFR density both robust against CV, and as a function of environment.

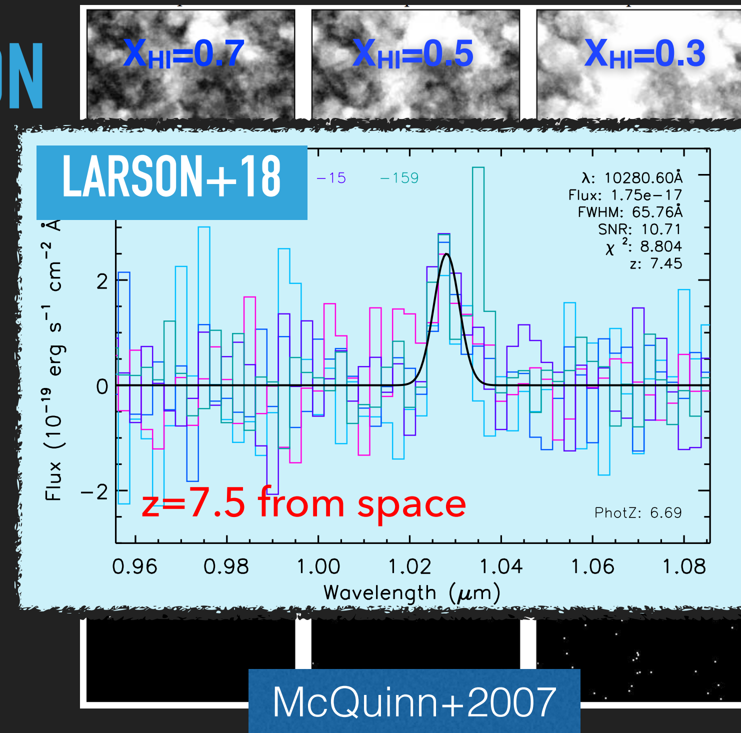


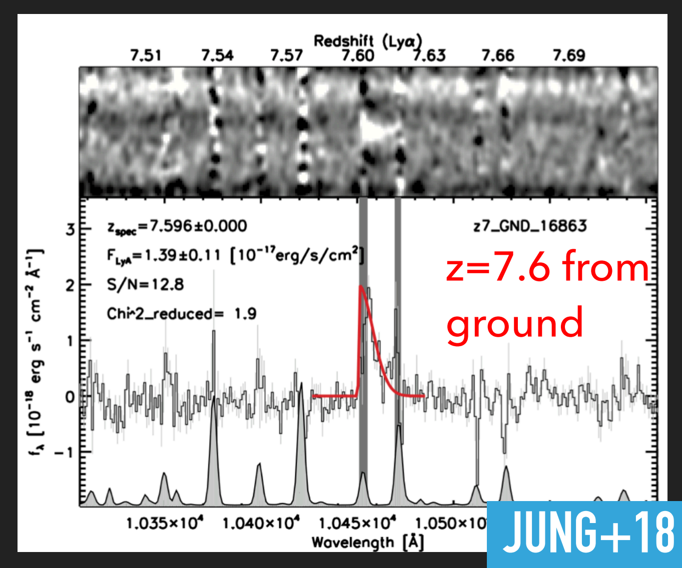
WHAT CAN WE LEARN SPECTROSCOPICALLY?

- Possible with the ATLAS deep survey (~1.2e-18 cgs) or an ultra-deep WFIRST 1-2 μm grism observation.
    - Topology of reionization via Lyα.
    - Physics of star-forming environments.
    - Presence of faint AGN.

THE LARGE-SCALE TOPOLOGY OF REIONIZATION

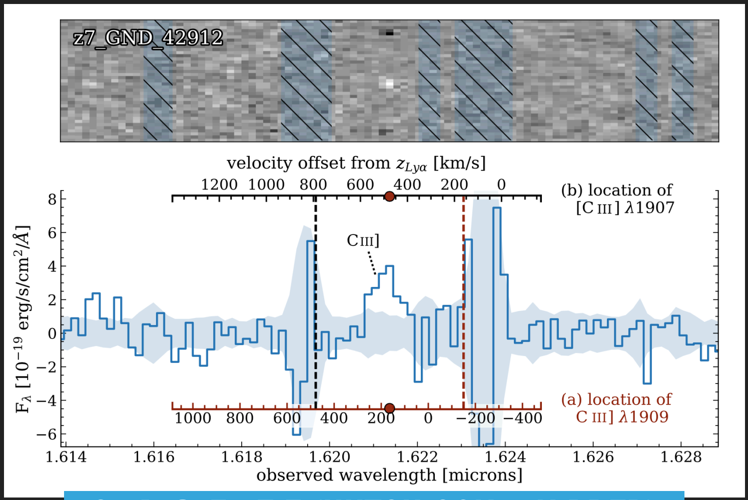
- Lya is resonantly scattered by neutral hydrogen, so if it is emitted from a galaxy with a surrounding neutral IGM, it will be significantly spatially diffused, well beyond detectable levels (e.g., Miralda-Escude+98, Malhotra & Rhoads 04, 06; Dijkstra+07).
  - Also, it is relatively “abundant” at z=6, just after the end of reionization.
- Simulations show that a patchy IGM should be directly traceable by the patchiness of Lya emission.
  - Large areas (1 deg^2+) need to be observed to overcome CV, and probe multiple ionized bubbles.
- Is it worth it? Deepest ever Keck-MOSFIRE integrations (~20 hr, 5σ=5e-18 cgs) detects Lya in 2/6 objects (Jung et al in prep), and 40-orbit/pointing FIGS detects z=7.5 Lya from HST.



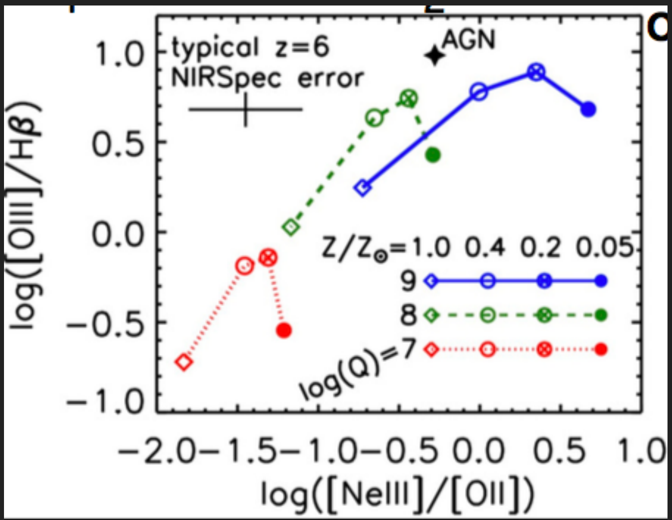


PHYSICAL CONDITIONS AND AGN

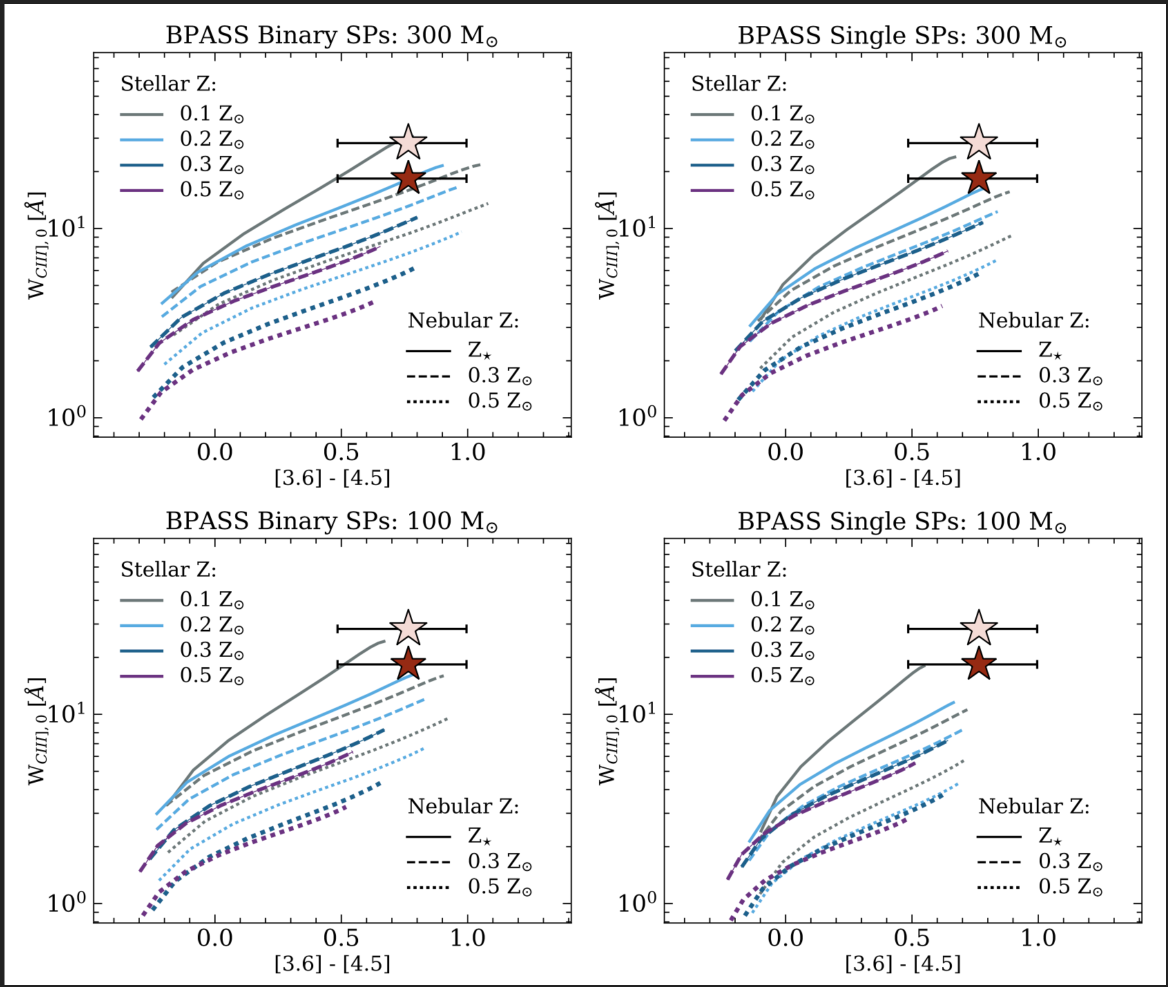
- JWST will do this for small samples, but not for large samples or rare sources



CIII] @ Z=7.5 (HUTCHISON+IN PREP)



All four lines to z~7, bottom axis to z~9



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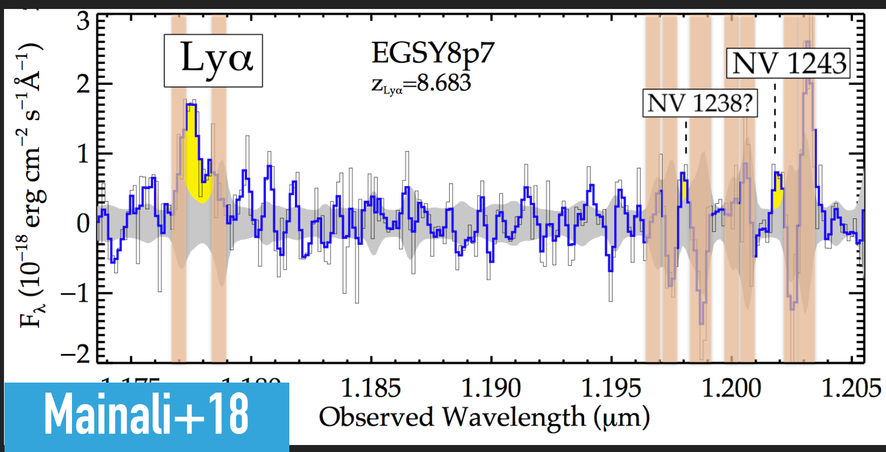

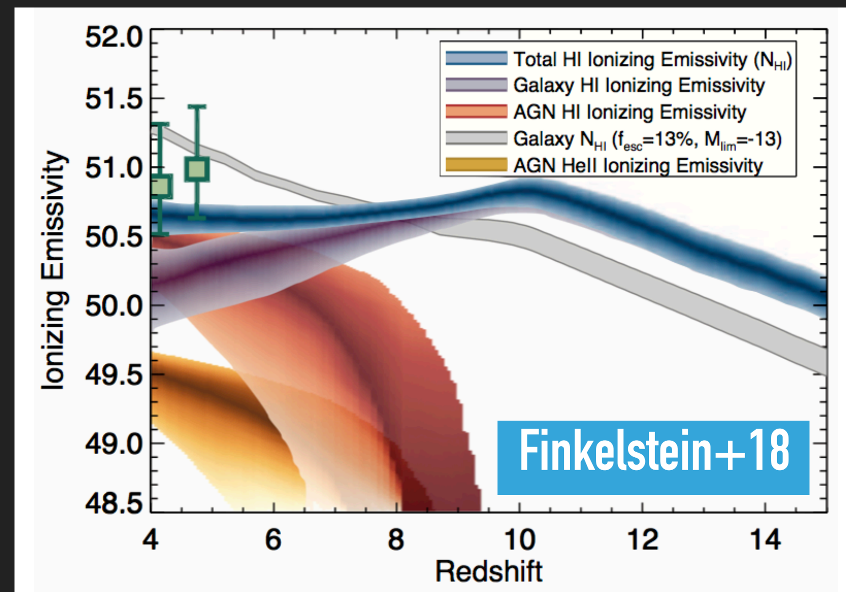

Moderate-luminosity AGN may be lurking in most known bright high-redshift galaxies, and an AGN-assisted end to reionization is being considered in many recent reionization modeling papers.

SUMMARY

- HST has opened the door on the high-redshift universe, and JWST will be amazing in a variety of ways.
- However, the small-field limitations of these facilities will leave several critical questions unanswered into the era of WFIRST
- Spectroscopic followup of some sort will enable key science, including the topology of reionization, probing the physics of star-formation to early times, and exploring the onset of the first AGNs.