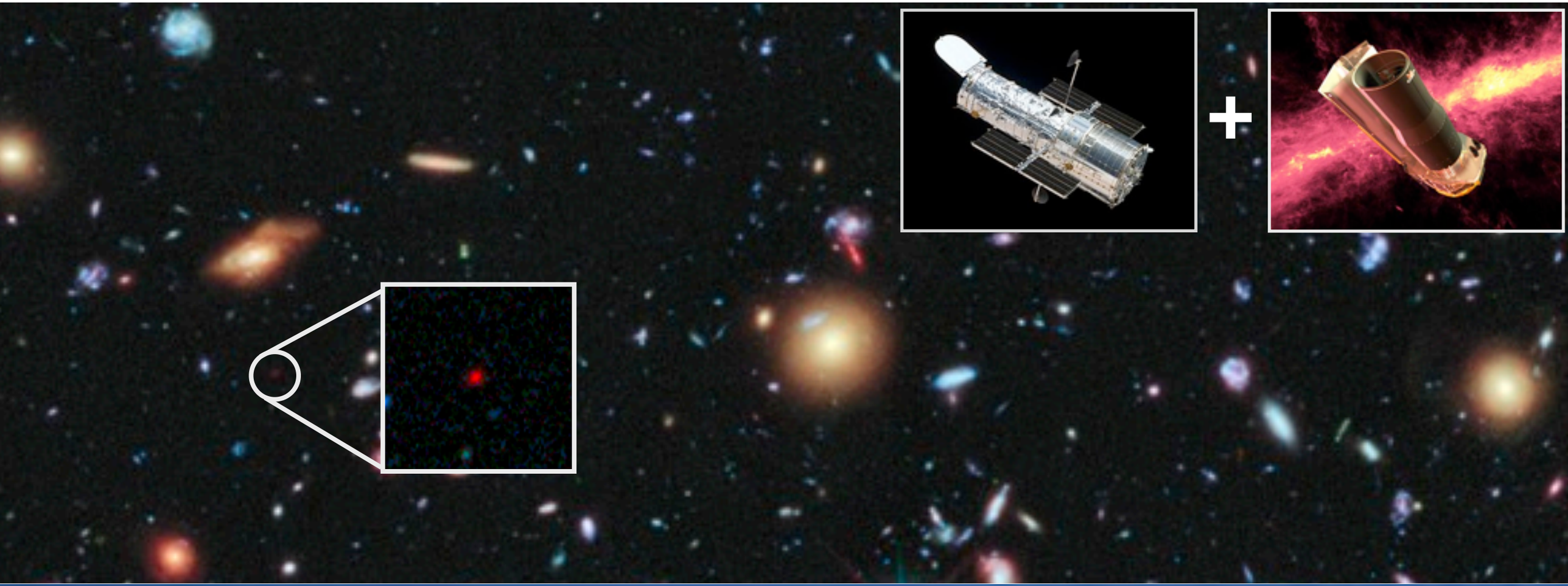
Yale Center for Astronomy and Astrophysics

YALE

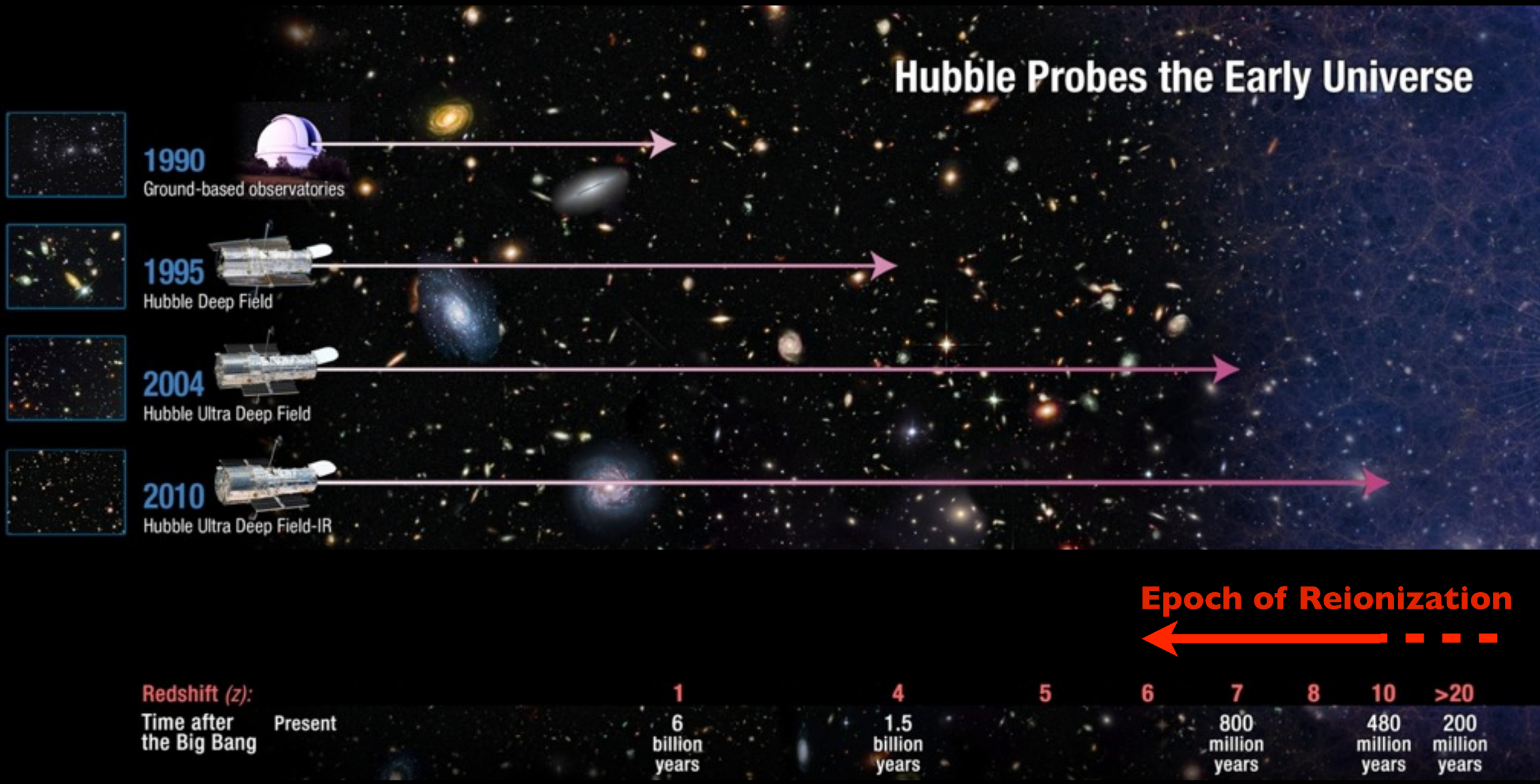
Probing the Dawn of Galaxies:
Lessons from Ultra-Deep Observations with Hubble and Spitzer

Pascal Oesch (YCAA Fellow, Yale)

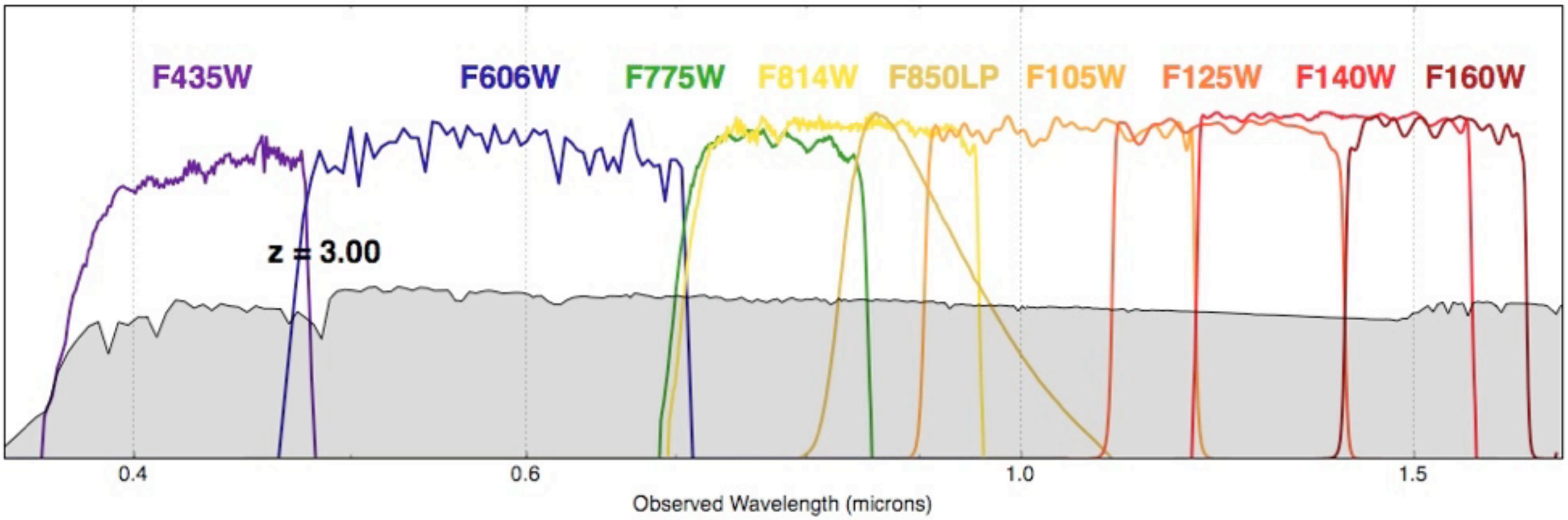
in collaboration with XDF Team Plus: G. Illingworth, R. Bouwens, I. Labbé, P. van Dokkum, M. Franx, V. Gonzalez, D. Magee, M. Trenti, C.M. Carollo, M. Stiavelli, R. Smit + G. Fazio, M. Ashby, S. Willner, J-S Huang, R. Barone-Nugent, S. Wyithe

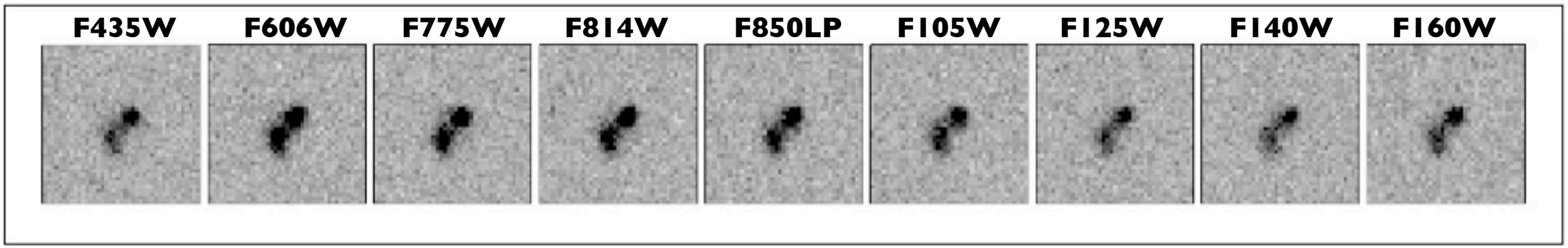


The Reionization Epoch with HST



WFC3/IR: efficient detection of galaxies to z~10

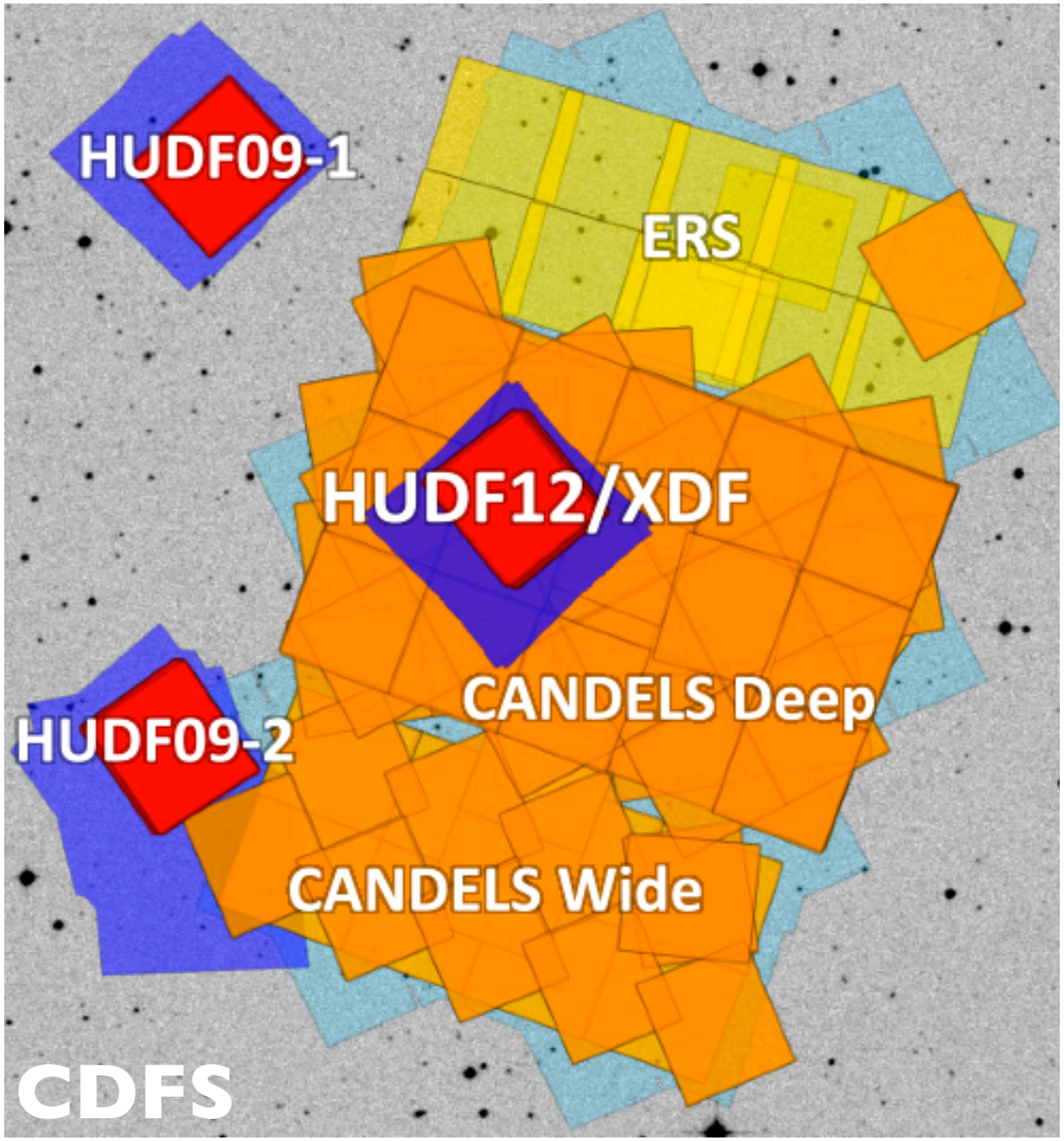




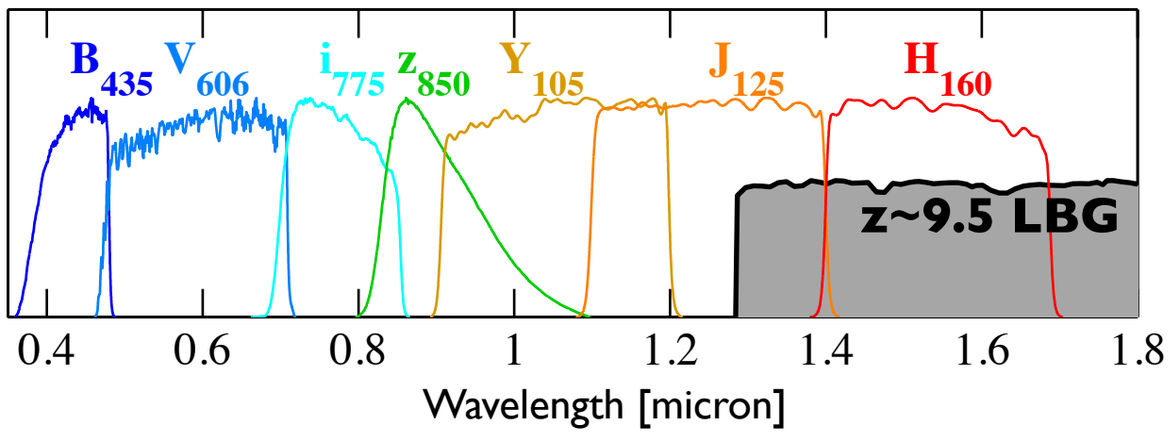
optical ACS

near-IR WFC3/IR

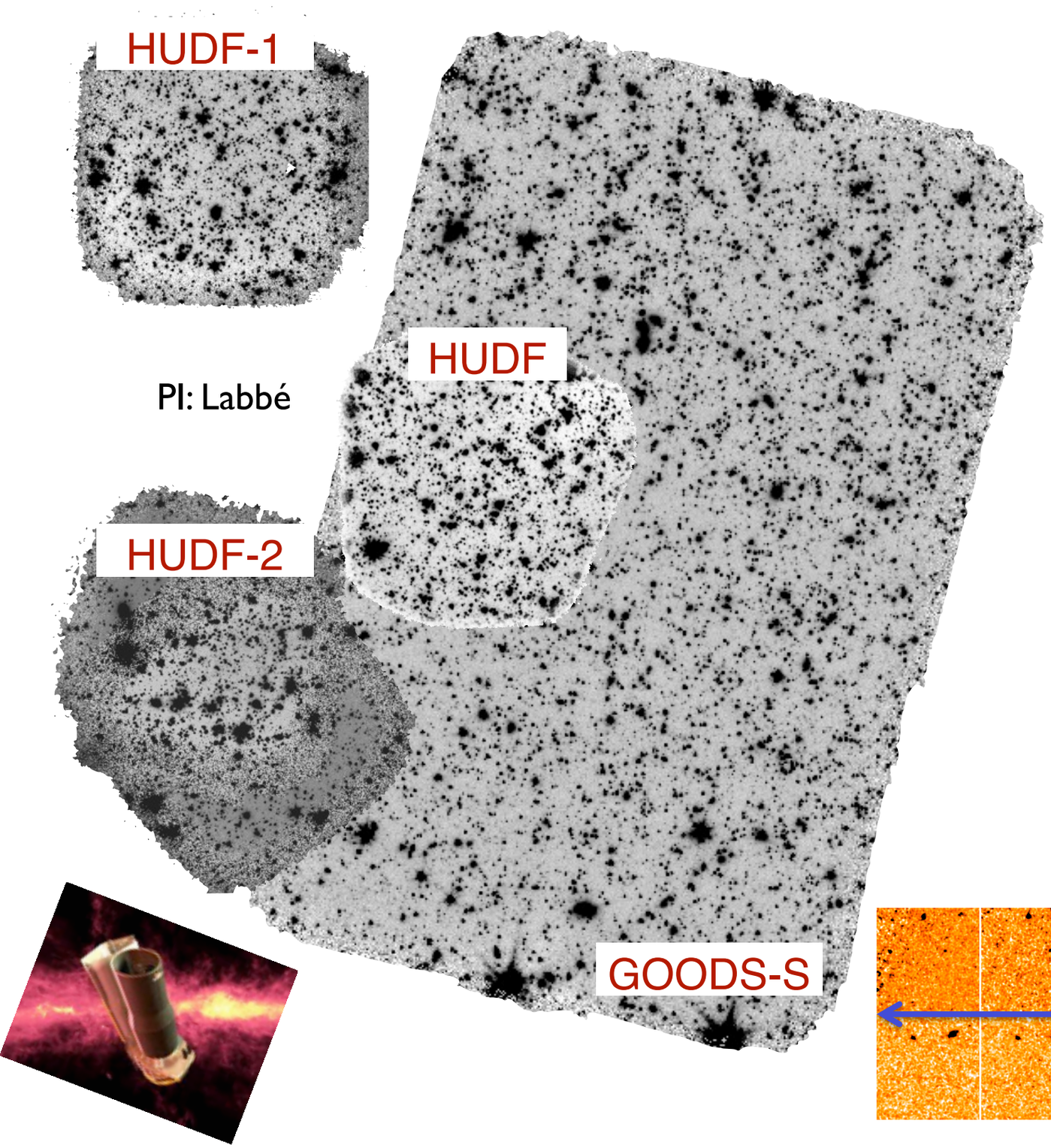
Large Archive of Deep HST Datasets



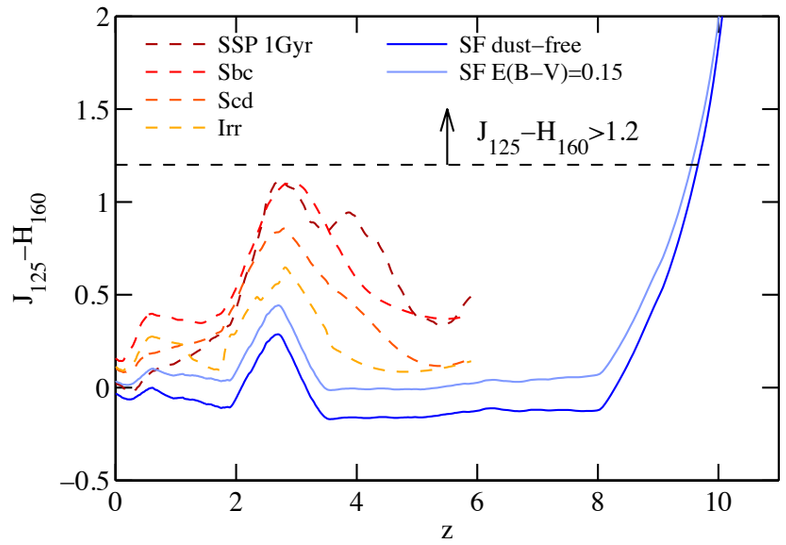
- Large amount of public optical (ACS) and NIR (WFC3) data
  - *HUDF12 & XDF*
  - *UDF05/HUDF09*
  - *ERS*
  - *CANDELS* (Deep & Wide)
- Total of ~730 arcmin^2 **(less than one WFIRST pointing!)**
- Reach to 27.5 - 29.8 AB mag

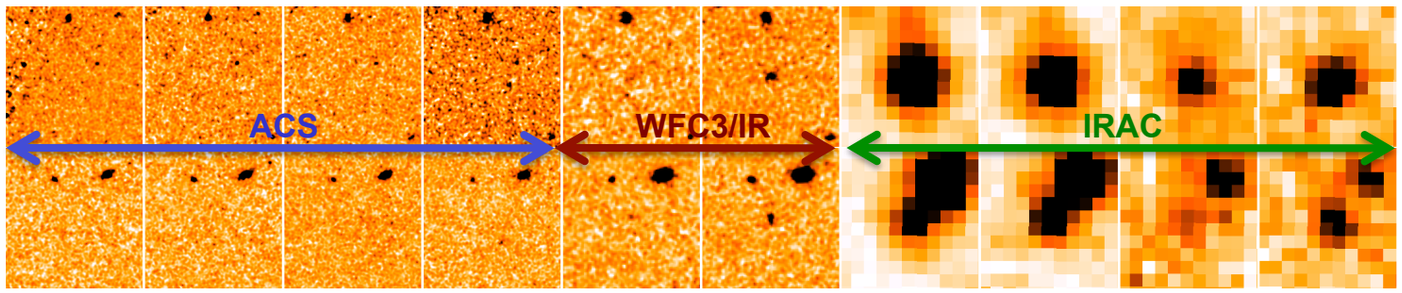


Matched Deep IRAC Data



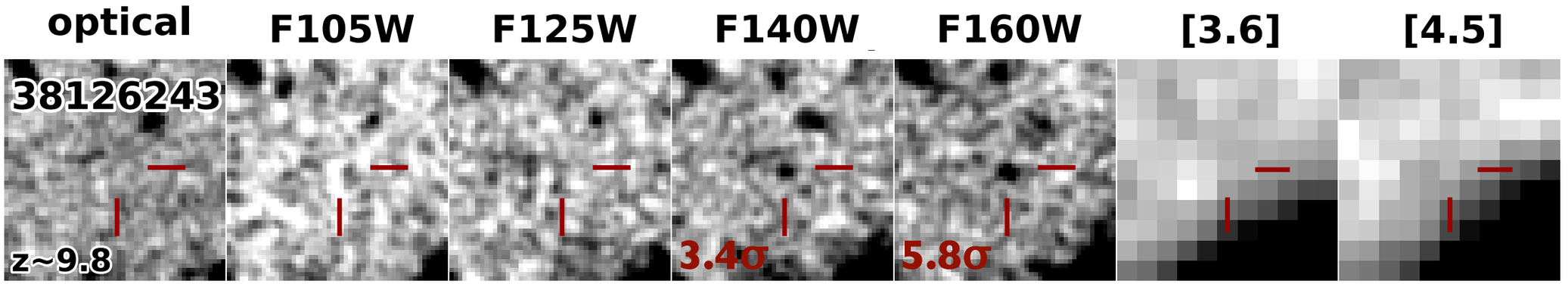
- Deep Spitzer/IRAC complemented all the HST datasets (S-CANDELS+SEDS)
- Deepest data available over HUDF09/ GOODS-S
- IRAC crucial for
  - stellar mass estimates
  - excluding contaminants





An extremely faint z~10 candidate in the XDF

Only one reliable z~10 galaxy candidate identified in three very deep WFC3/IR fields of HUDF09 + HUDF12/XDF!

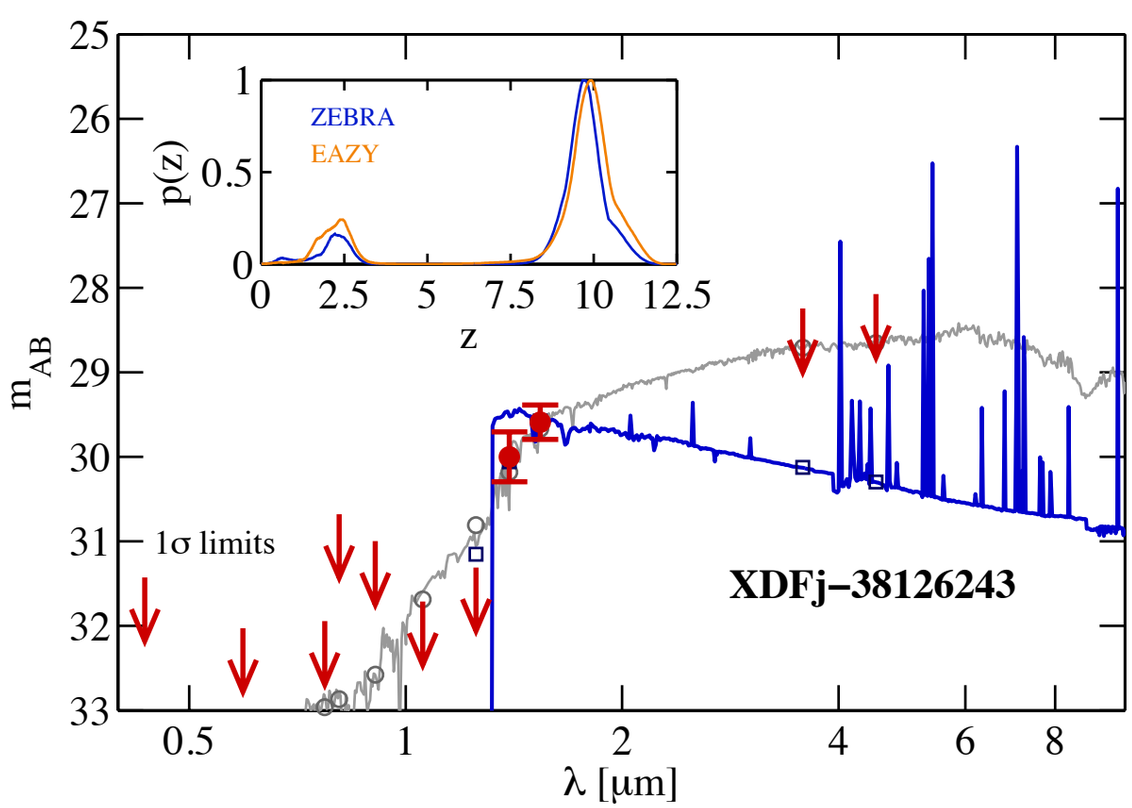


Oesch+13b

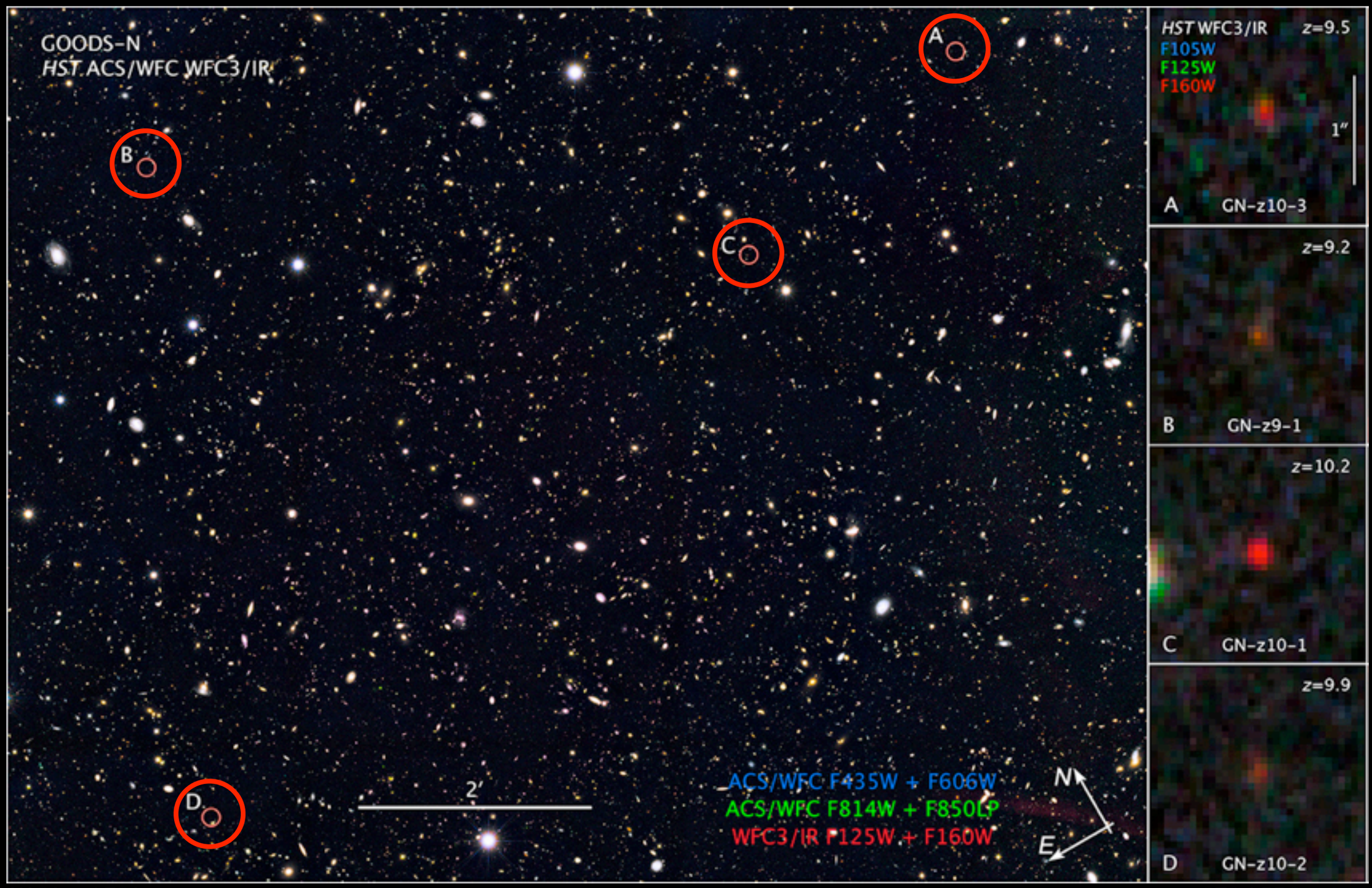
The source is definitely real. It is detected at >3σ in several independent subsets of data

It is has S/H = 3.4 and 5.8 in JH_{140} and H_{160}.

It has H_{AB}=29.8 mag and a photometric redshift of z_{phot} = 9.8±0.6



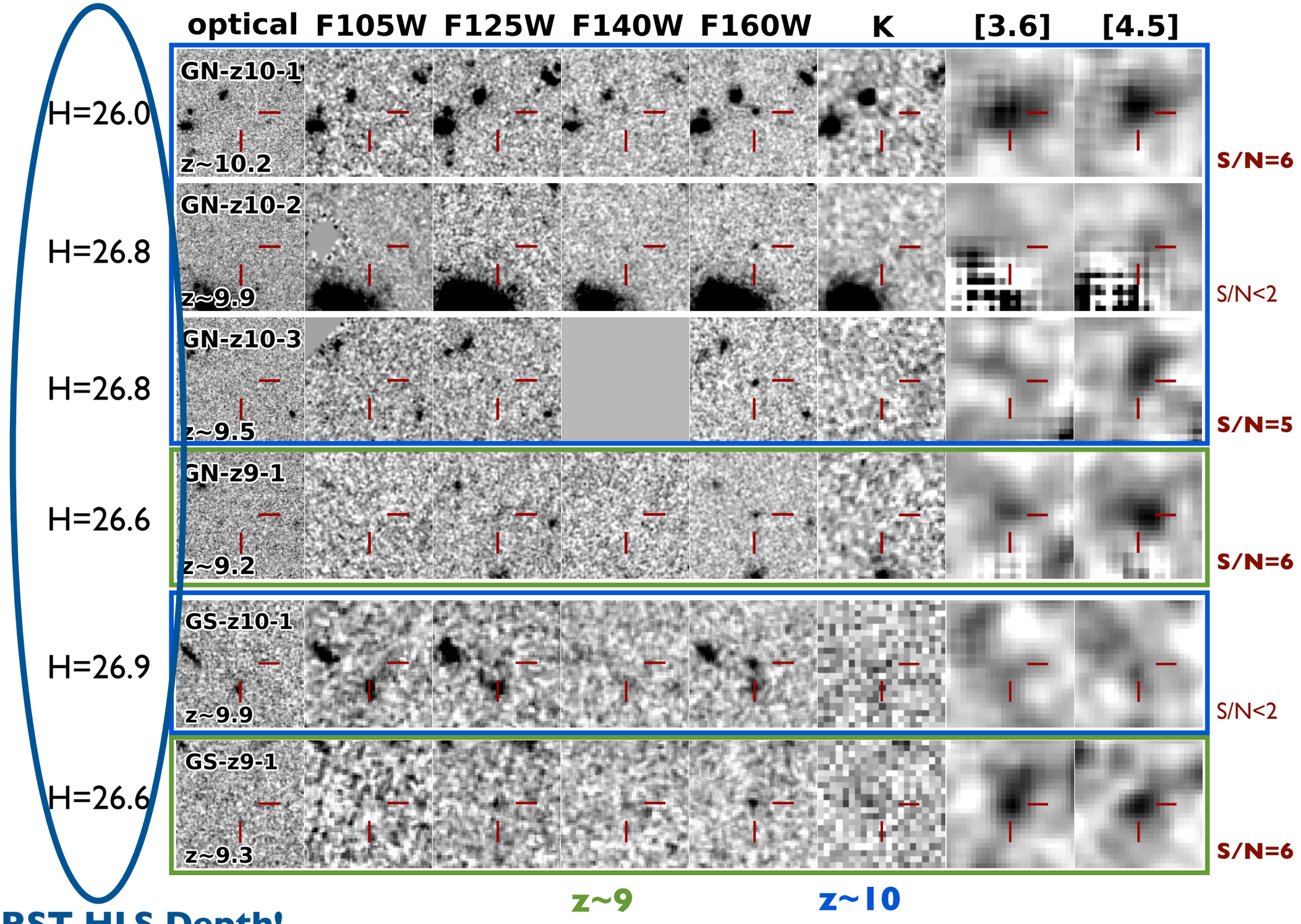
Sample of Bright z~9-10 Galaxy Candidates



NASA and ESA STScI-PRC14-05a

4 candidates in GOODS-N, 2 candidates in GOODS-S

Sample of Bright z~9-10 Galaxies in GOODS



WFIRST HLS Depth!

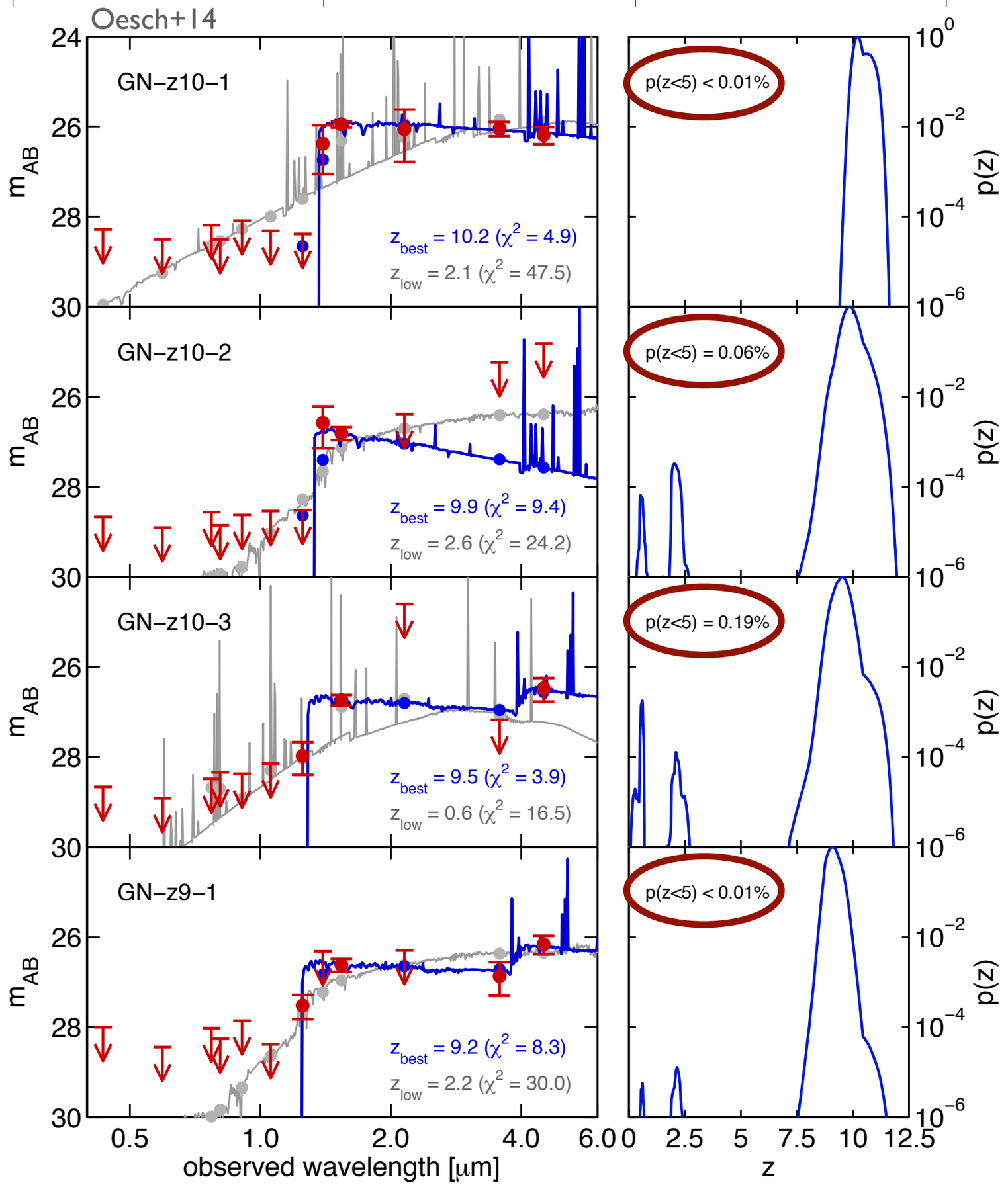
Accurate Sampling of Spectral Energy Distribution

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

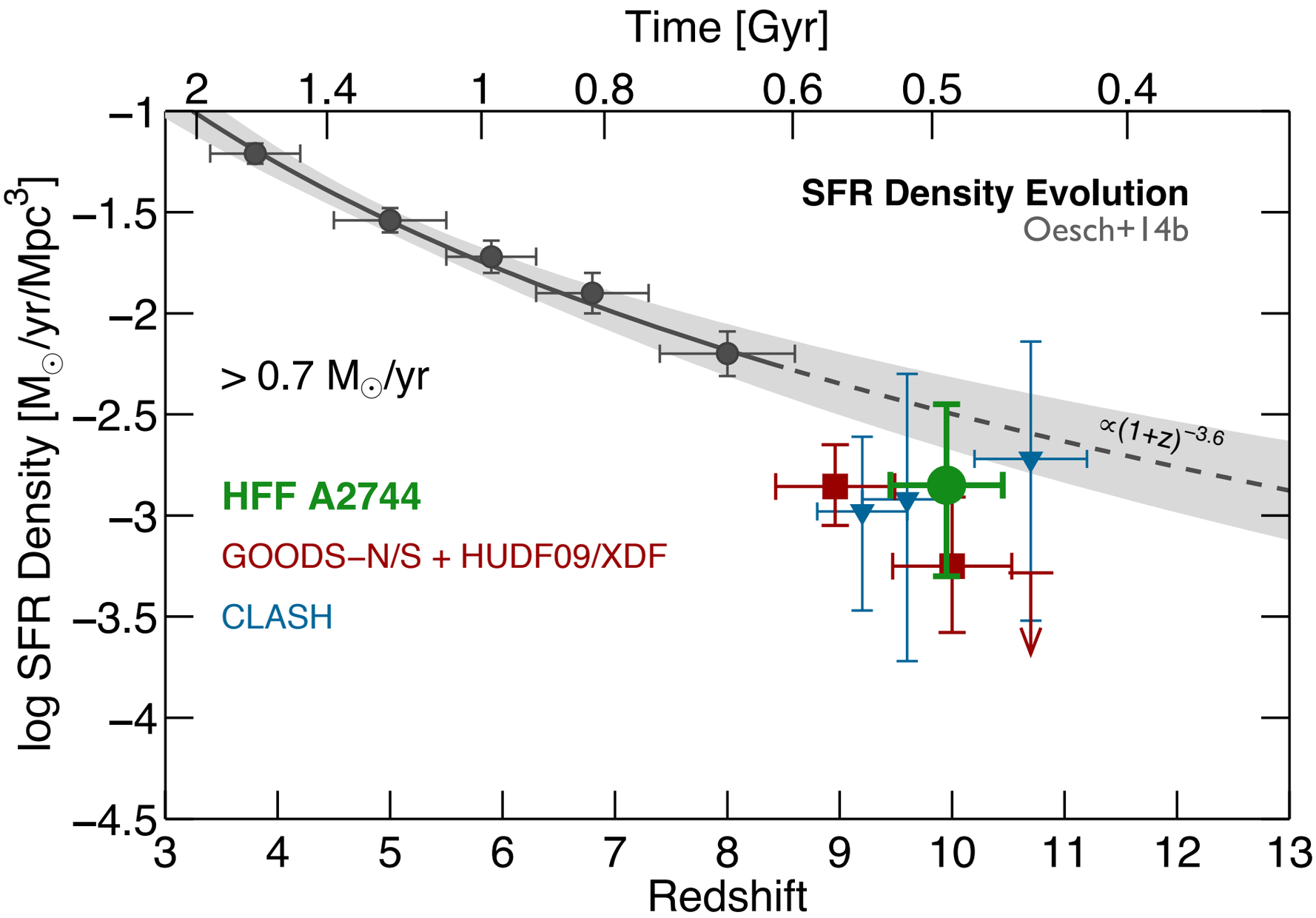
Photometric Redshift Estimates:
z~9.2-10.2

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**



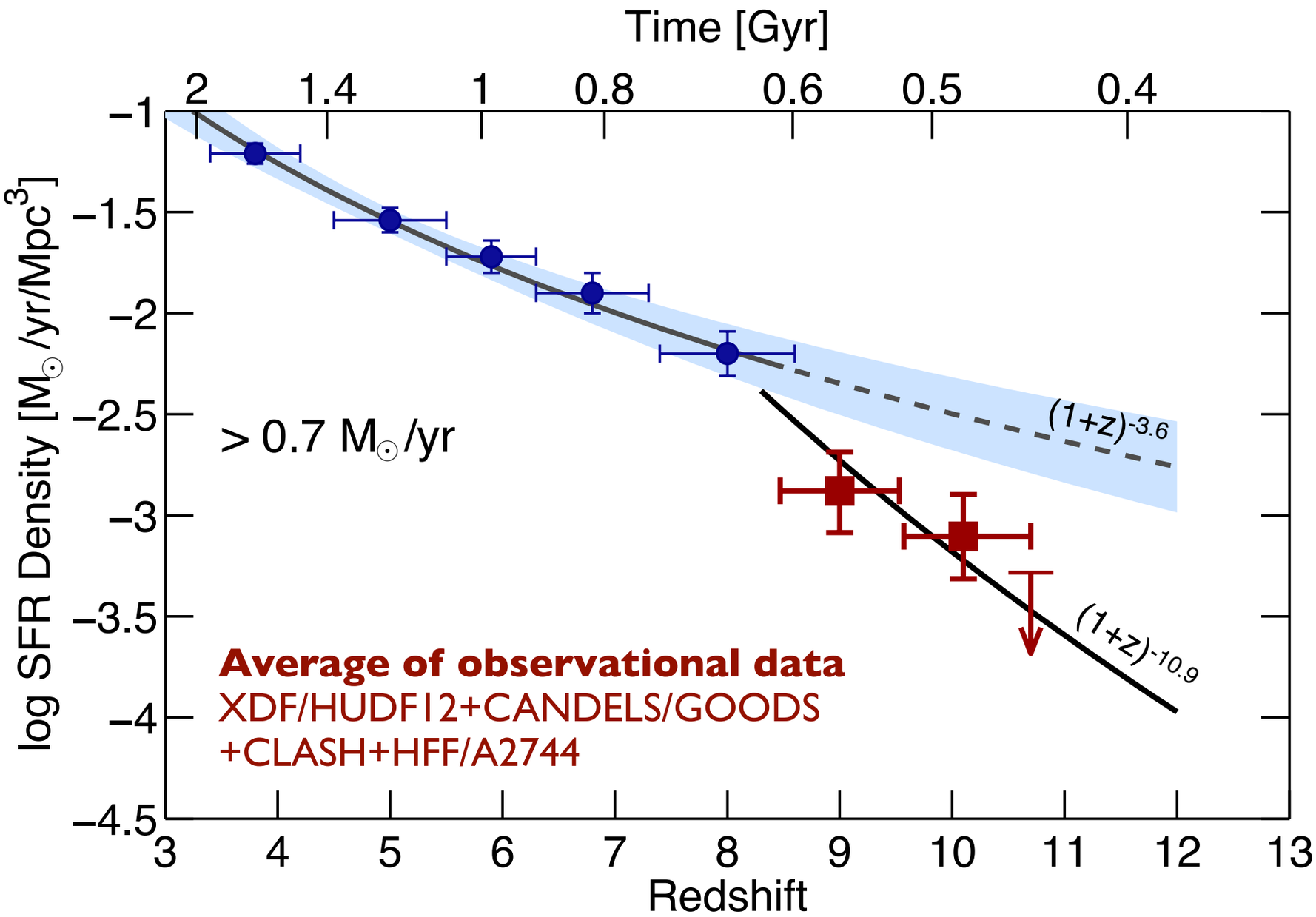
SFRD Evolution at z>8



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

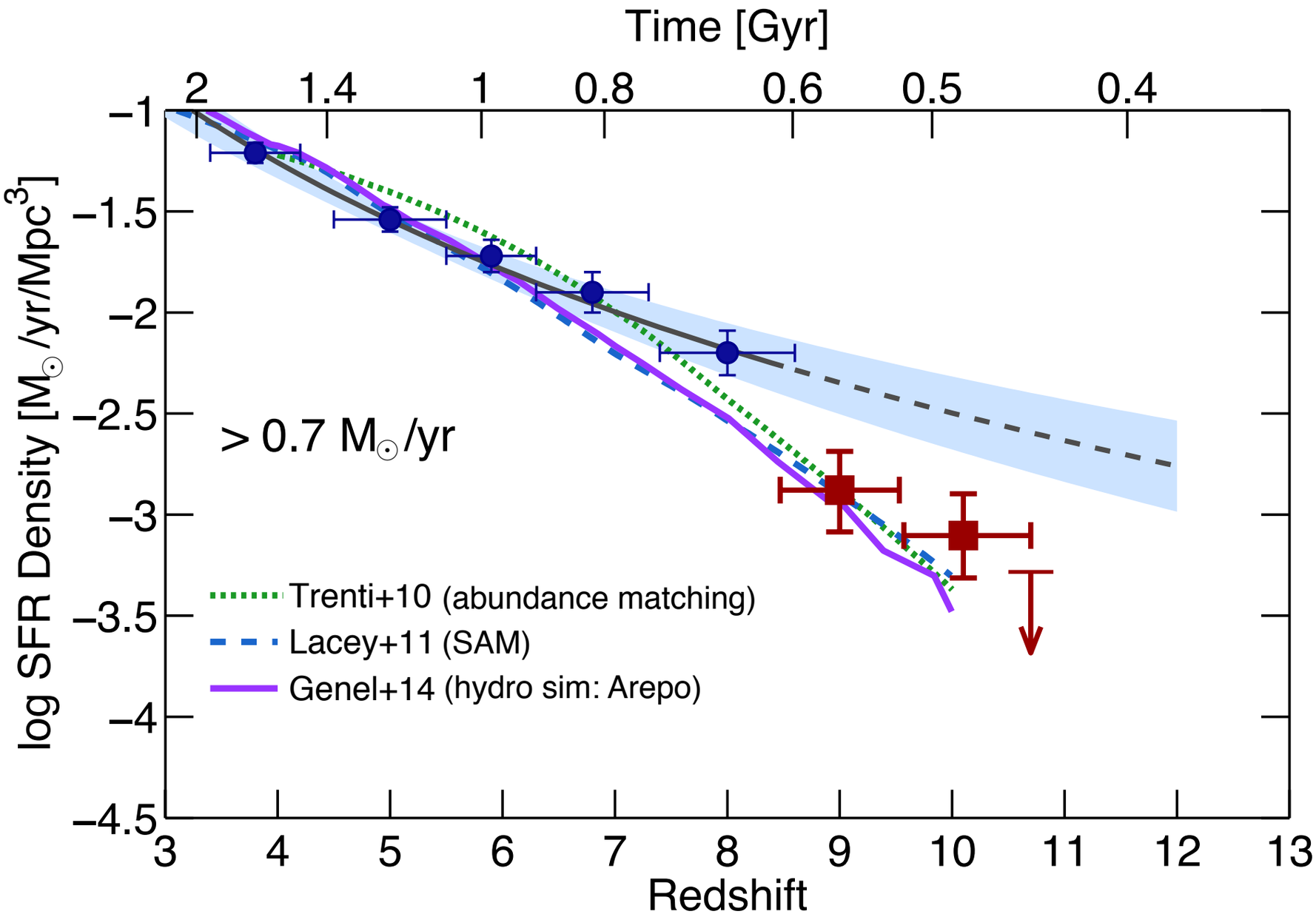
see also: Zheng+12, Coe+13, Bouwens+13/14, Ellis+13, McLure+13, Ishigaki+14

SFRD Evolution at z>8



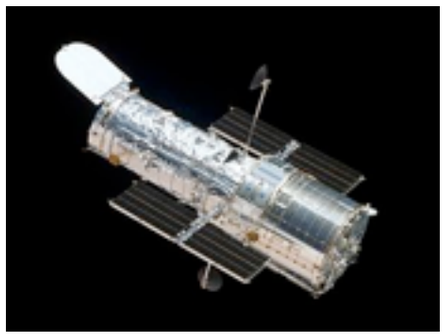
Combining the current constraints from all datasets:
very rapid evolution in the cosmic SFRD at z>8 (factor ~10x in 170 Myr).

SFRD Evolution at z>8

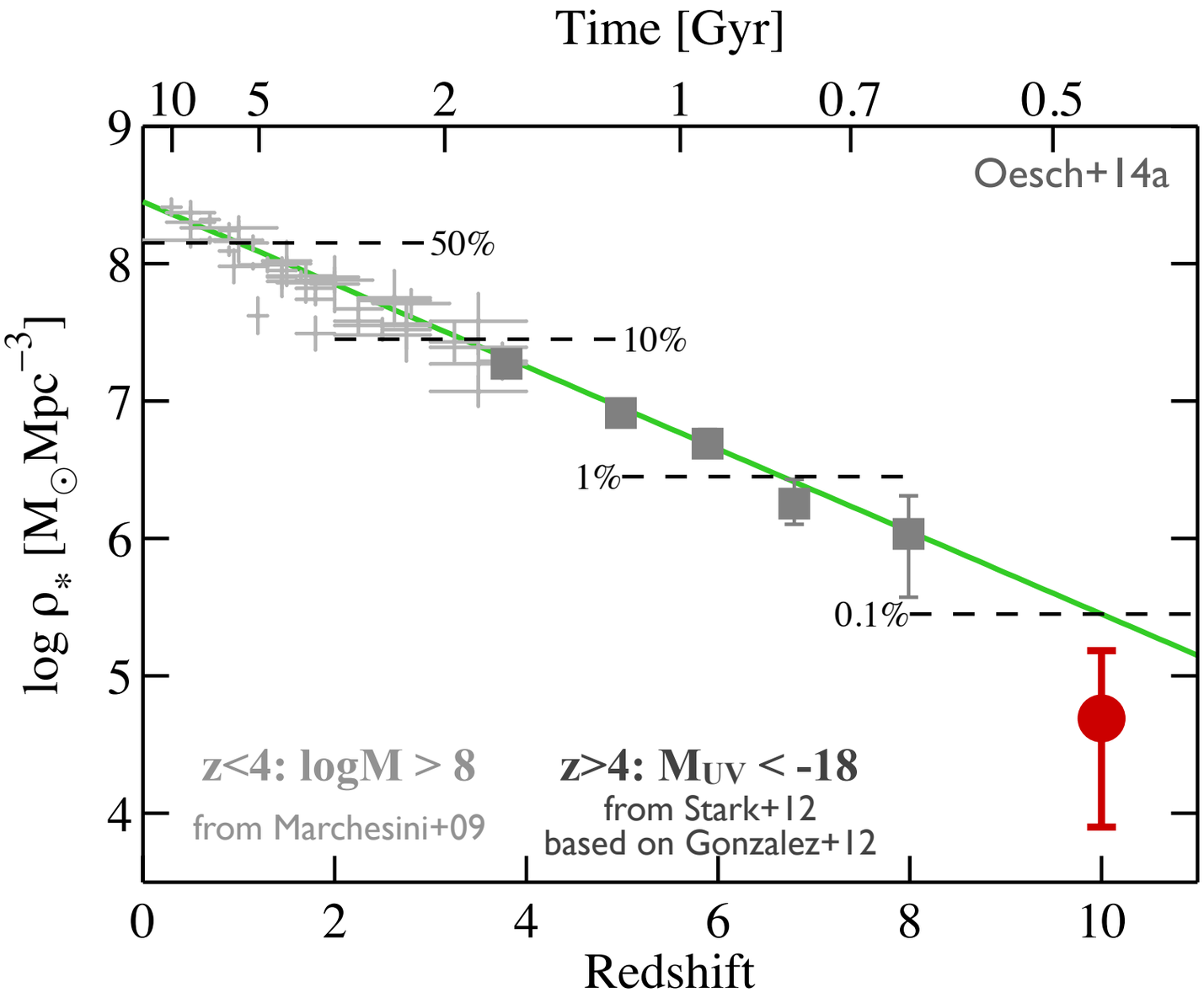


Drop in SFRD is in good agreement with several model predictions.
Imprint of underlying DM halo MF?

Stellar Mass Density Evolution to z~10



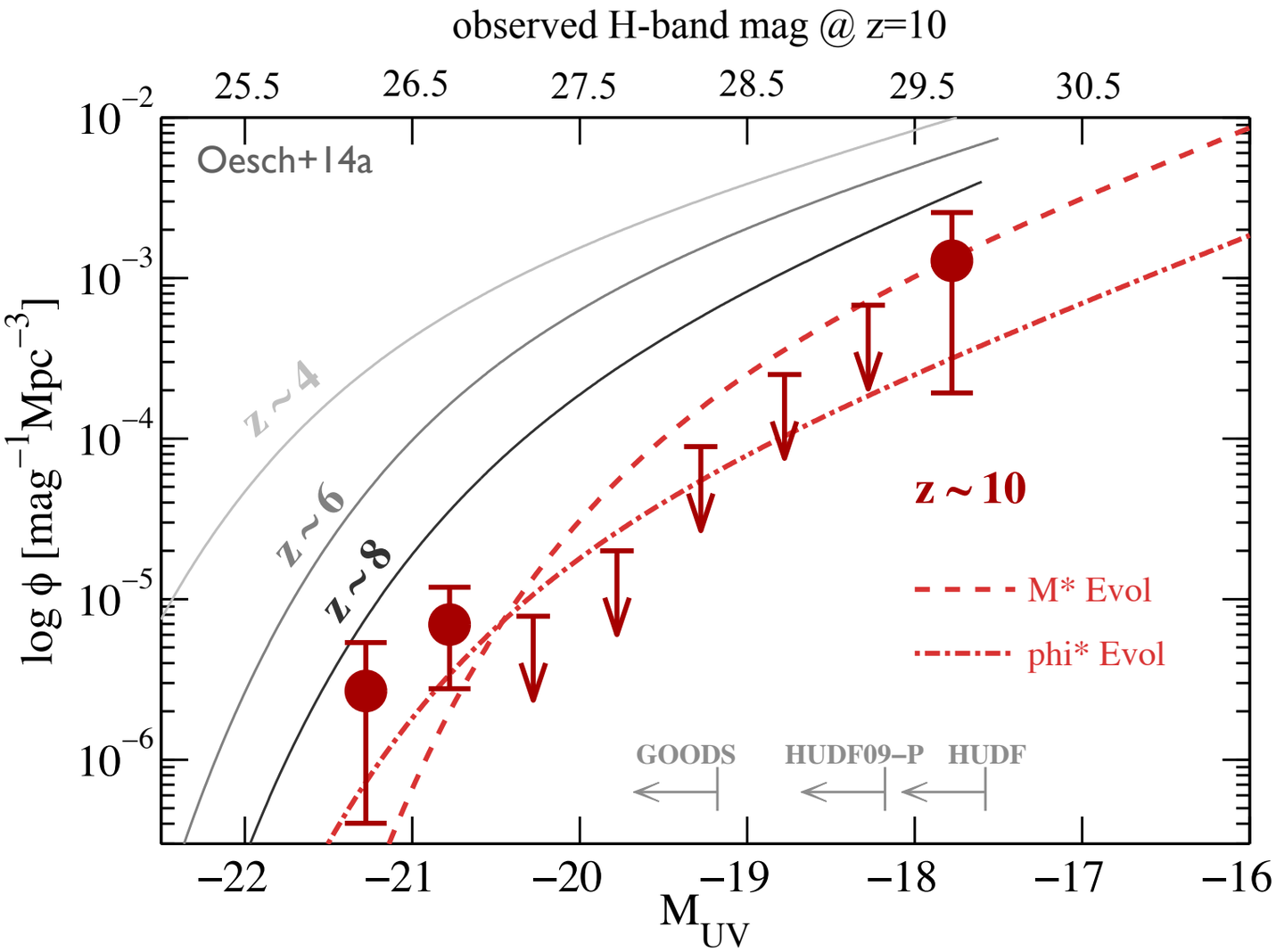
+



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

Probe the SMD over 96% of the age of the universe and
are witnessing the assembly of the first 0.1% of local stellar mass density!

UV LF Evolution still very uncertain



based on 5 galaxies in GOODS-N+S + HUDF09/12

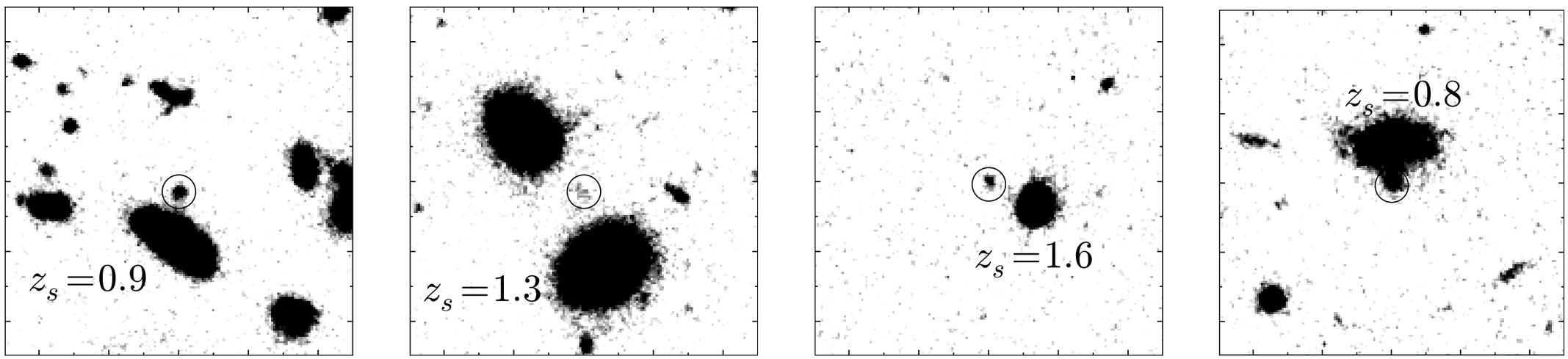
Can clearly rule out no evolution since z~8 (should have detected 48 z~10 galaxies!)
But: evolutionary scenario from z~8 to z~10 is still very uncertain

Where are intermediate mag (~27-29) galaxies? Frontier Fields are addressing this now.

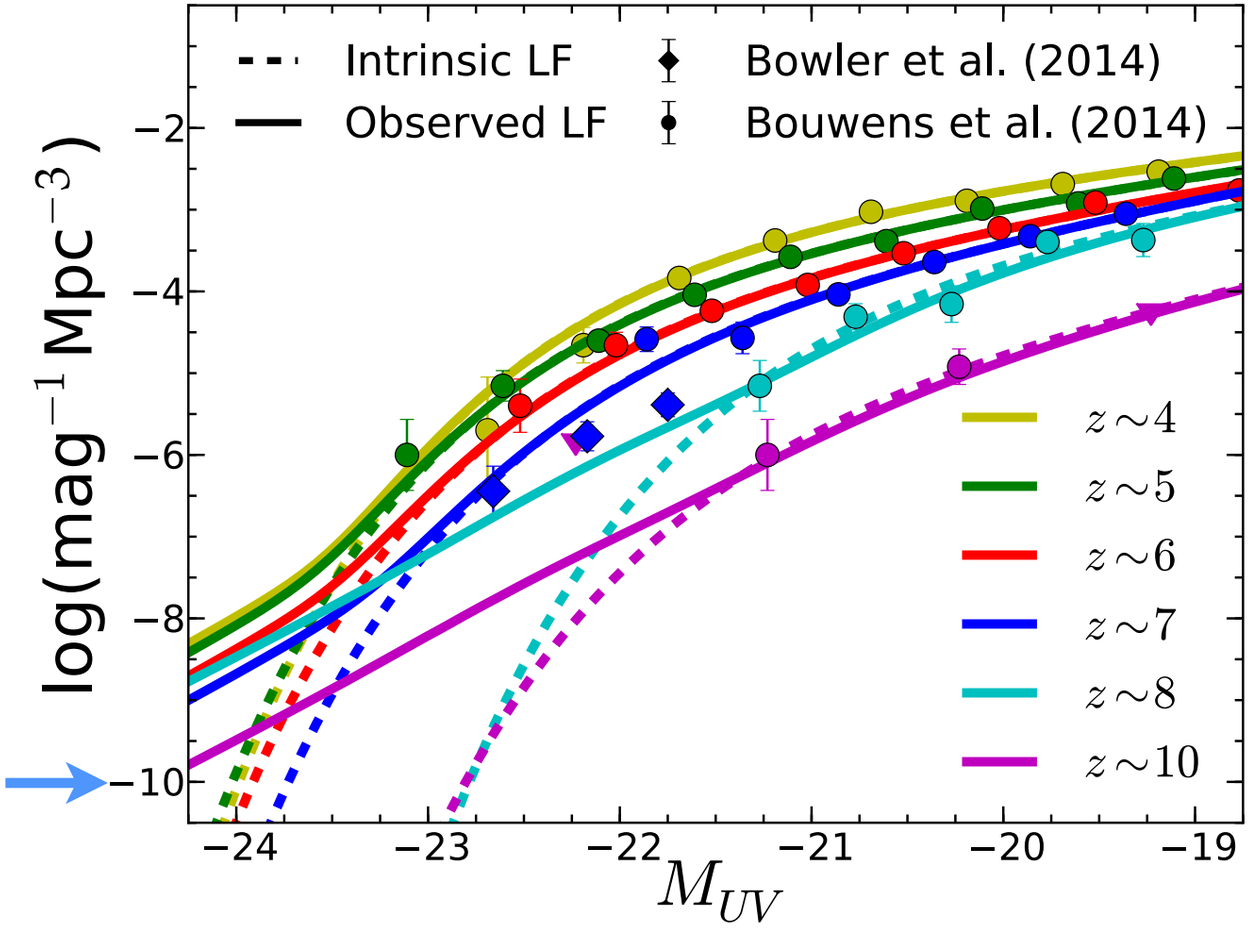
However: **bright end can only be constrained by WFIRST!**

Magnification Bias

Wyithe+12, Barone-Nugent+14, in prep.



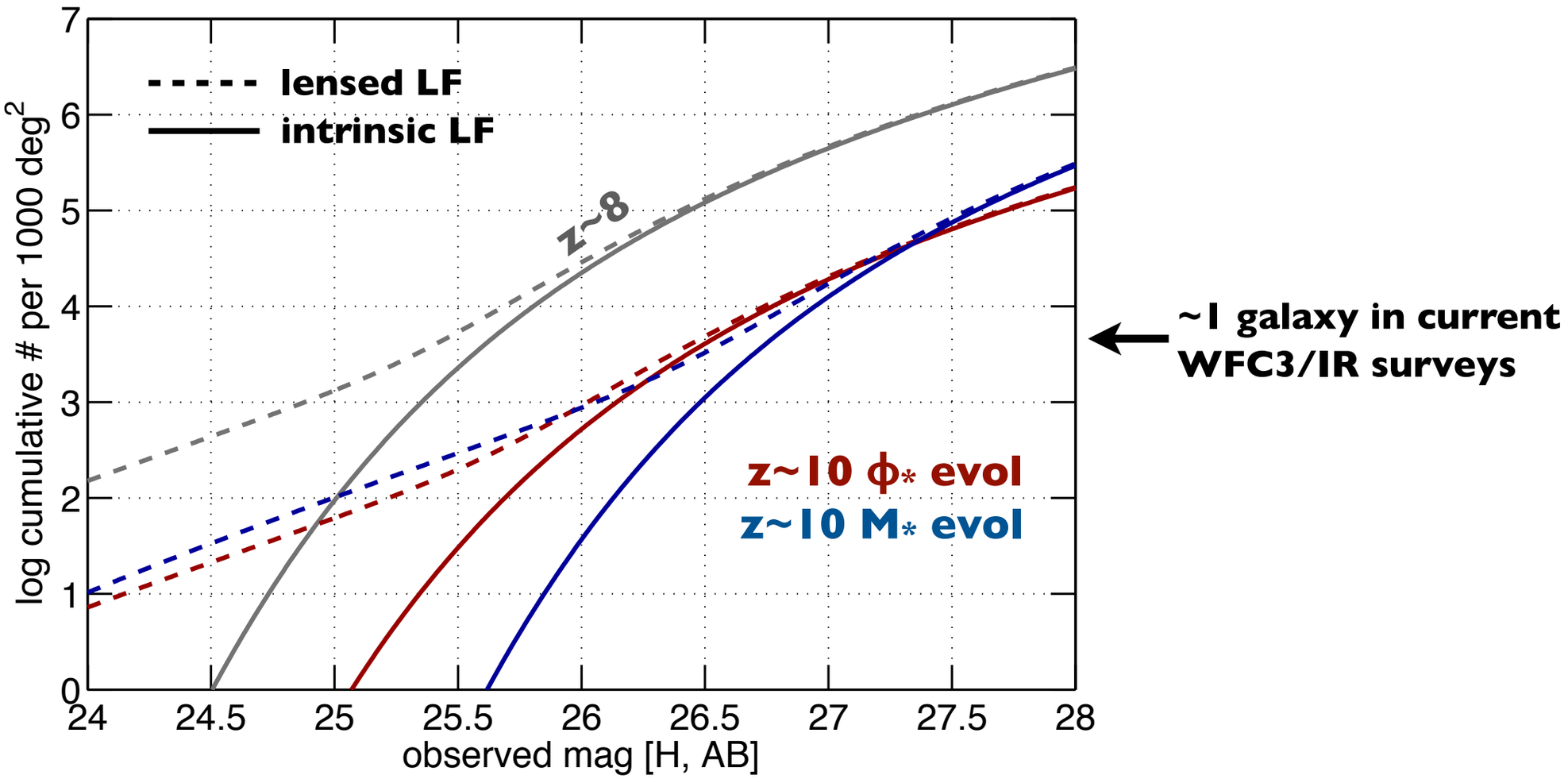
- massive foreground sources will magnify high-redshift galaxies
- clearly detected in current samples (~few percent of brightest z>4 galaxies likely lensed)
  Barone-Nugent,...,PO+14, in prep.
- lensing results in skewed UV LF
- current LFs not yet affected, but larger volumes of WFIRST need to account for this



~1000 deg²

Including Lensed Fraction to Skew Observed LF

Wide area survey with WFIRST will be absolutely crucial to constrain bright end of the UV LF at z~7-11



Down to 26 mag, UV LF is completely dominated by lensed galaxies, washing out differences between two evolutionary scenarios.

Summary

- WFC3/IR has opened up the window to very efficient studies of z>6.5 galaxies: extended our **cosmic frontier to z~9-10**

- Found a small sample of **bright** (H=26-27 mag) **z~9-10** galaxies in GOODS fields. Current dataset **<1 WFIRST pointing** ➡ WFIRST will detect lots of z>8 galaxies (>10'000x larger survey volume!)

- Galaxy SFRD increases by ~1 order of mag in 170 Myr from z~10 to z~8 (down to our current completeness limit!).
  ➡ **Accelerated evolution** is most likely explained by growing DM halo MF

- **Combination of HST and Spitzer/IRAC is extremely powerful** to probe the stellar mass build-up even out to z~10, where we are witnessing the build-up of the first 0.1% of today's galaxy mass density being assembled

- **Magnification bias** will be important to account for in wide area surveys: results in **skewed** bright end of the **UV LF**