Probing Galaxy Build-up at the Edge of the Universe:

Insights from Ultra-Deep HST and Spitzer Observations

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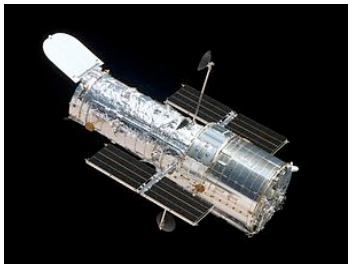
When and how did the first galaxies form?

How did they grow and build up their mass?

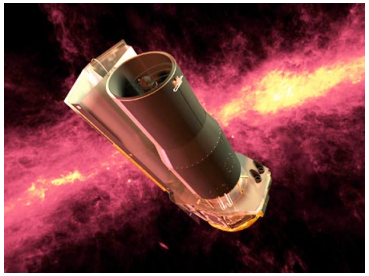
The First 1Gyr

Use Hubble and Spitzer to search and characterize our cosmic origins!



rest-UV SFRs

+



rest-optical Masses

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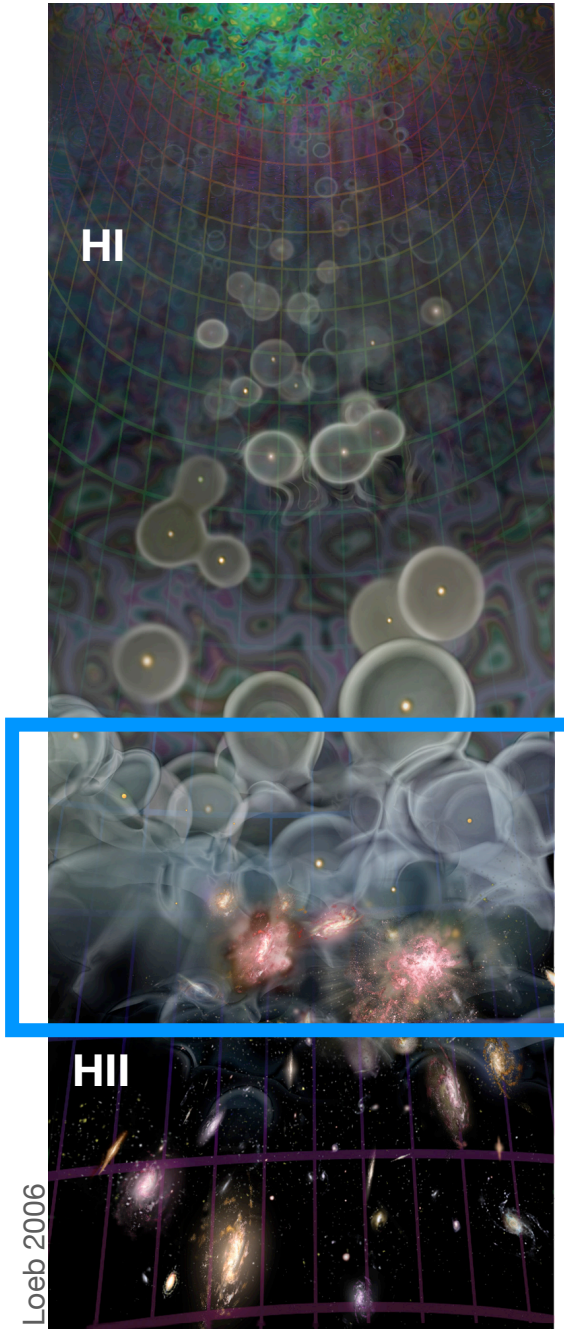
spectra + K-band



Loeb 2006

← z~1100: CMB
(0.4 Myr)

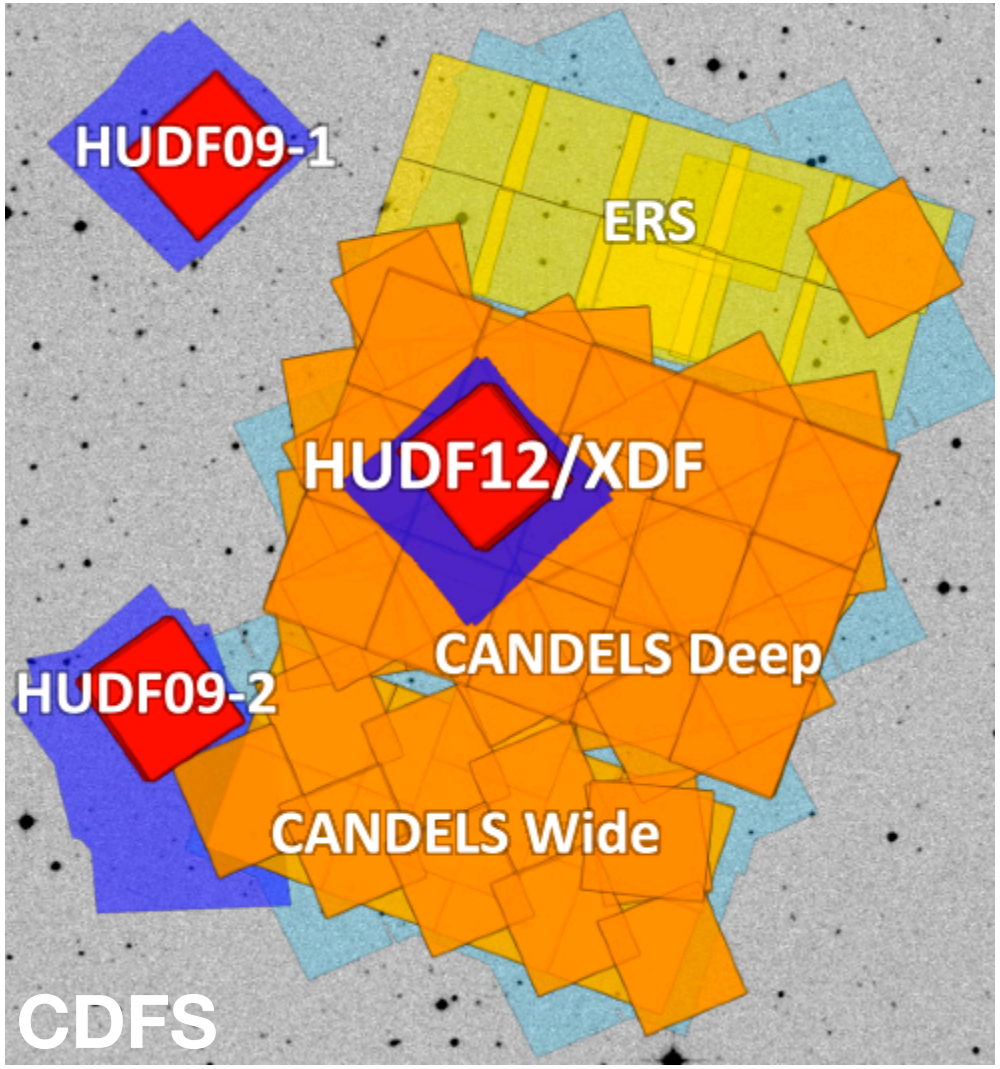
← z~20-30: First Stars
(100-200 Myr)

This Talk

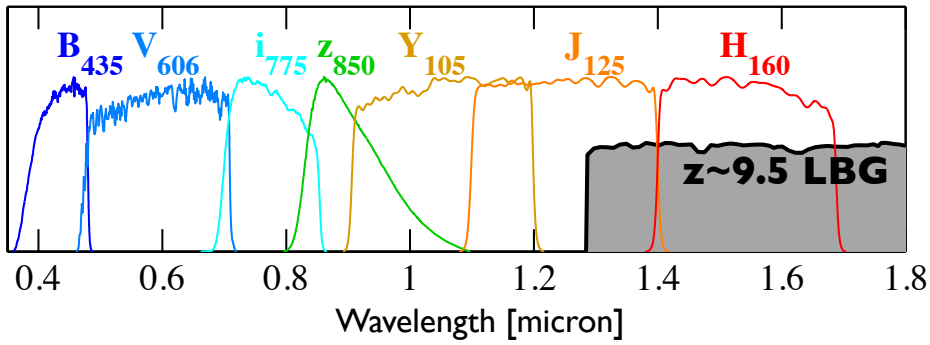
← z~12-6: Reionization
(0.3 - 1 Gyr)

← z<6: Build-up of today's galaxies

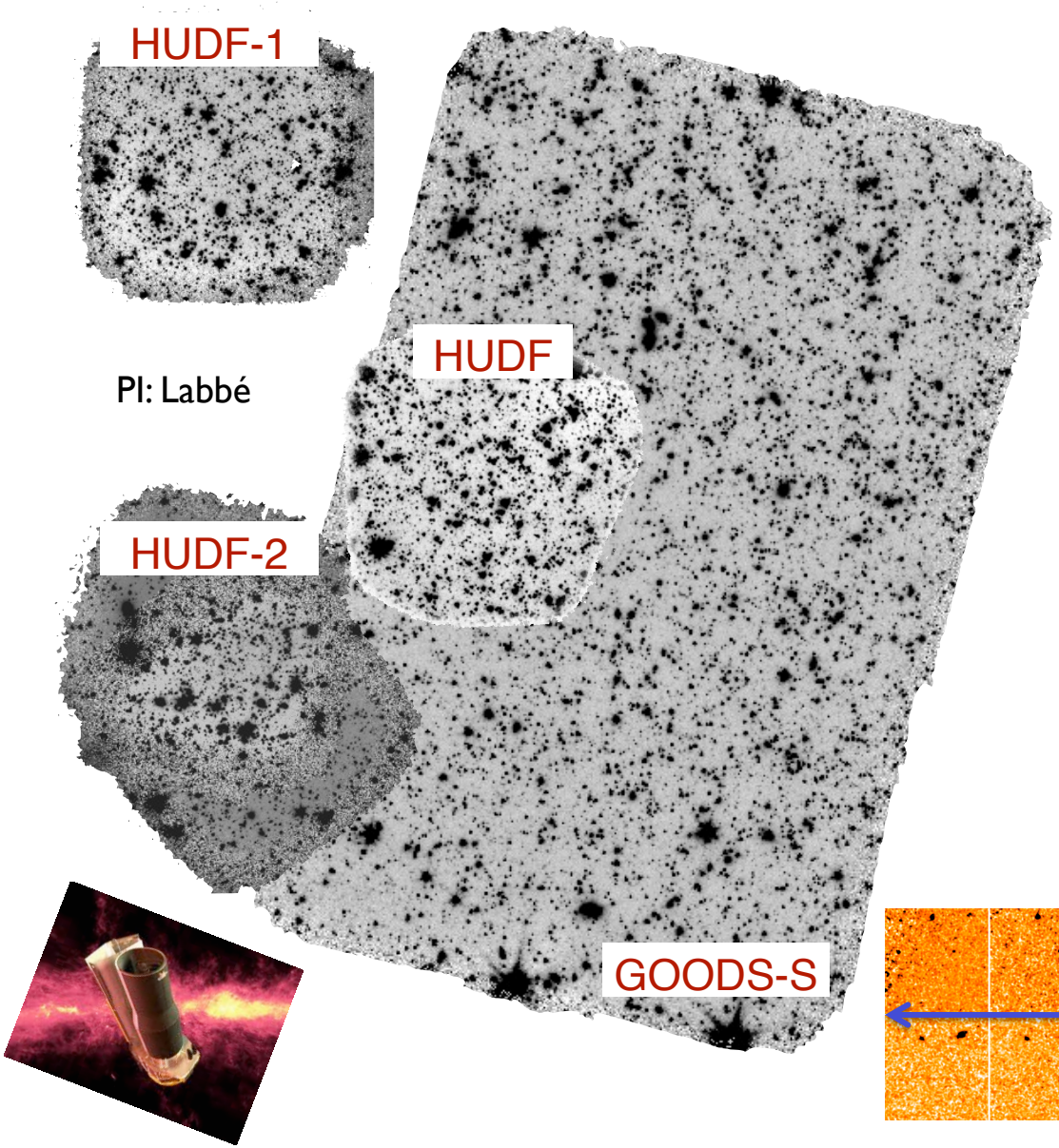
Large Archive of Deep HST Datasets



- Large amount of public optical (ACS) and NIR (WFC3) data
  - *HUDF12 & XDF*
  - *UDF05/HUDF09*
  - *ERS*
  - *CANDELS* (Deep & Wide)
- Total of ~730 arcmin^2
- Reach to 27.5 - 29.8 AB mag

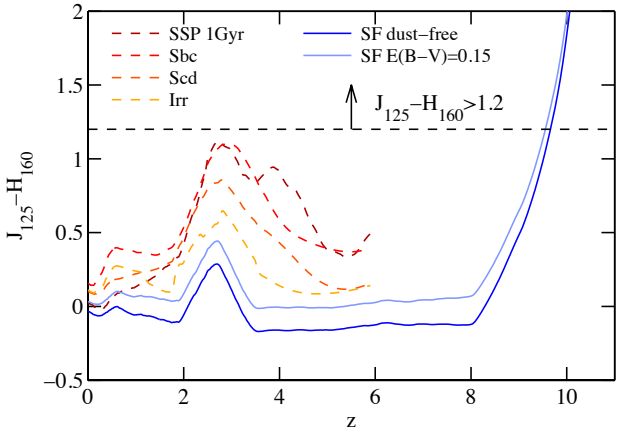


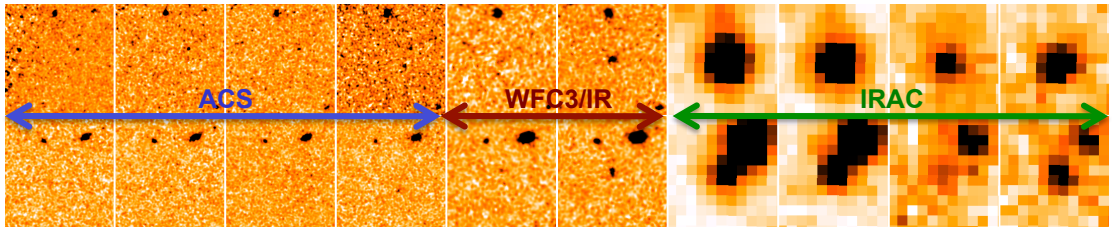
Matched Deep IRAC Data



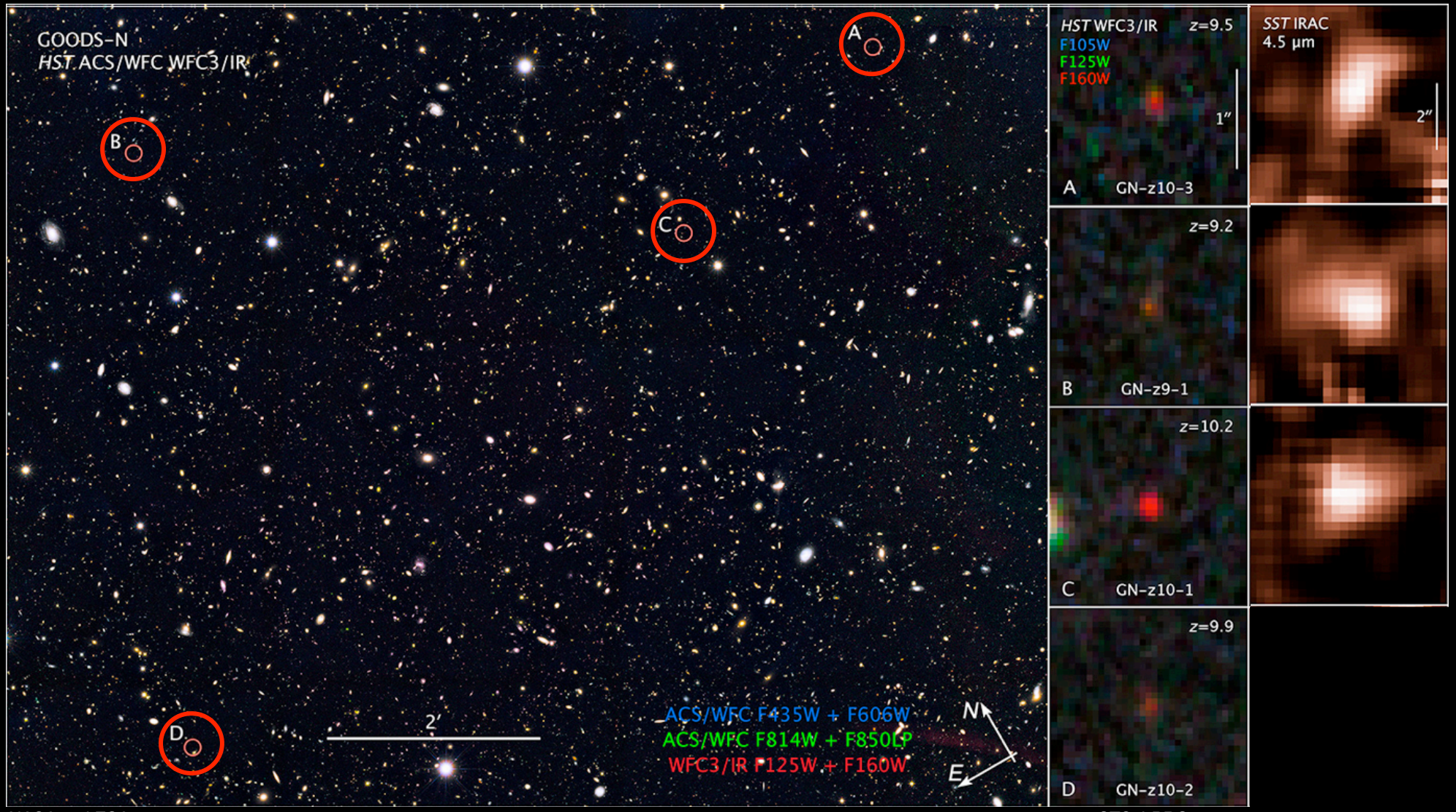
PI: Labbé

- Deep Spitzer/IRAC complemented all the HST datasets (S-CANDELS+SEDS)
- Deepest data available over HUDF09/ GOODS-S
- IRAC crucial for
  - stellar mass estimates
  - excluding contaminants





Sample of 4 Bright z~9-10 Galaxy Candidates

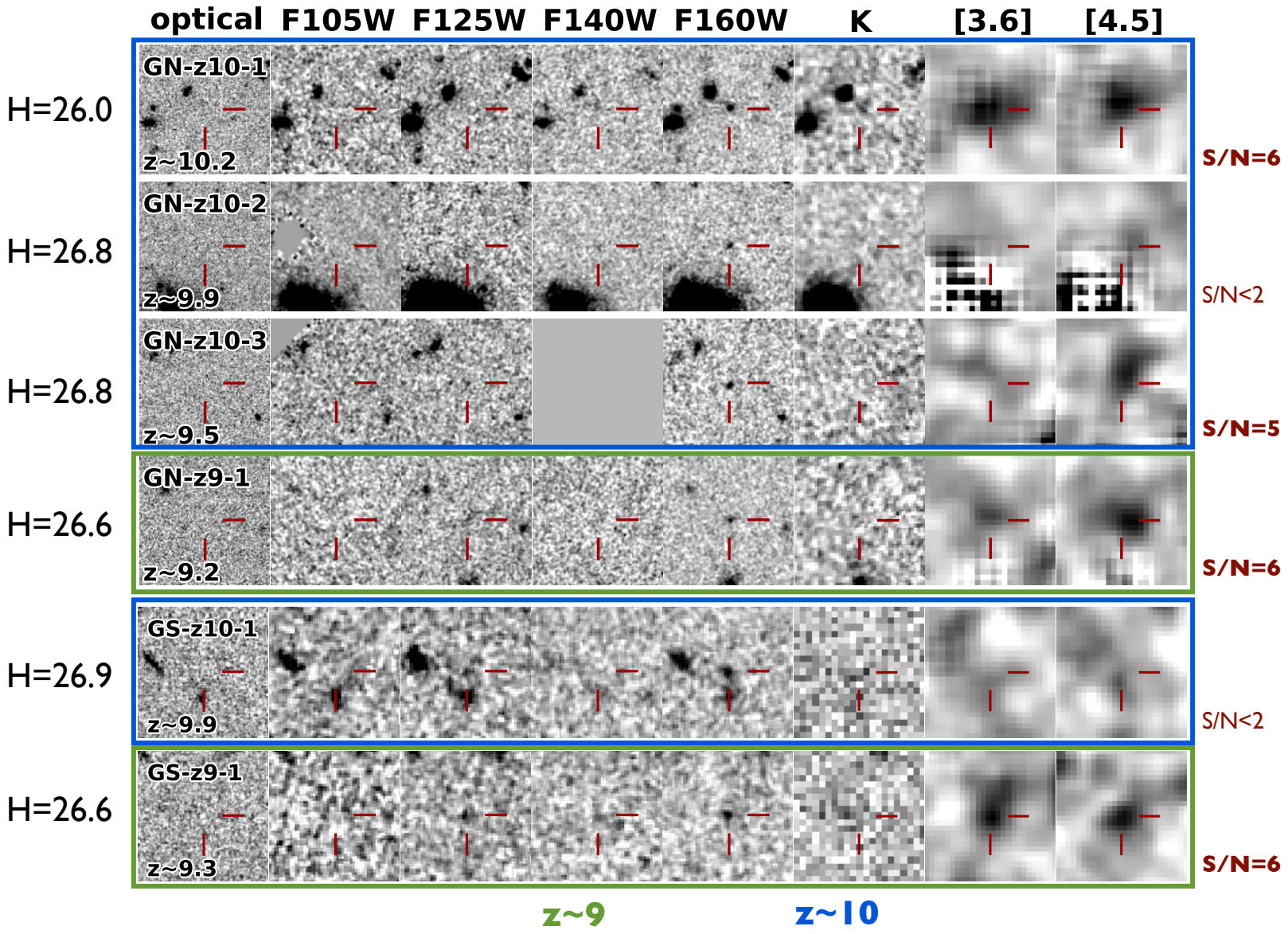


NASA and ESA

STScI-PRC14-05a

Power of combining HST and Spitzer to explore most distant galaxies

Sample of Bright z~9-10 Galaxies in GOODS



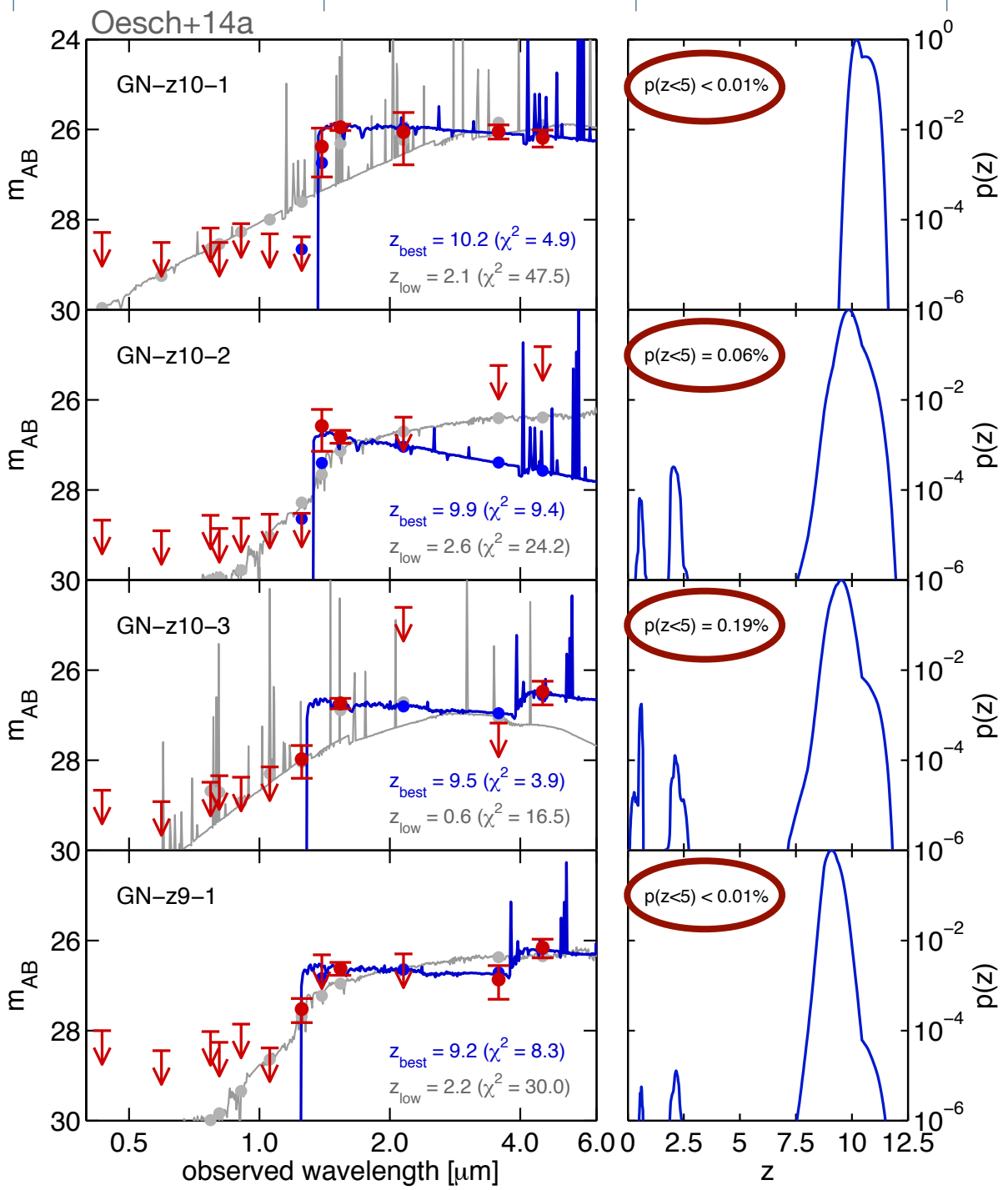
Accurate Sampling of Spectral Energy Distribution

Photometry from rest-frame UV to optical, thanks to IRAC detections

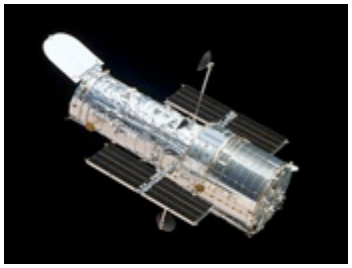
Photometric Redshift Estimates: **z~9.2-10.2**

Three sources have secondary, low-z peak in their p(z), but at very low probability.

Constraints on Masses: **~10^9 $M_\odot$** and Ages: **100-300 Myr**



Stellar Mass Density Evolution to z~10



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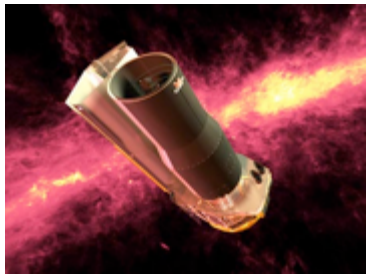
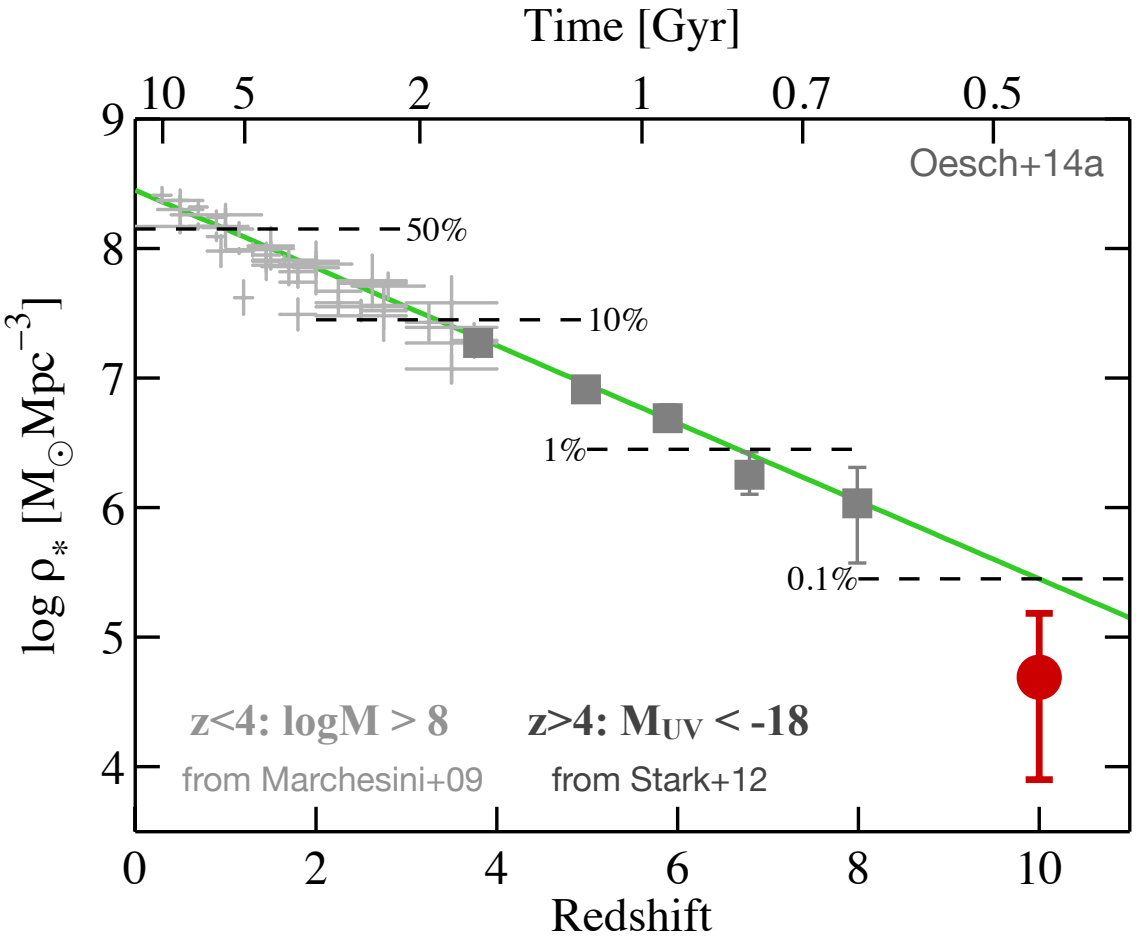


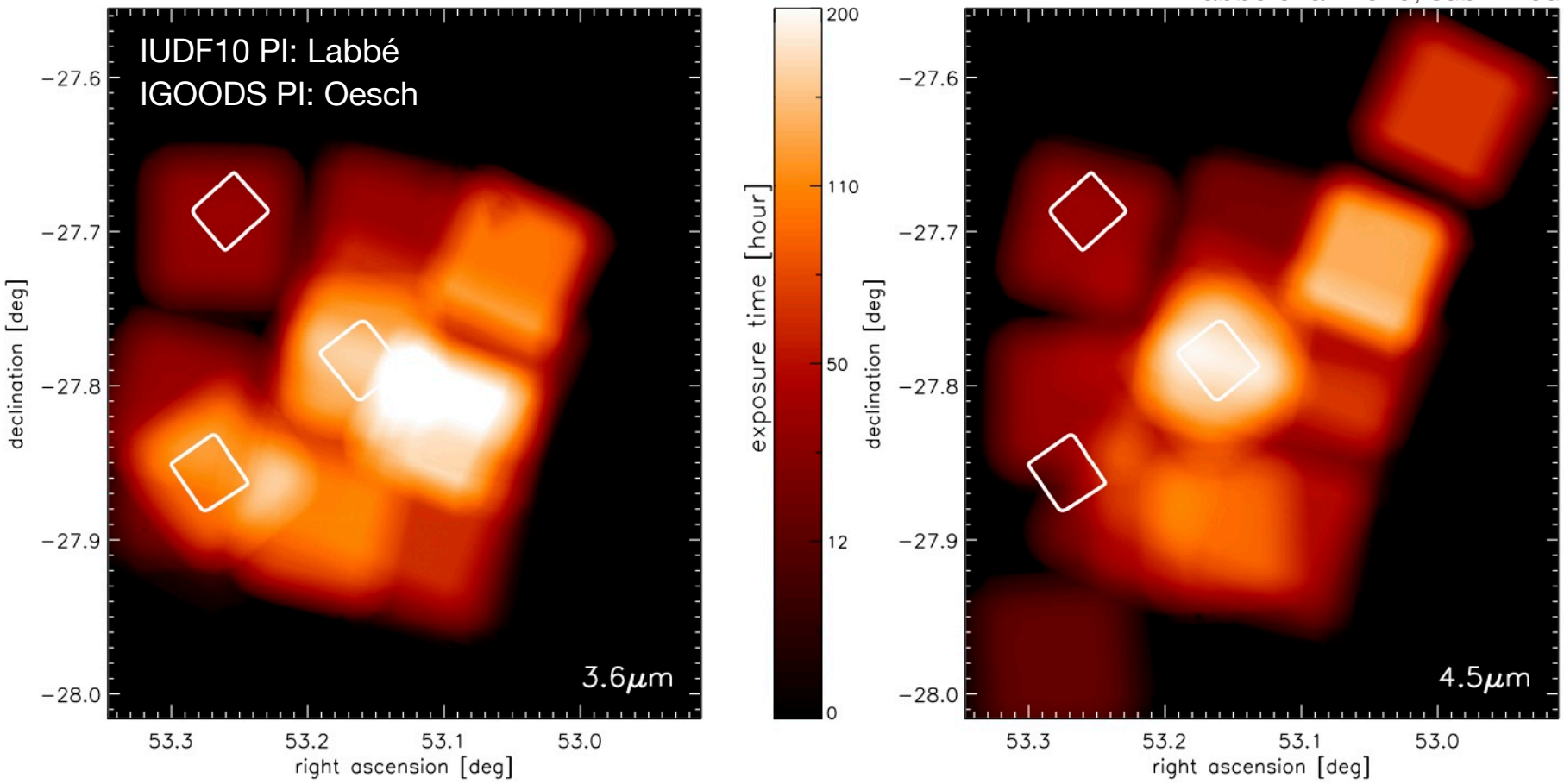


Luminosity limited SMD estimates at z>4 nicely match up with mass limited studies at z<4.

Are witnessing the assembly of the first 0.1% of local stellar mass density!

Pushing Spitzer/IRAC to the Edge of the Universe

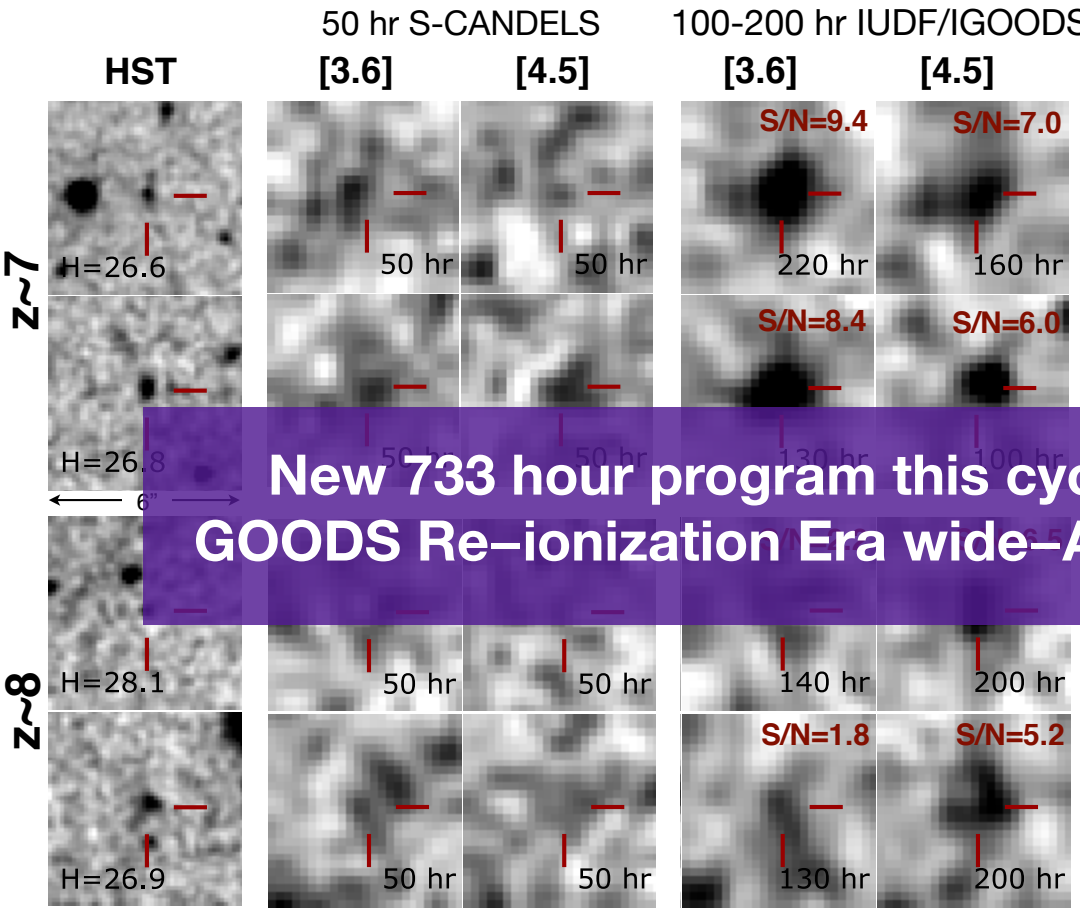
Labbe et al. 2015, submitted

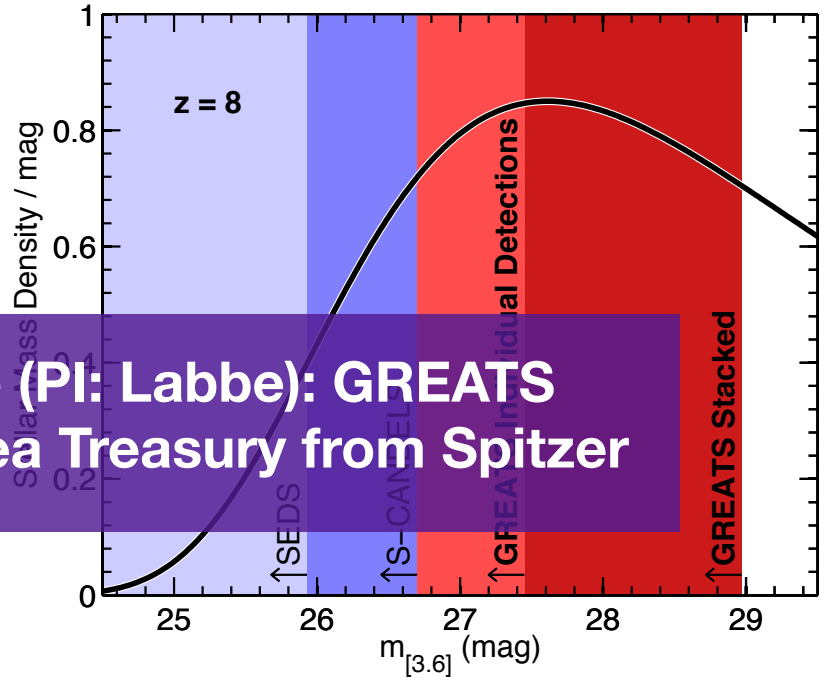


Small area already has 180-220 hour IRAC exposure times (27.2 mag; 3σ)!

These images are being released through our survey webpage and through IRSA.

Individually Detected z~7-8 Sources



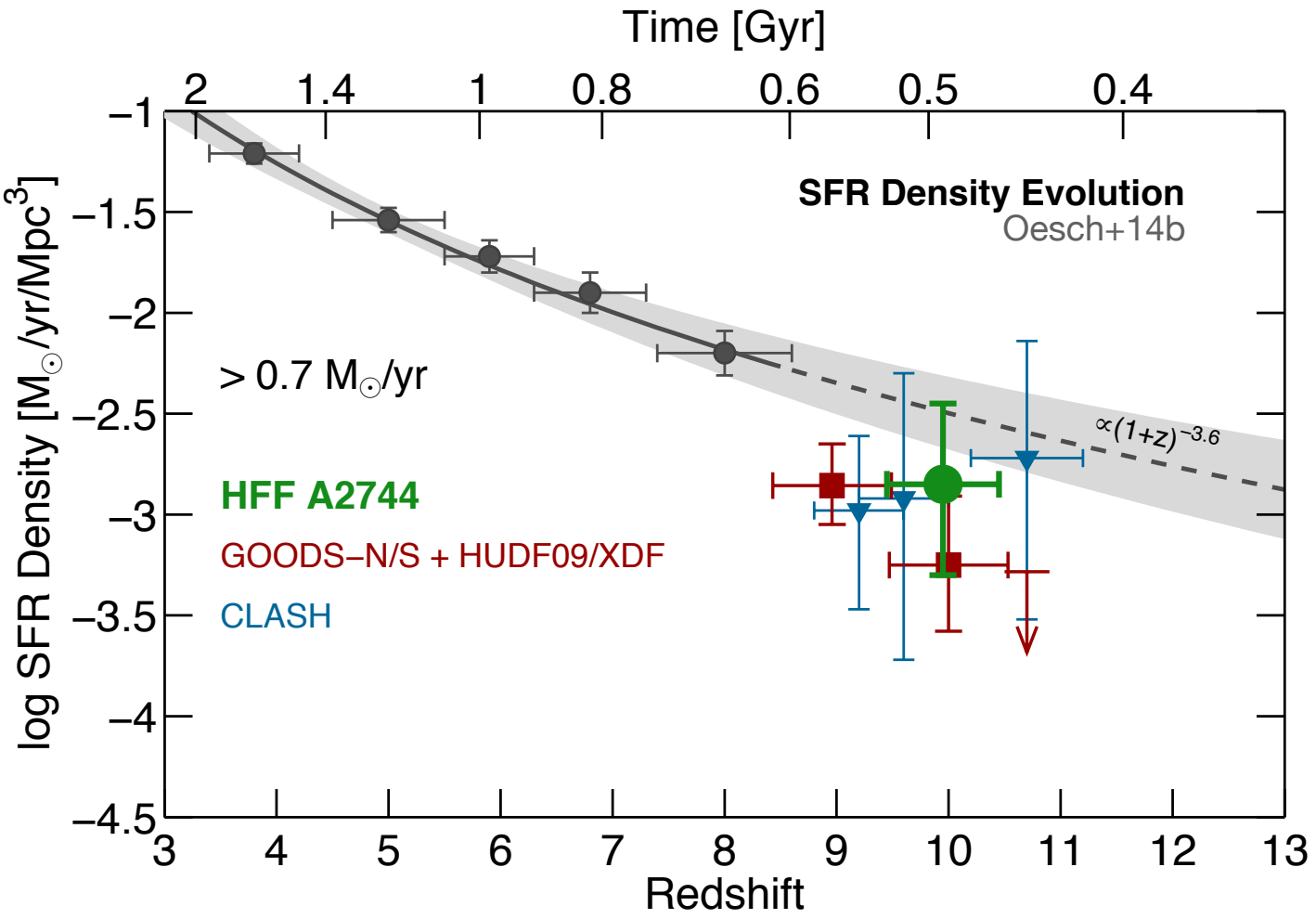


200 hour IRAC data probes peak of mass density at z~8

New 733 hour program this cycle (PI: Labbe): GREATS GOODS Re–ionization Era wide–Area Treasury from Spitzer

Enables next steps forward with **individual detections** to probe **dispersion** in known relations (e.g., SFR-Mass)

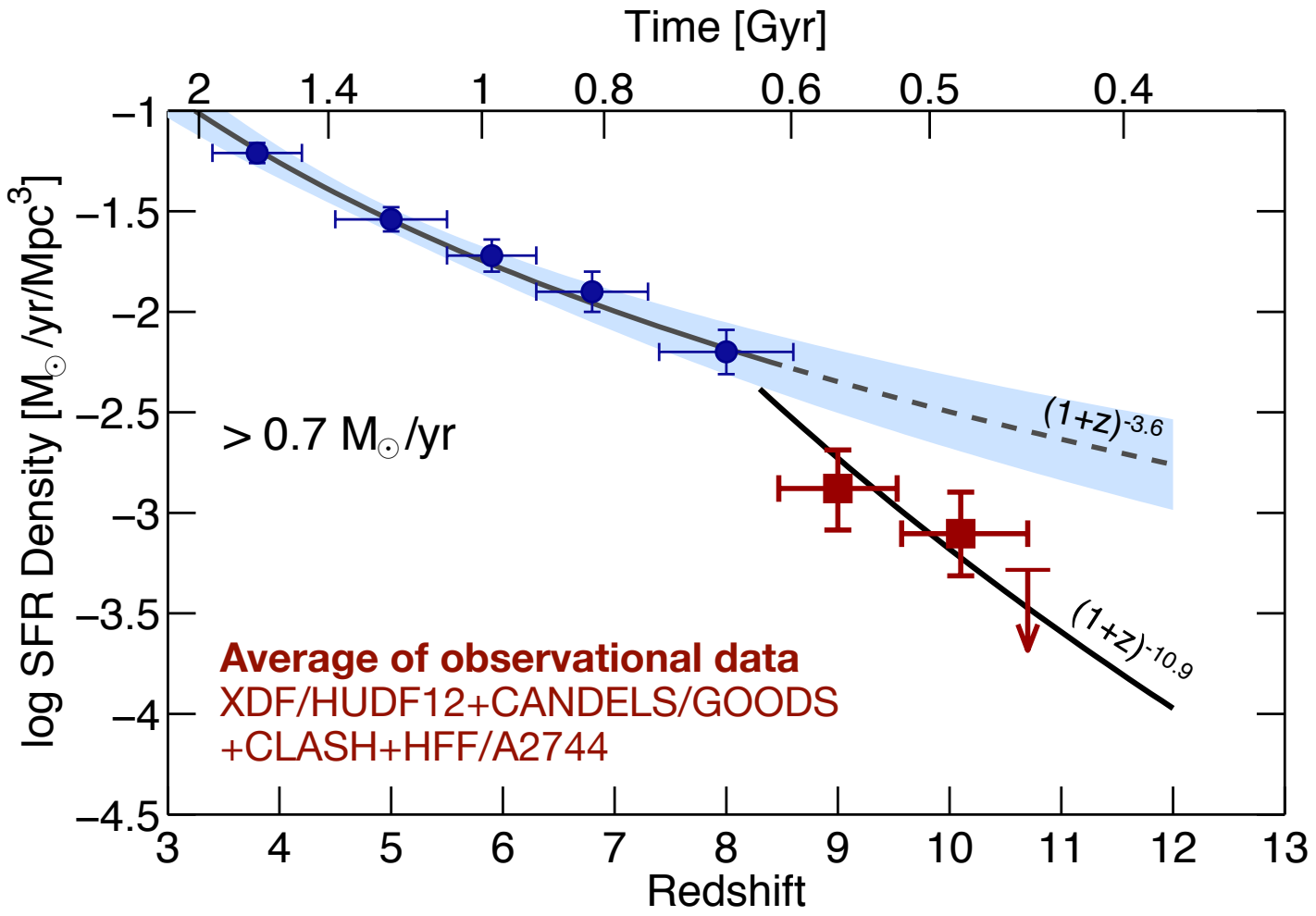
SFRD Evolution at z>8



All current estimates seem to indicate that the cosmic SFRD evolves more rapidly at z>8 than at lower redshift!

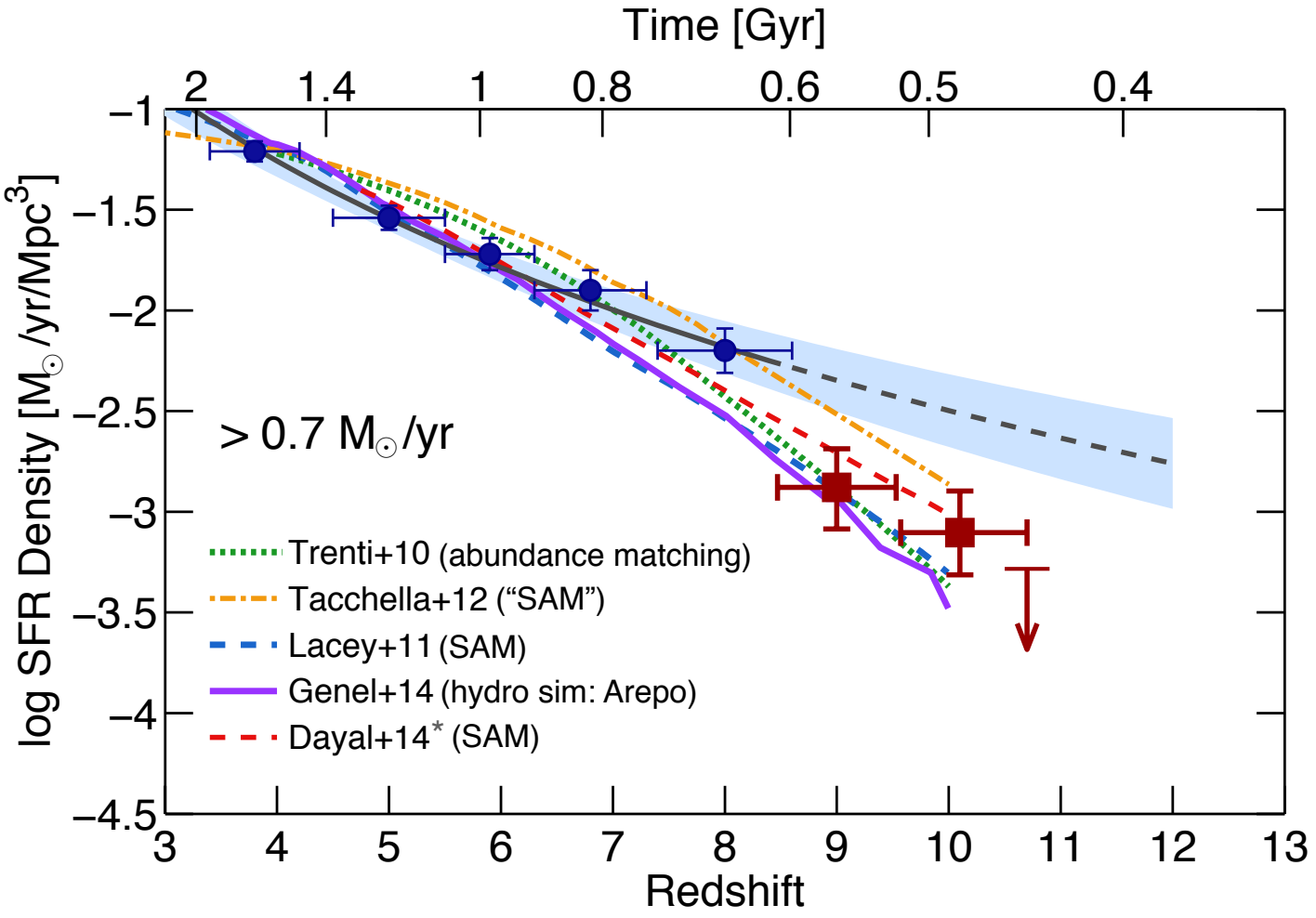
see also, e.g.: Zheng+12, Coe+13, Bouwens+13/14, Ellis+13, McLure+13, Ishigaki+14, McLeod+14

SFRD Evolution at z>8



Combining the current constraints from all datasets:
very rapid evolution in the cosmic SFRD at z>8 (factor ~10x in 170 Myr).

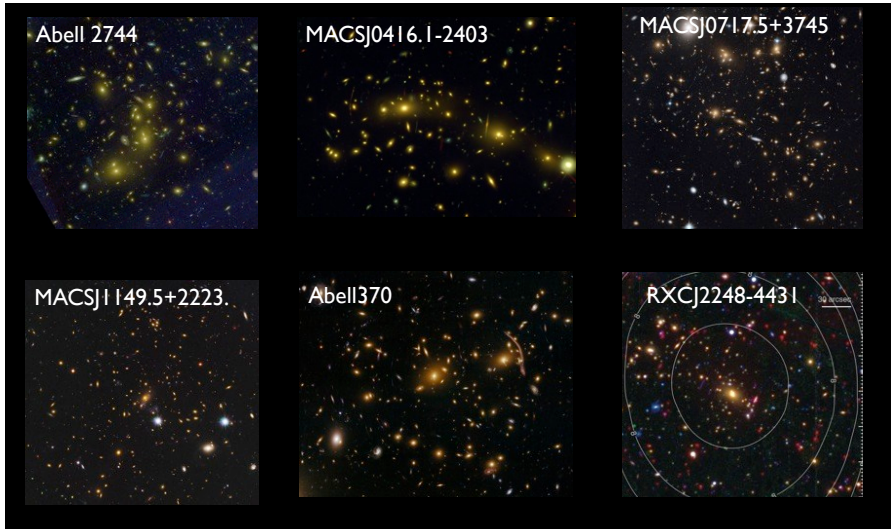
SFRD Evolution at z>8

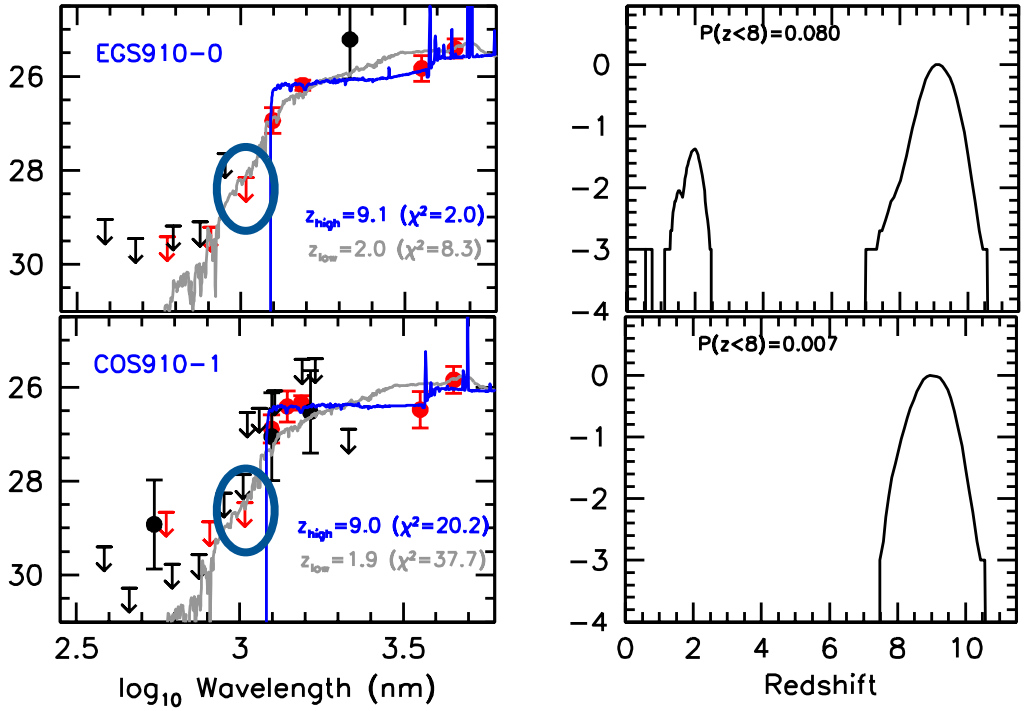


Drop in SFRD is in good agreement with several model predictions.
Imprint of underlying DM halo MF.

*corrected for average dust extinction

Next Steps at z~9-10





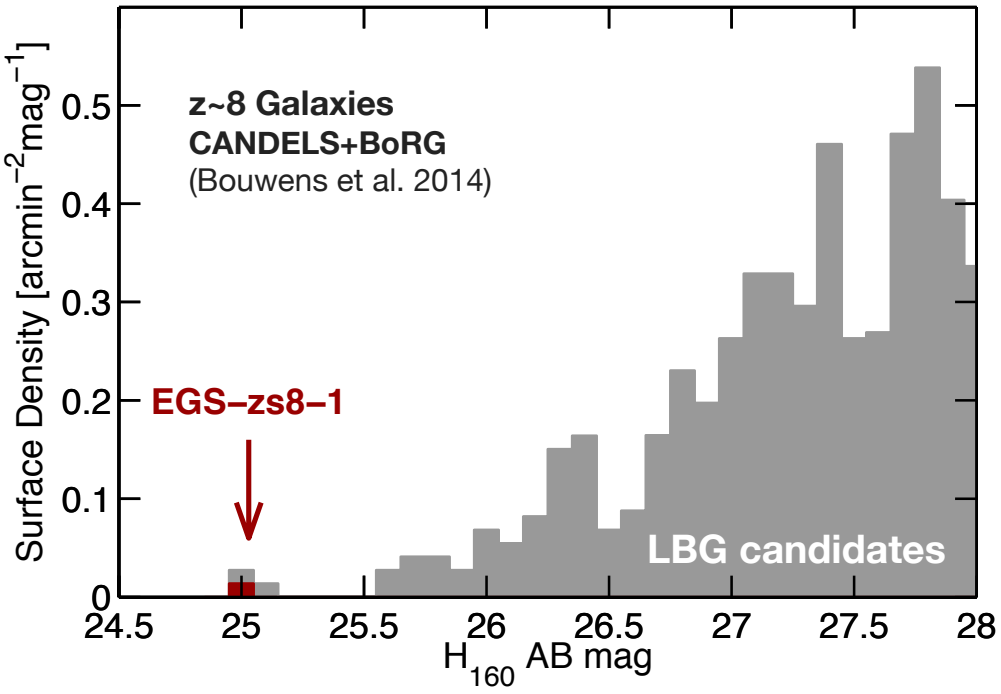
- Hubble Frontier Fields

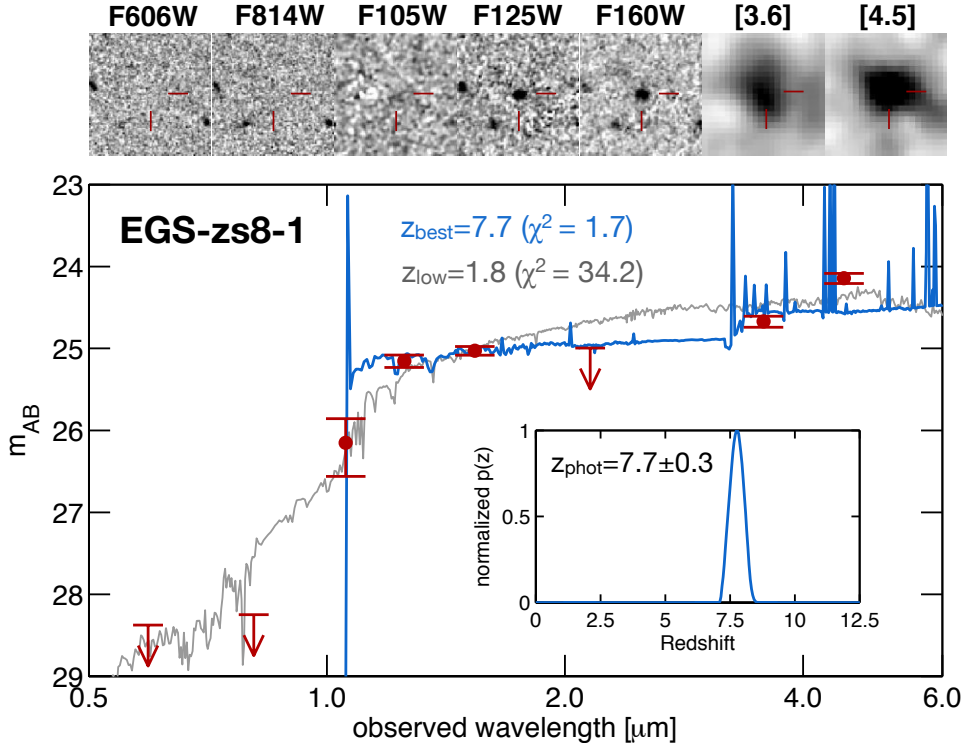
  ➔ see talks by Hakim Atek, Derek McLeod, Ryota Kawamata, Masafumi Ishigaki, and others..

- Our follow-up program of CANDELS-WIDE z~9-10 galaxy candidates (PI: Bouwens)

Spectroscopic Follow-up of Luminous Sources

Search over CANDELS-WIDE for z~8 galaxy candidates revealed three remarkably bright sources with H = 25 mag



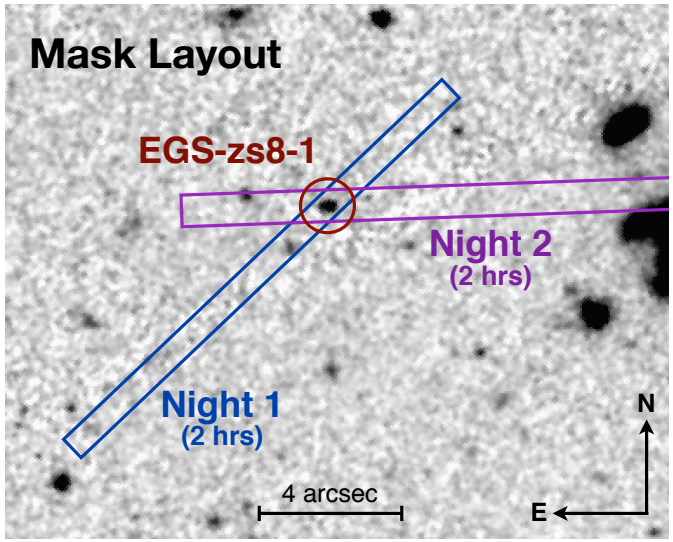


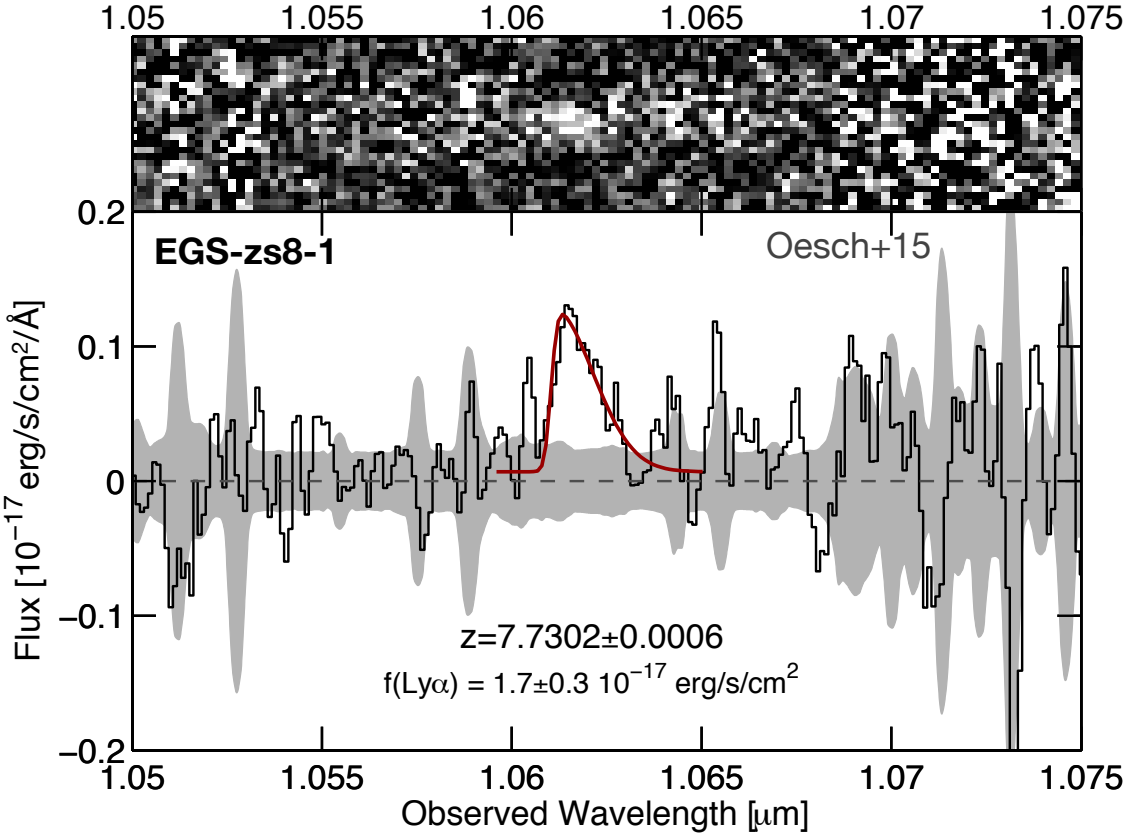
All of these show extremely red IRAC colors, indicating strong rest-frame optical emission lines dominating the IRAC flux at 4.5 μm

The Most Distant Confirmed Source

MOSFIRE

Multi-Object Spectrometer for Infra-Red Exploration



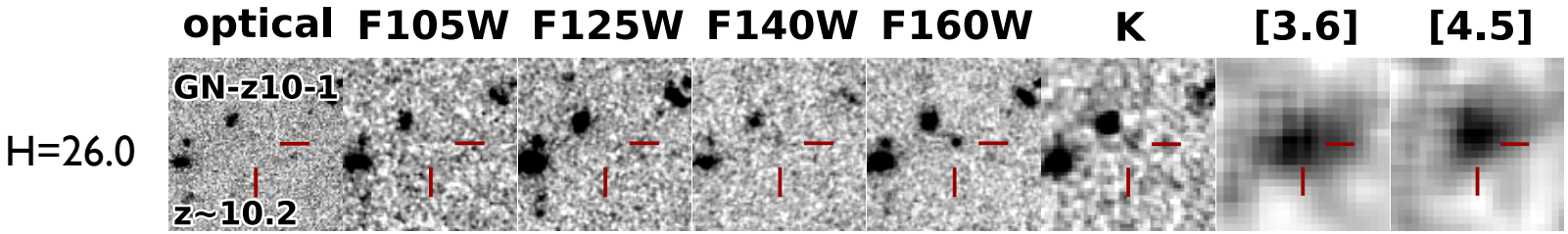


A 2x2hr MOSFIRE exposure in two masks revealed a significant emission line in both. Combined line shows asymmetric profile as expected for Lyα at high redshift.

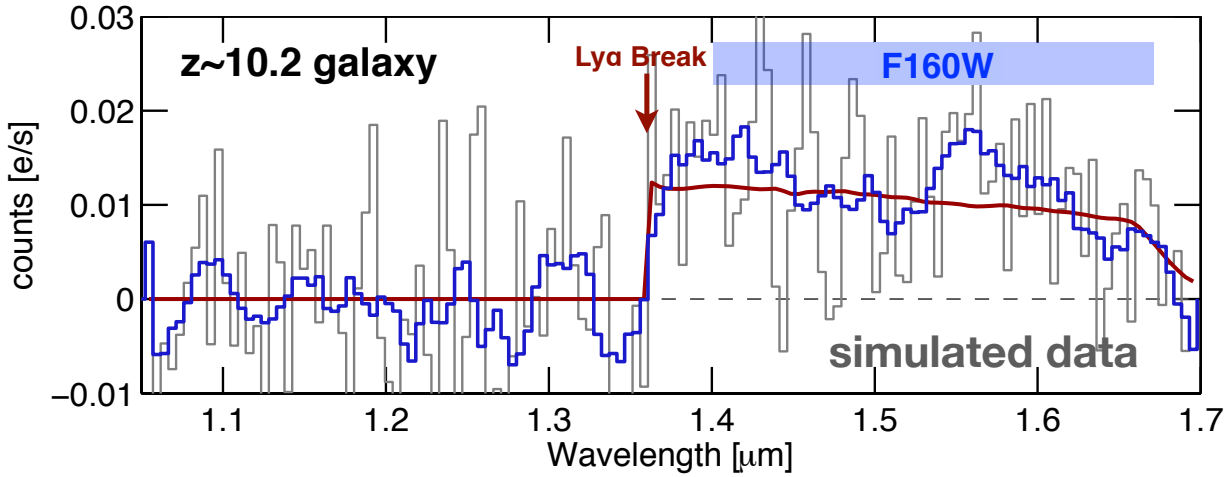
A handful of confirmed redshifts exist now at z>7.0

(e.g. Ono et al. 2012, Finkelstein et al. 2013, Oesch et al. 2015, Watson et al. 2015)

Grism Continuum Redshift at z~10?



Upcoming HST spectra
end of March 2015
(GO 13871, PI Oesch)



see also: Coe et al. in prep for similar program for z~10.7 source

Summary

- Combination of very deep **HST and Spitzer/IRAC** imaging is **very efficient** allowing us to measure rest-frame optical colors and **stellar mass build-up** even out to **z~10**

- First **detections** of **z~10** galaxies with Spitzer **IRAC** show these galaxies are not primordial (onset of SF at z~12-15), and galaxy mass density at z~10 is <0.1% of today

- **GREATS** will cover two GOODS fields, pushing IRAC exposure times to **200 hours** in both **3.6 and 4.5 μm** filters, enabling **individual detections** of z~8 galaxies down to the limit of HST

- Spectroscopic confirmations of z>~7 galaxies are slowly being assembled, we **confirmed** likely the **brightest z~8** candidate in all CANDELS fields