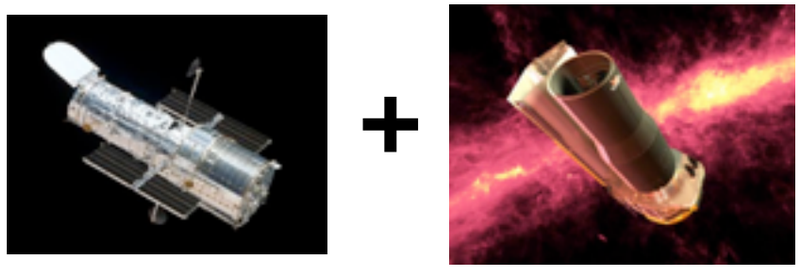
Yale Center for Astronomy and Astrophysics

YALE

# Probing Galaxy Build-up at the Cosmic Dawn in the Frontier Field Era

**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

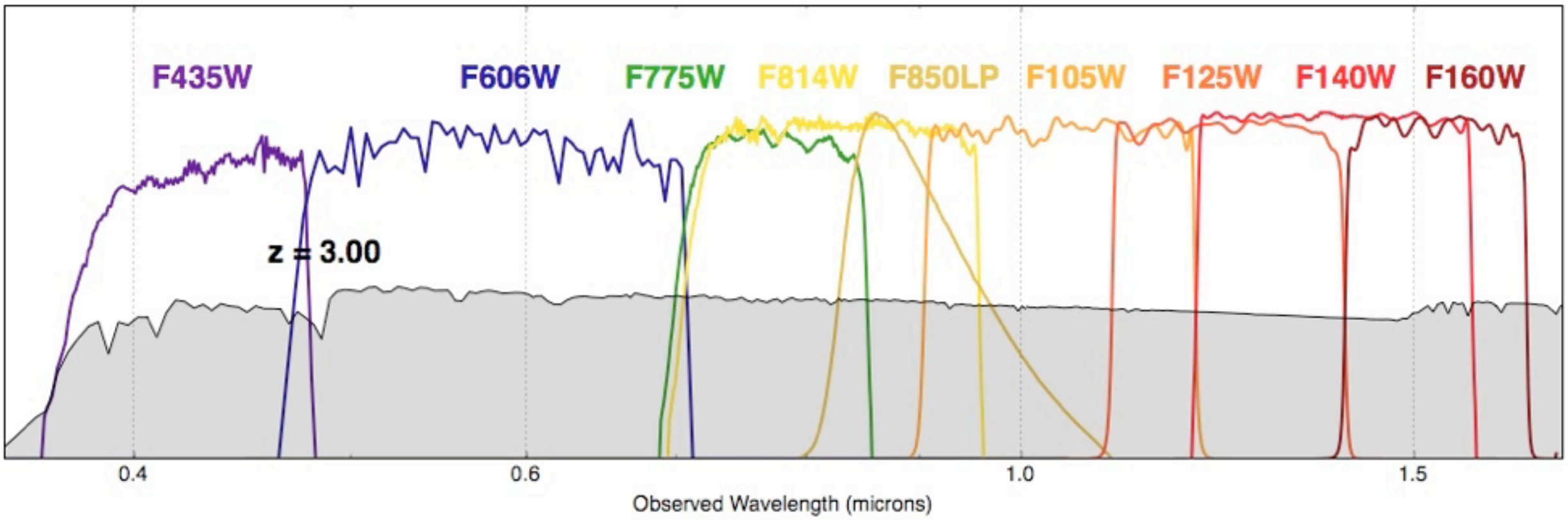
# Optical HUDF

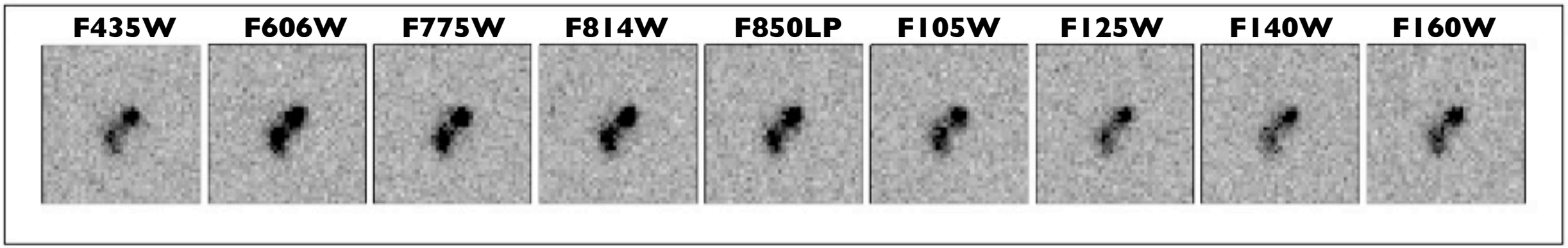
XDF

XDF

WFC3/IR extended the view of the Hubble Ultra-deep Field into the NIR, making z>6 galaxies visible by eye

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

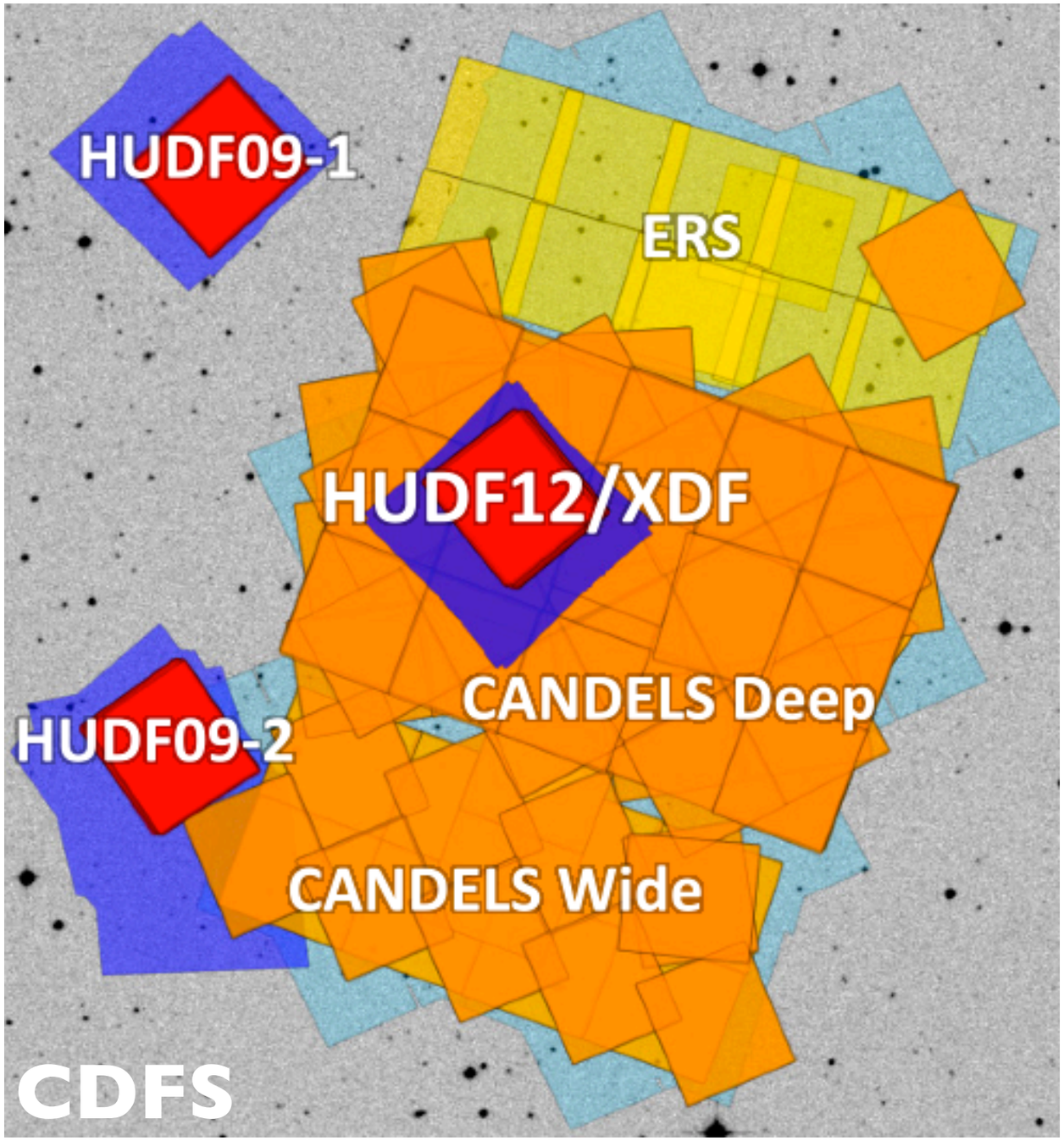


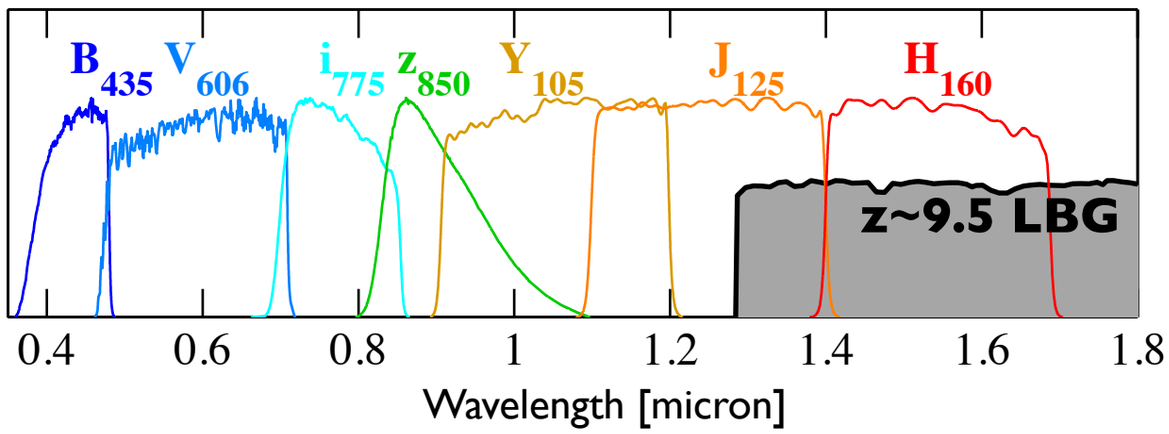

optical ACS

near-IR WFC3/IR

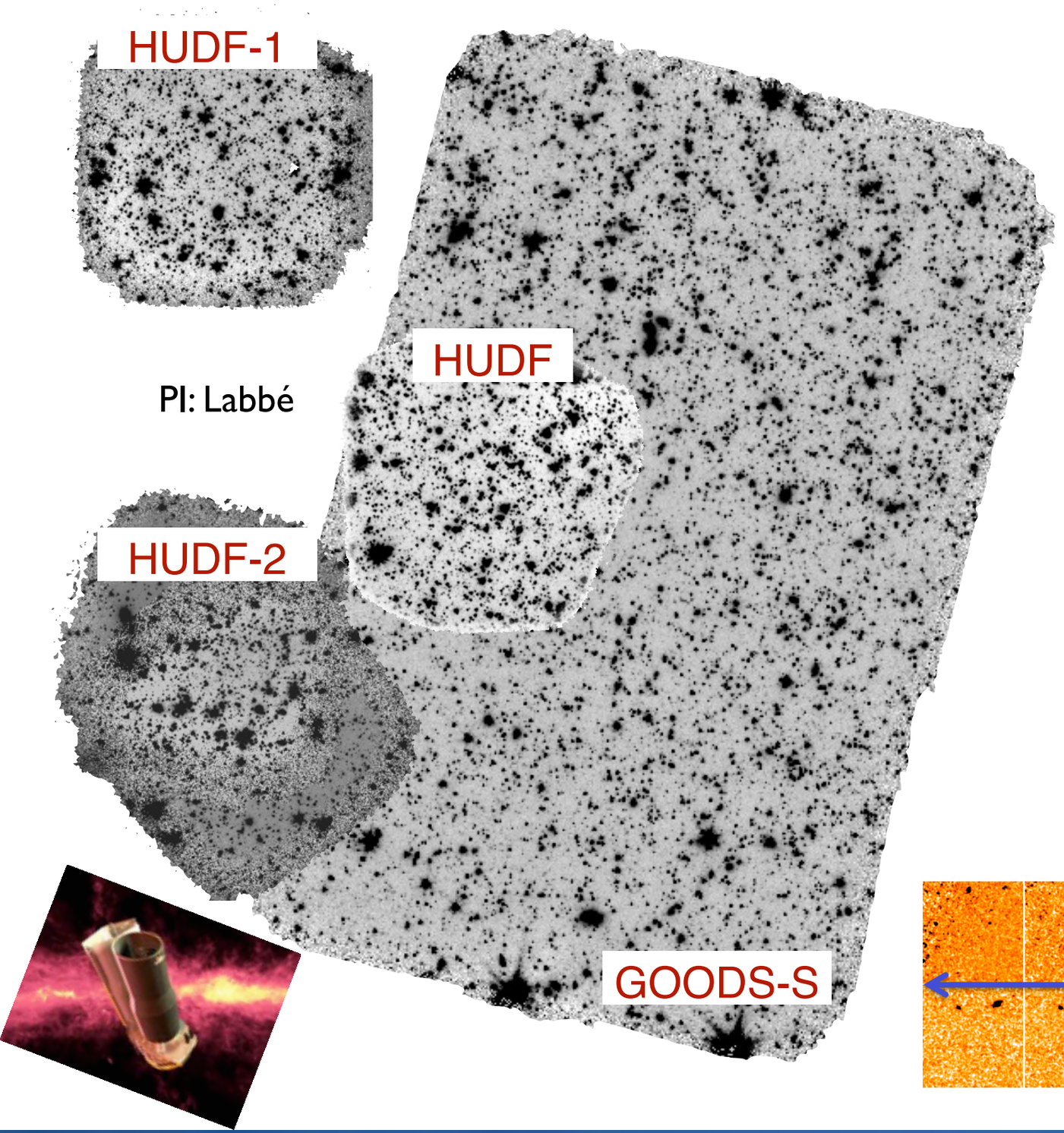
# Large Archive of Blank Field Datasets




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



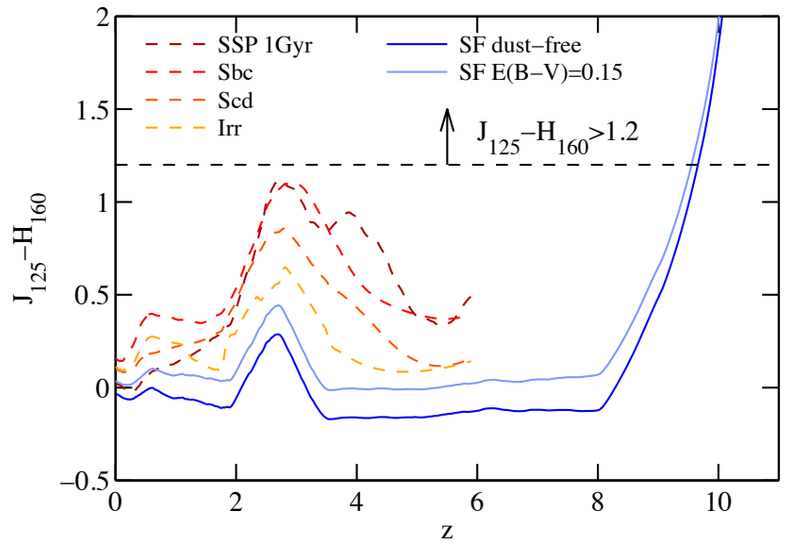
# Deep IRAC Data over HUDF09 + CANDELS

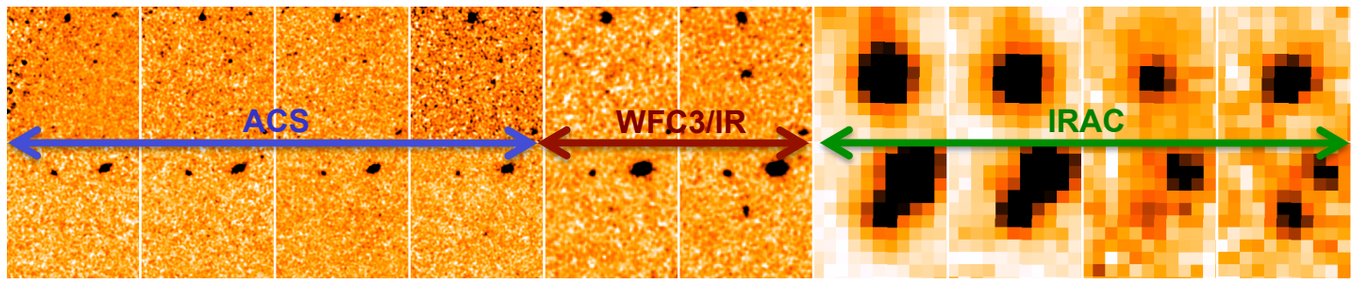



PI: Labbé



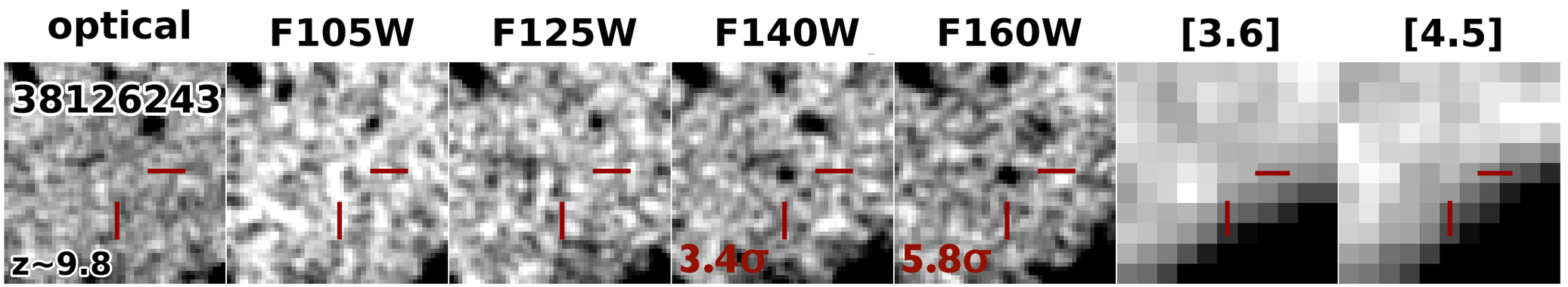
- Deep Spitzer/IRAC complemented all the HST datasets (S-CANDELS+SEDS)
- Deepest data available over HUDF09/ GOODS-S
- IRAC crucial for
  - stellar mass estimates
  - excluding contaminants



# 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 + HUDF/XDF!

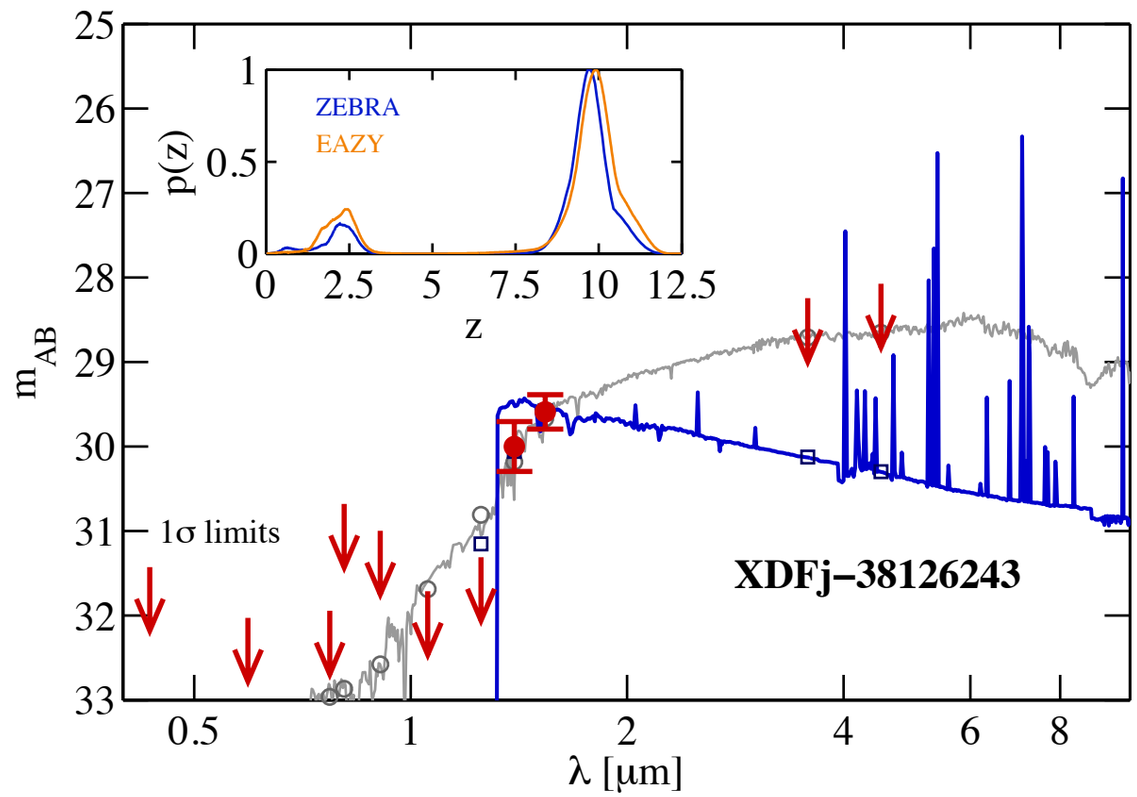



Oesch+13b

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

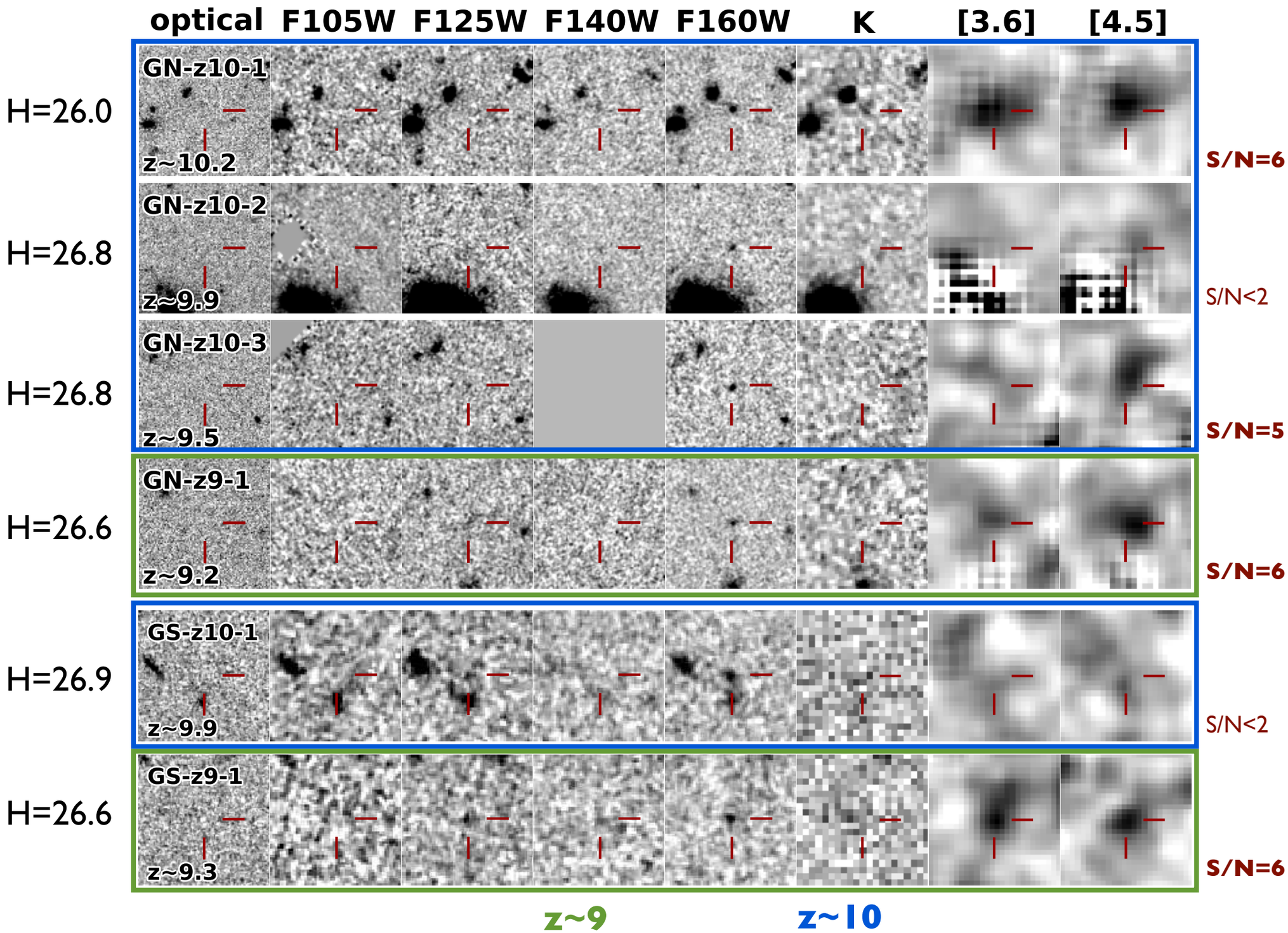
It is has S/H = 3.4 and 5.8 in $JH_{140}$ and $H_{160}$.

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




**Plus: small sample of 7 faint z~9 candidates in XDF**

# Sample of Bright z~9-10 Galaxies in GOODS



# Accurate Sampling of Spectral Energy Distribution

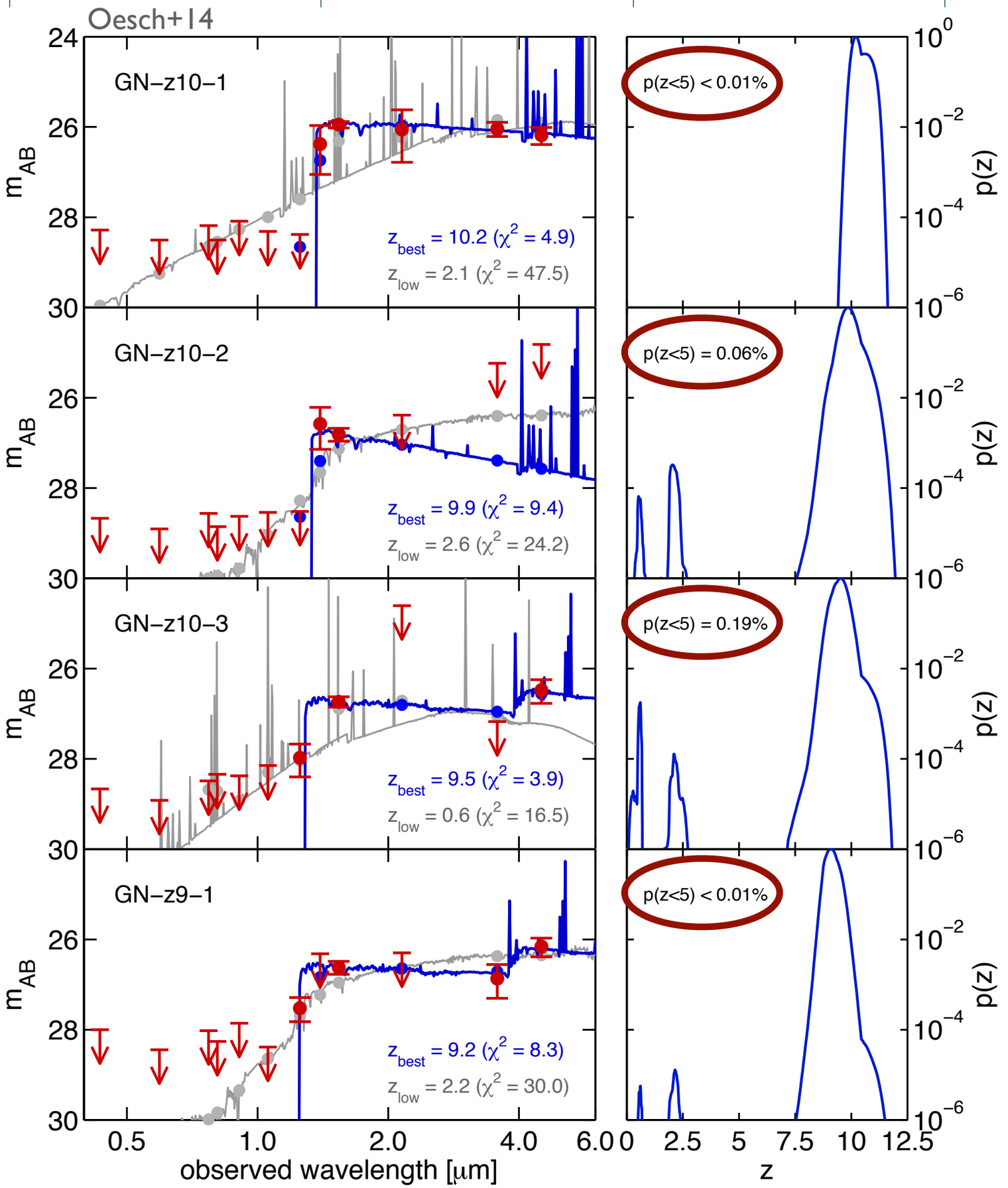
Photometry from rest-frame UV to optical, thanks to IRAC detections

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

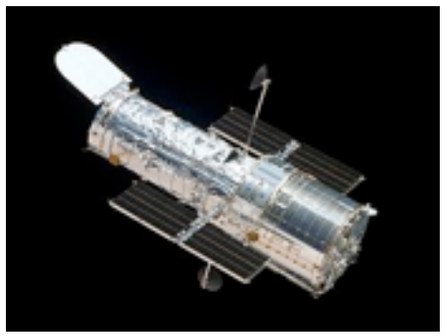
Three sources have secondary, low-z peak in their p(z), but at very low probability.

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

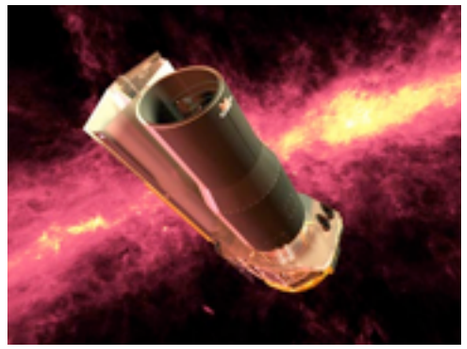
These galaxies are **not** primordial!

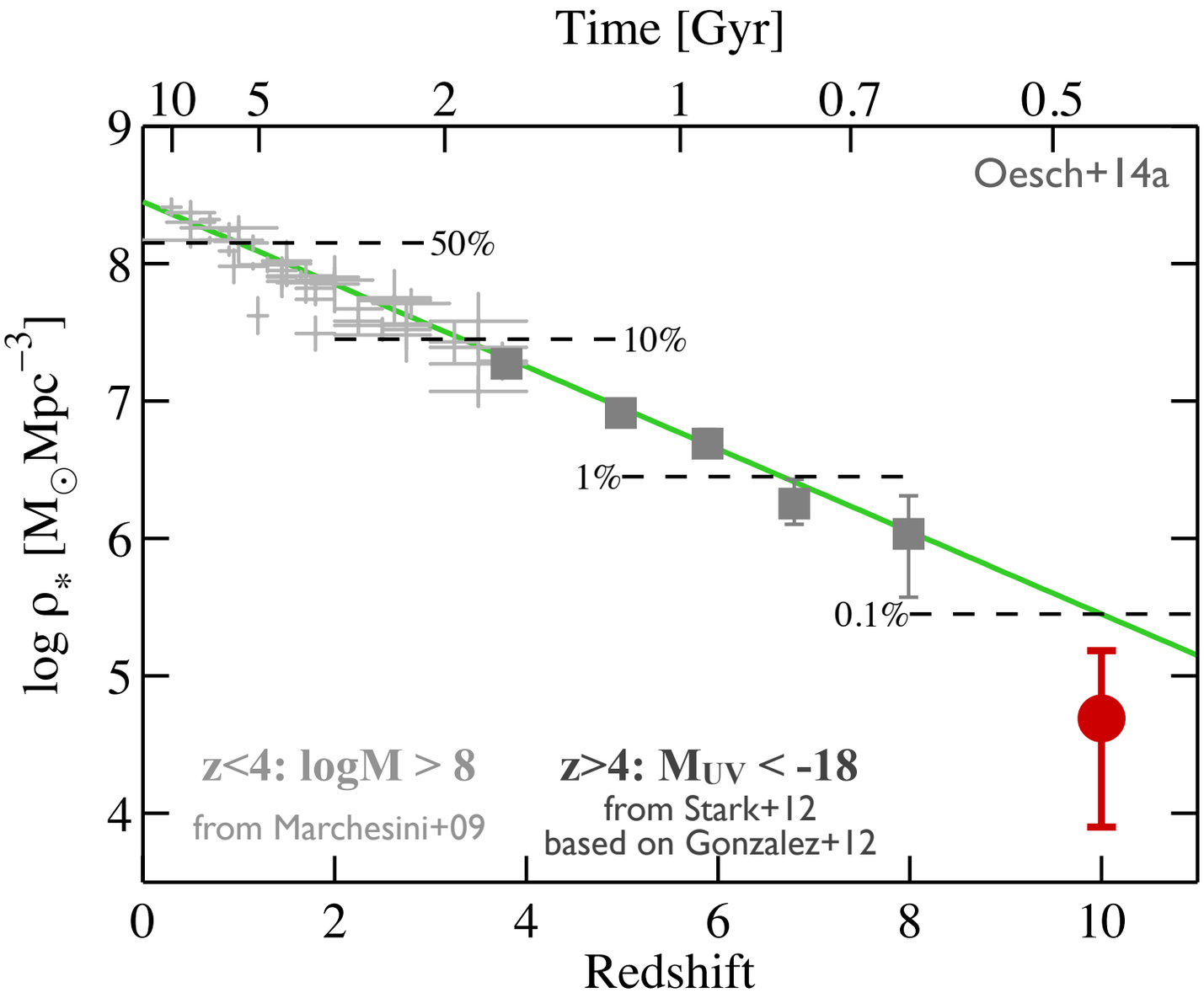


# Stellar Mass Density Evolution to z~10



+

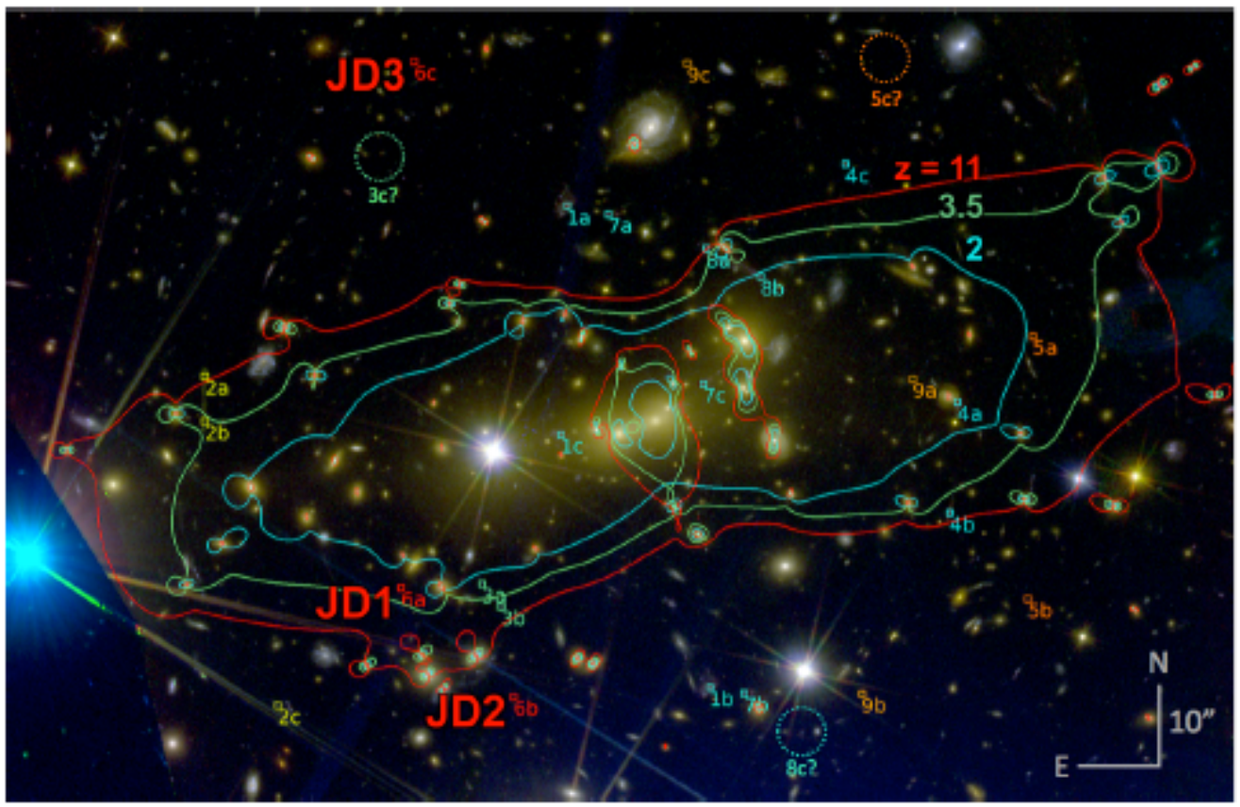




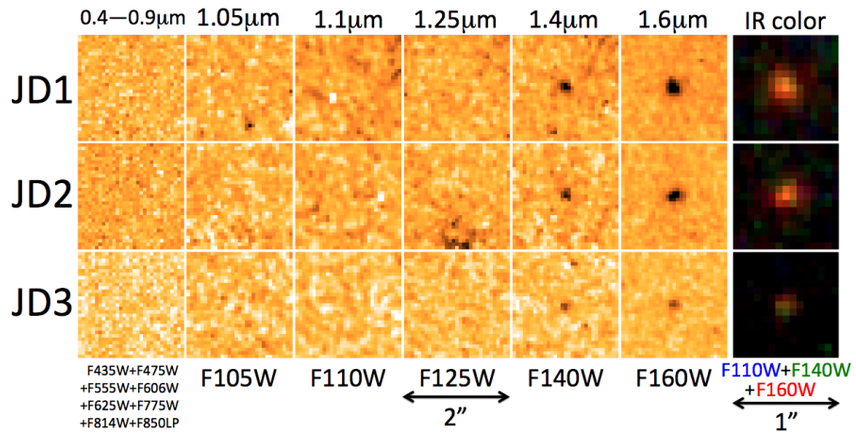

Luminosity limited SMD estimates at z>4 nicely match up with mass limited studies at z<4.

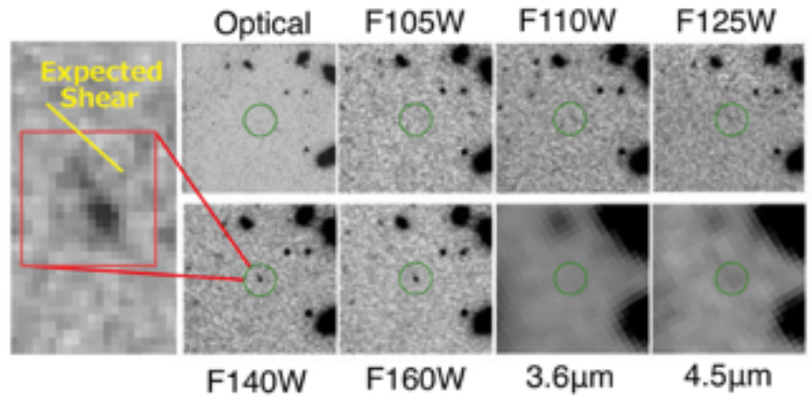
Probe the SMD over 96% of the age of the universe and
are witnessing the assembly of the first 0.1% of local stellar mass density!

# z~9-10 Candidates from CLASH

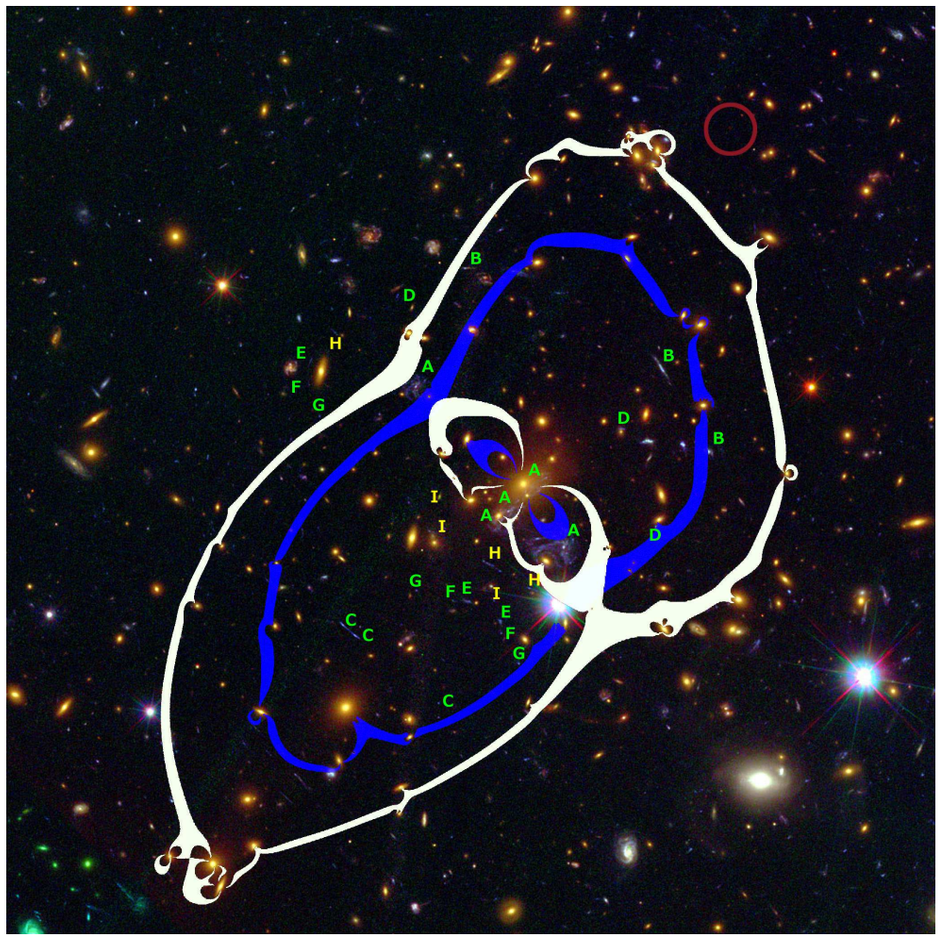



Coe+12 z=10.7, H=25.9/26.1/27.3, mu~8/7/2



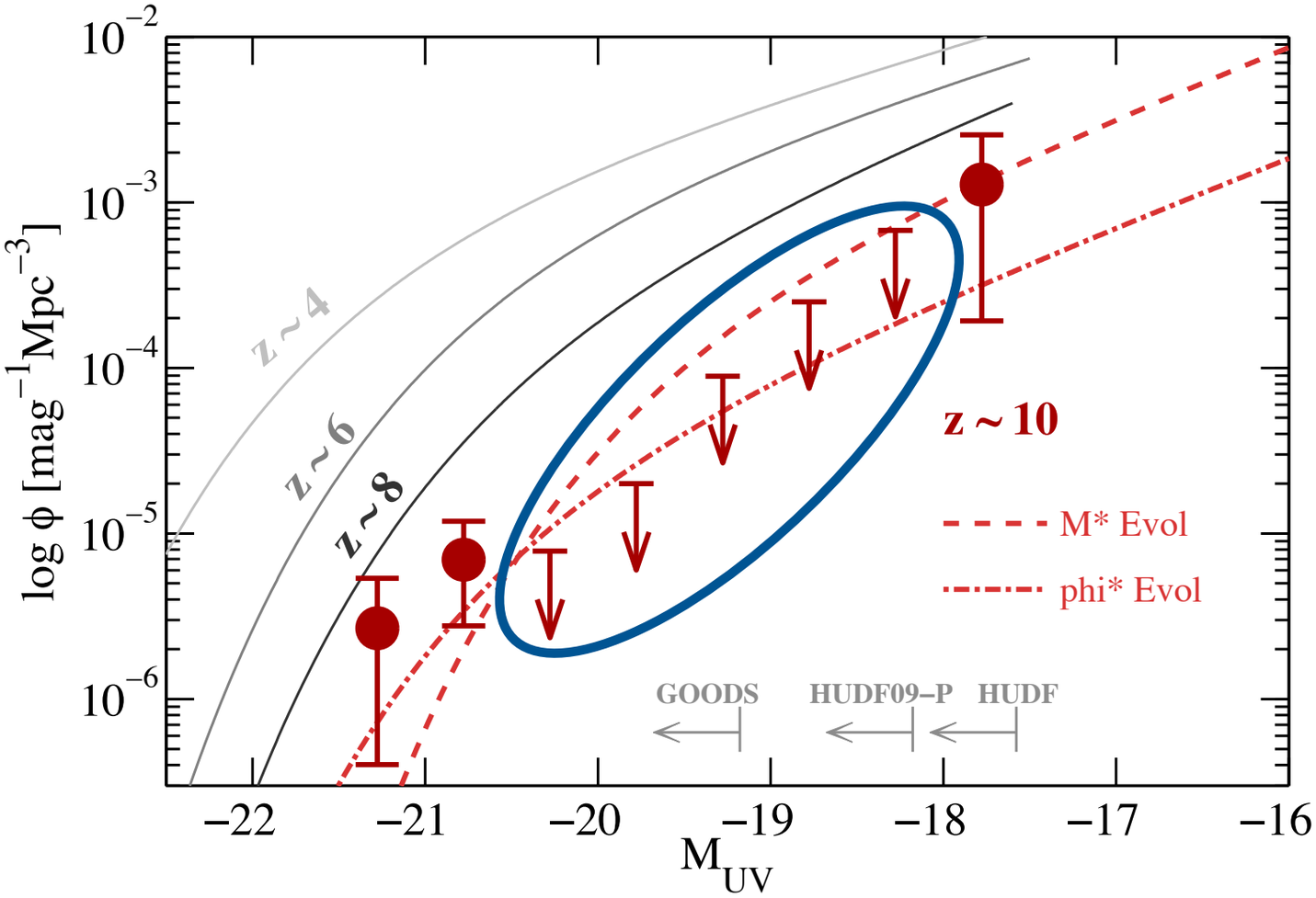

Zheng+12 z=9.6, H=25.7, mu=14-26



**Plus: Additional sample of two z~9 galaxy candidates** (Bouwens+13)

# Where did we stand before the HFFs?

UV LF from blank field z~10 galaxy candidates

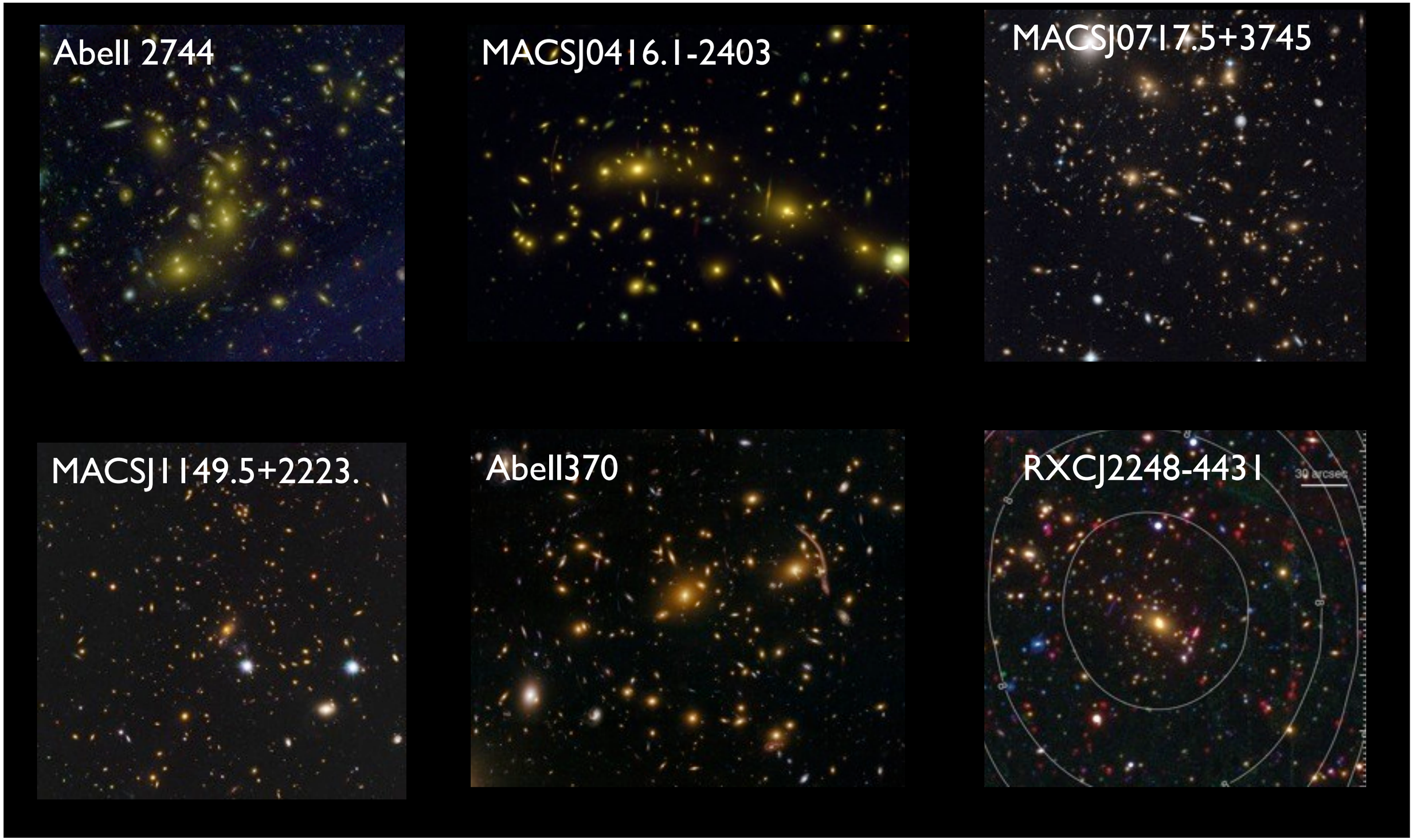



based on 5 galaxies in GOODS-N+S + HUDF09/12

Can clearly rule out no evolution since z~8 (should have detected 48 z~10 galaxies!)

Where are all the intermediate mag (~27-29) galaxies?
Frontier Fields ideally suited to address this.

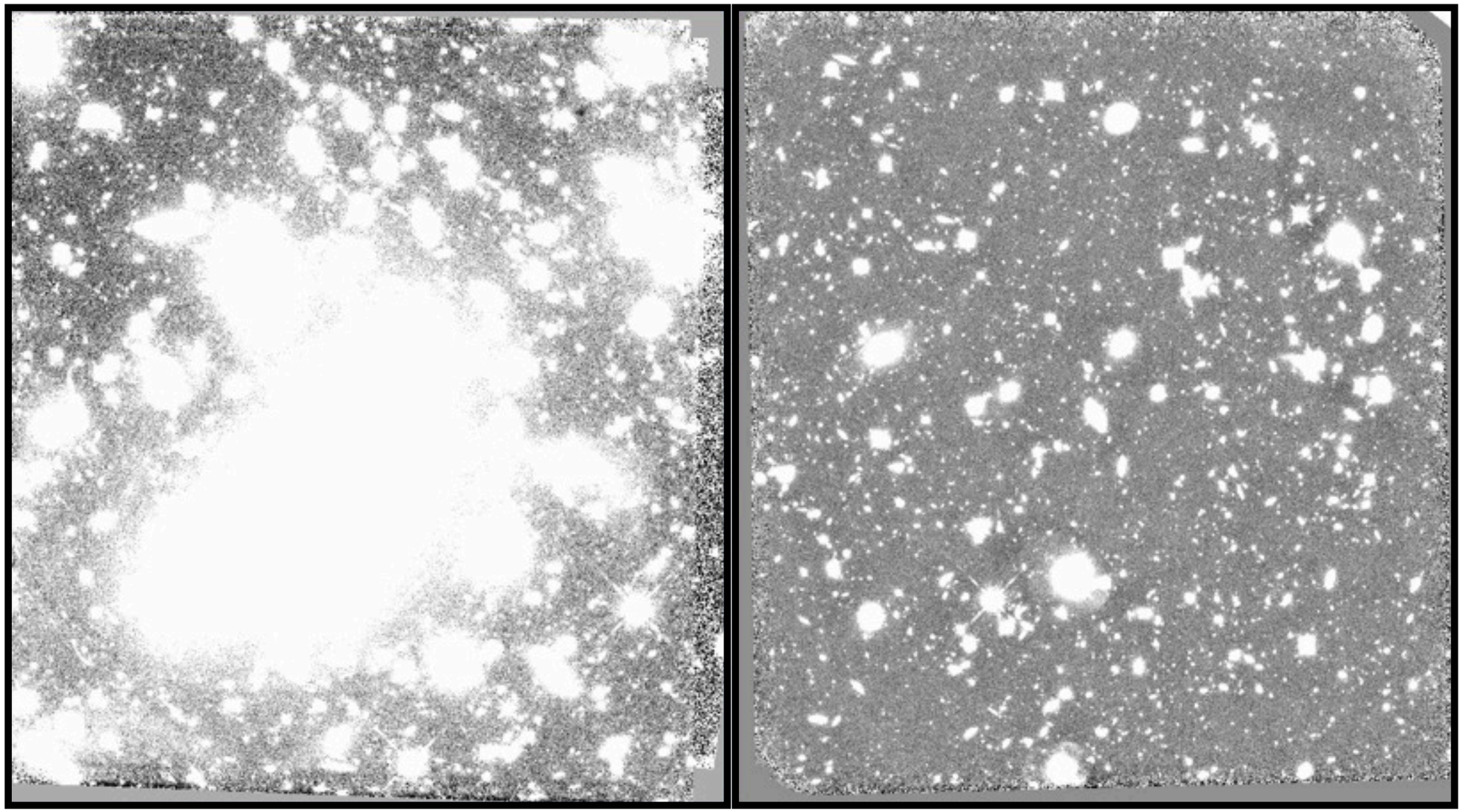
# Hubble Frontier Fields



# Intra-Cluster Light

**A2744 original**

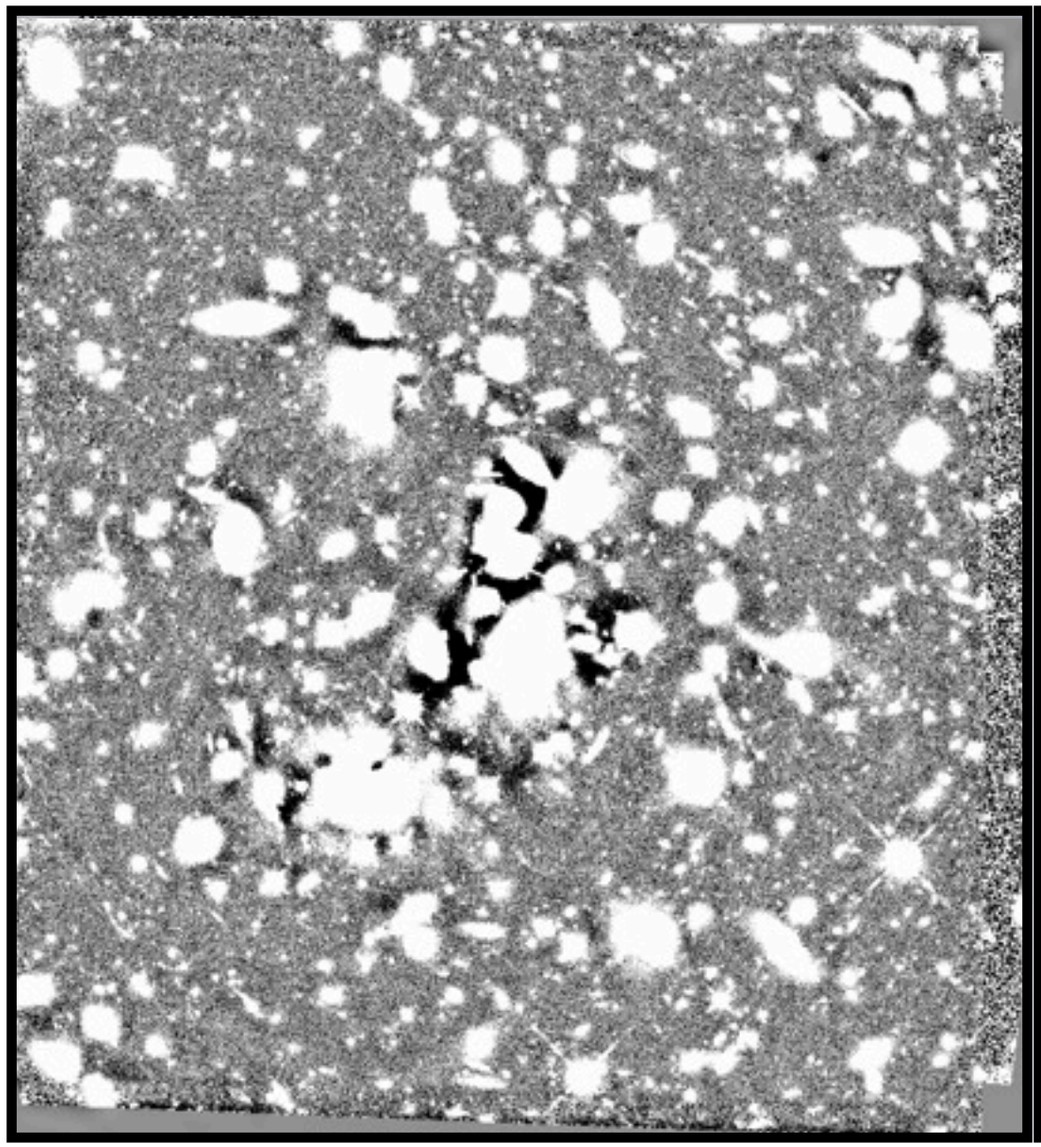
**HUDF092 original**



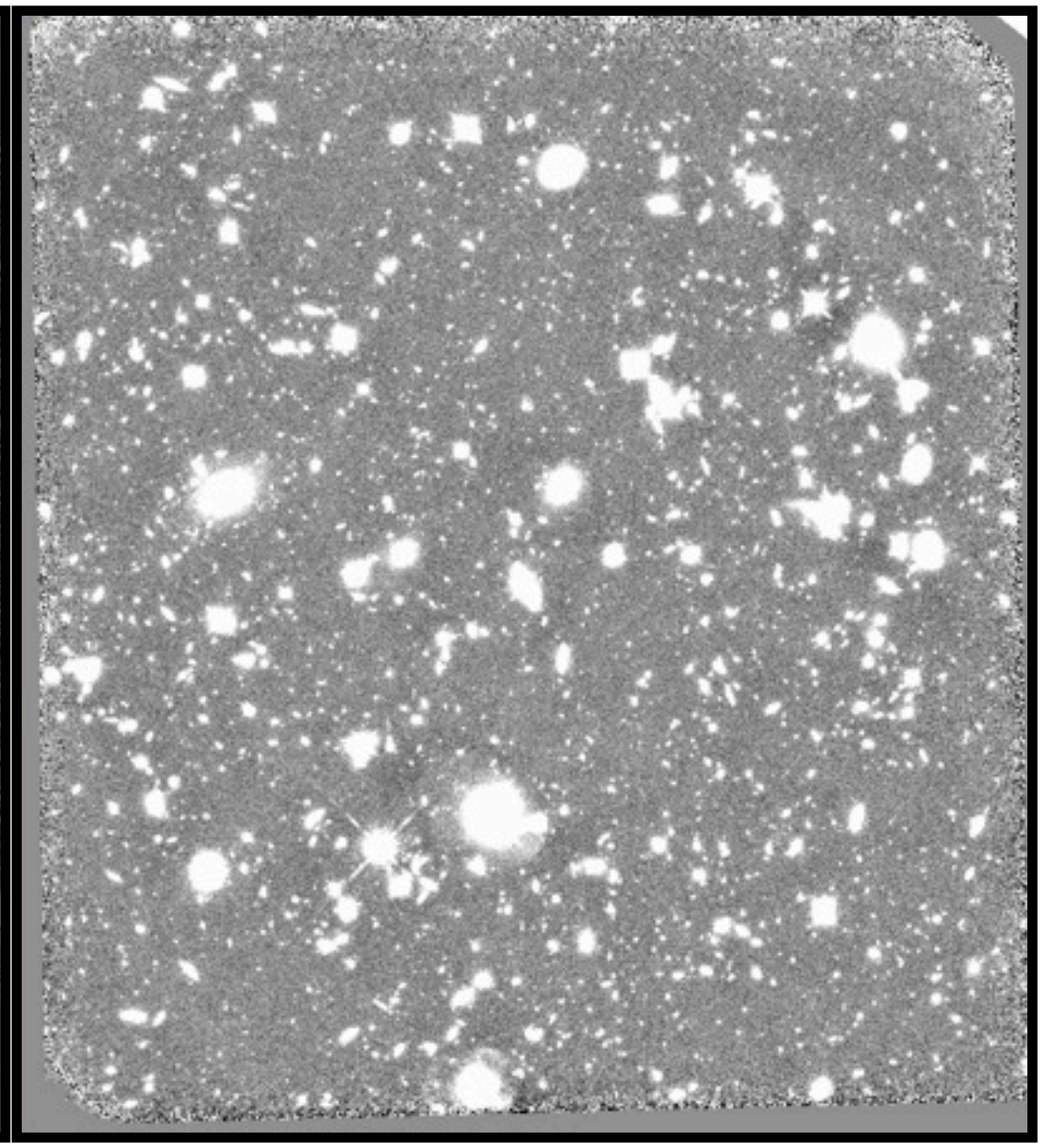
see also Montes & Trujillo 14 + Mireia's talk

# Intra-Cluster Light

**A2744 - Sextractor Background**



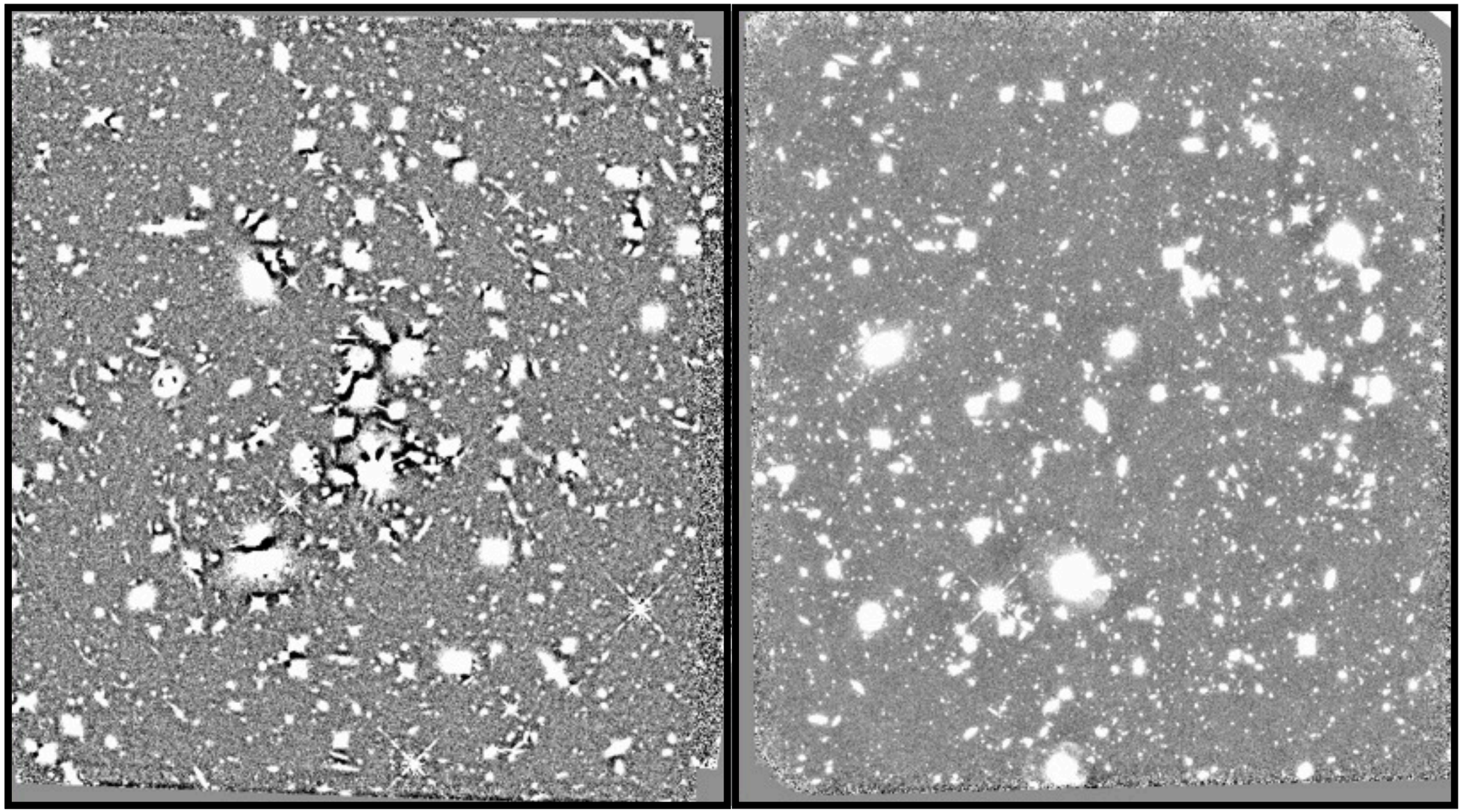
**HUDF092 original**



# Intra-Cluster Light

**A2744 - Median Background**

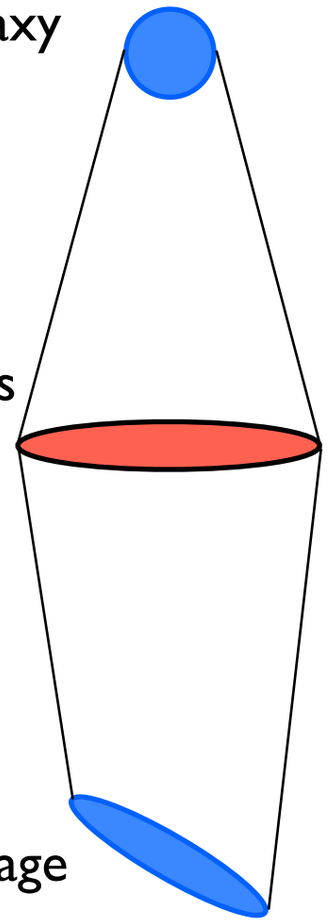
**HUDF092 original**



# Using Lensing Clusters for High-z Science

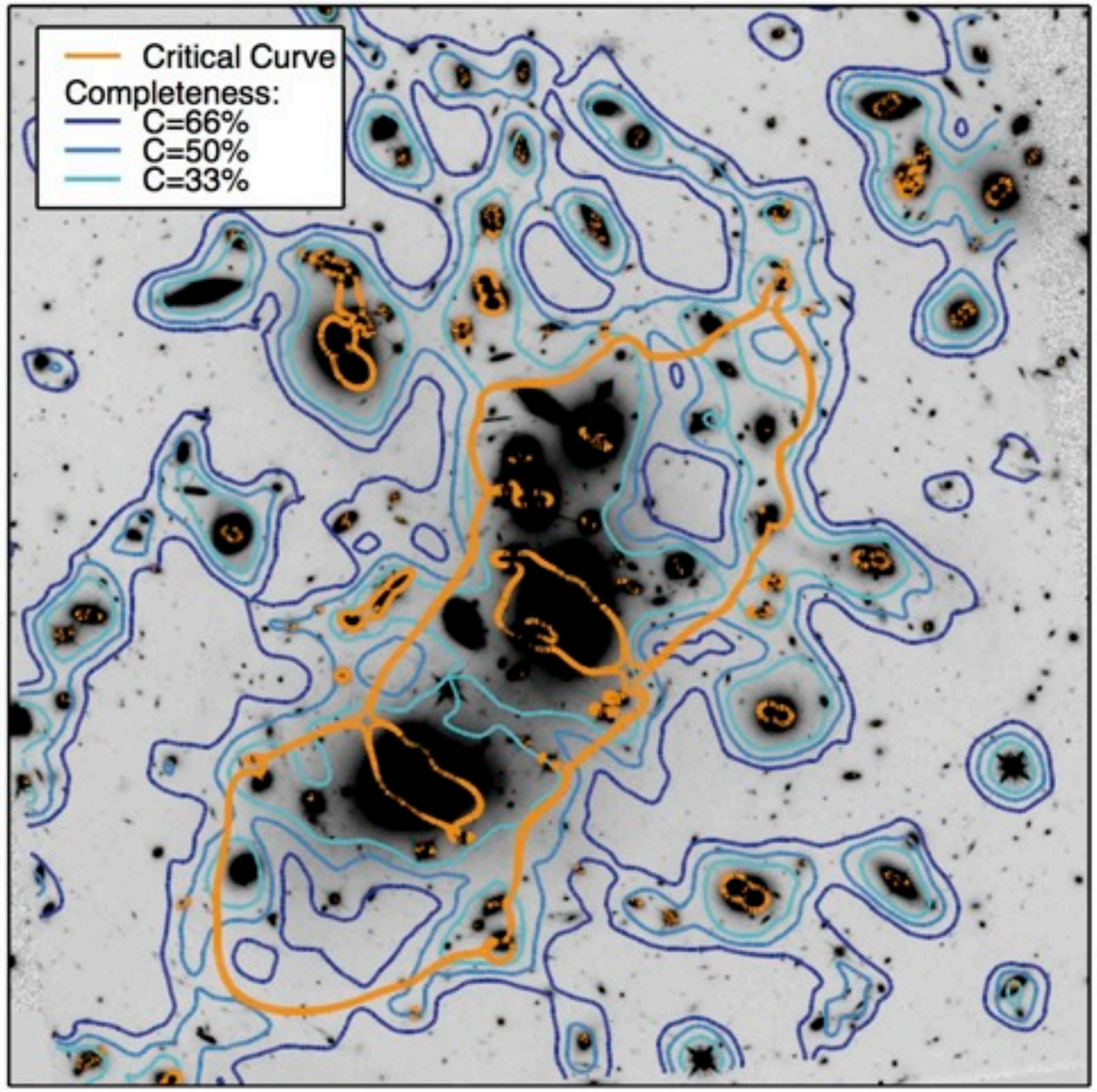
Two effects affect source completeness at high magnification factors: ***Shear + Blending***

High-z Galaxy (resolved!)



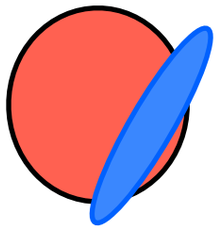
Cluster Lens

Sheared Image



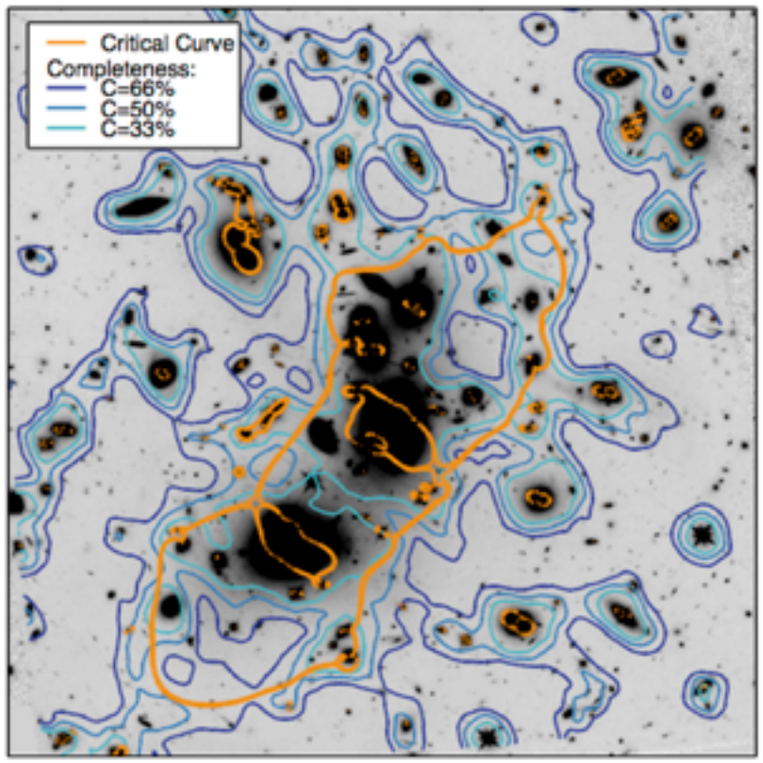

Zitrin-NFW mass model

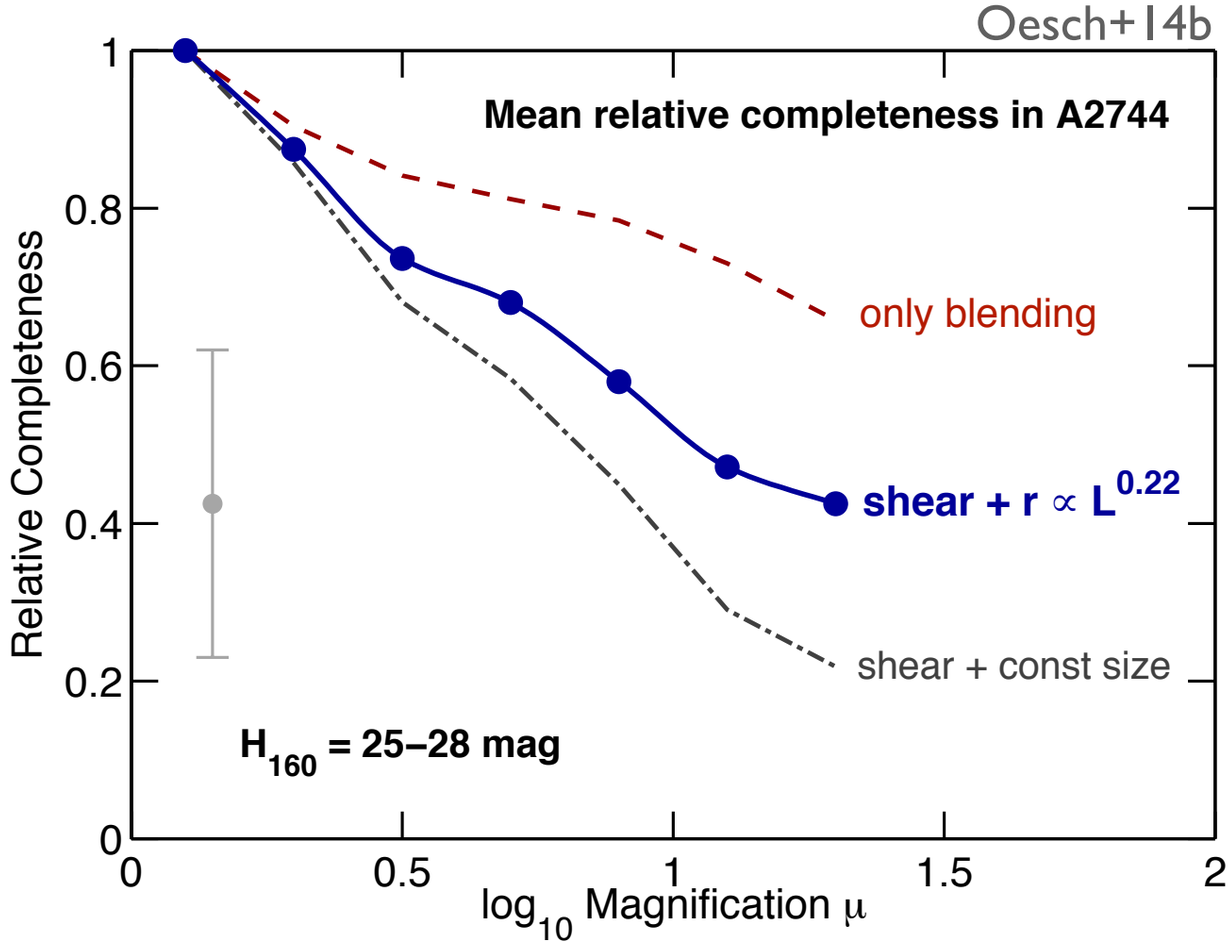
Source Blending



# Using Lensing Clusters for High-z Science

Two effects affect source completeness at high magnification factors: ***Shear + Blending***

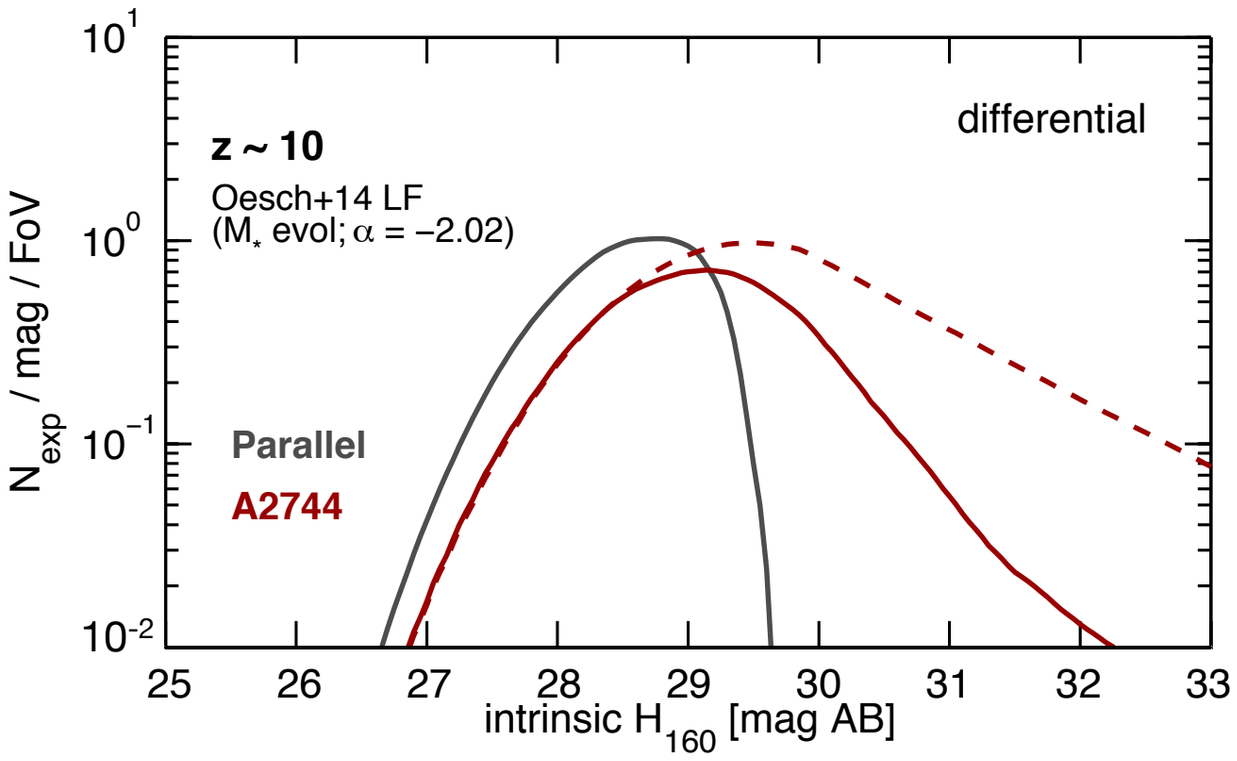


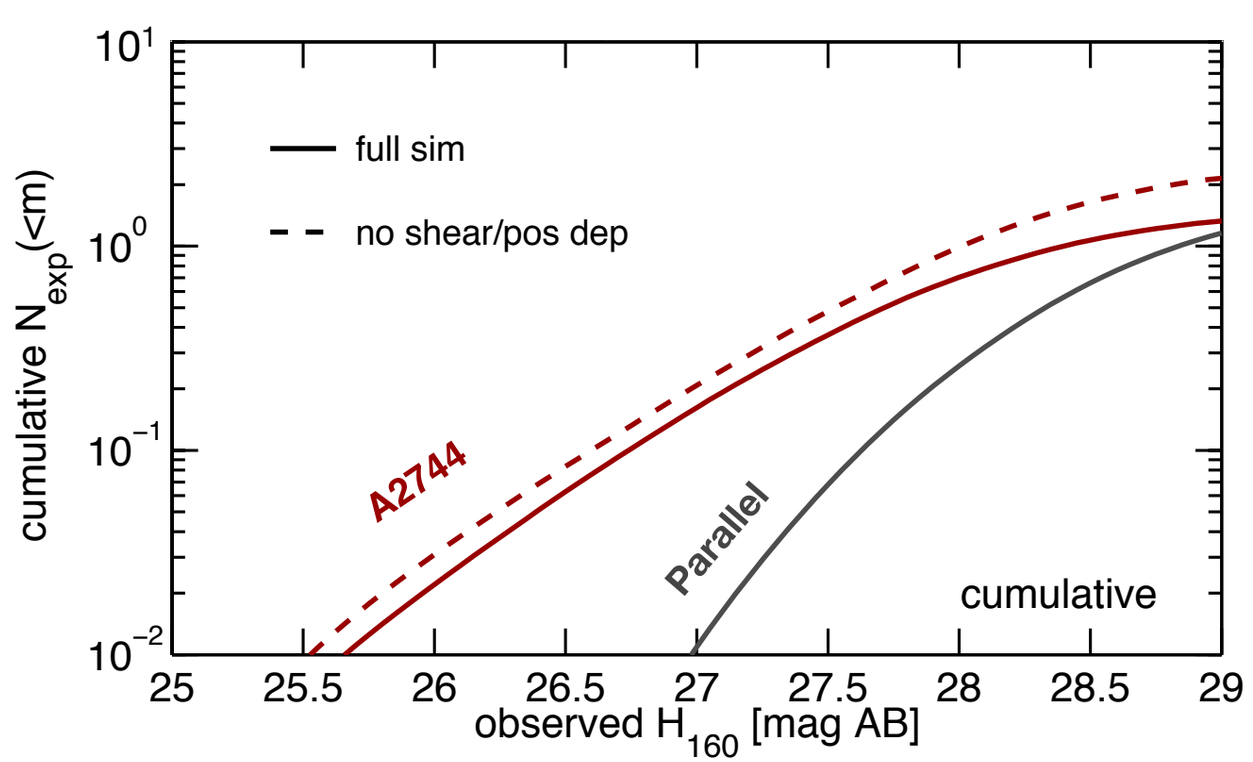




Size-Luminosity relation is additional uncertainty for use of clusters for high-z analyses!

First results on Size-Luminosity evolution at these redshifts and at these luminosities: e.g. Holwerda+14, Kawamata+14, Ono+13

# Expected Number of z~10 Galaxies: A2744



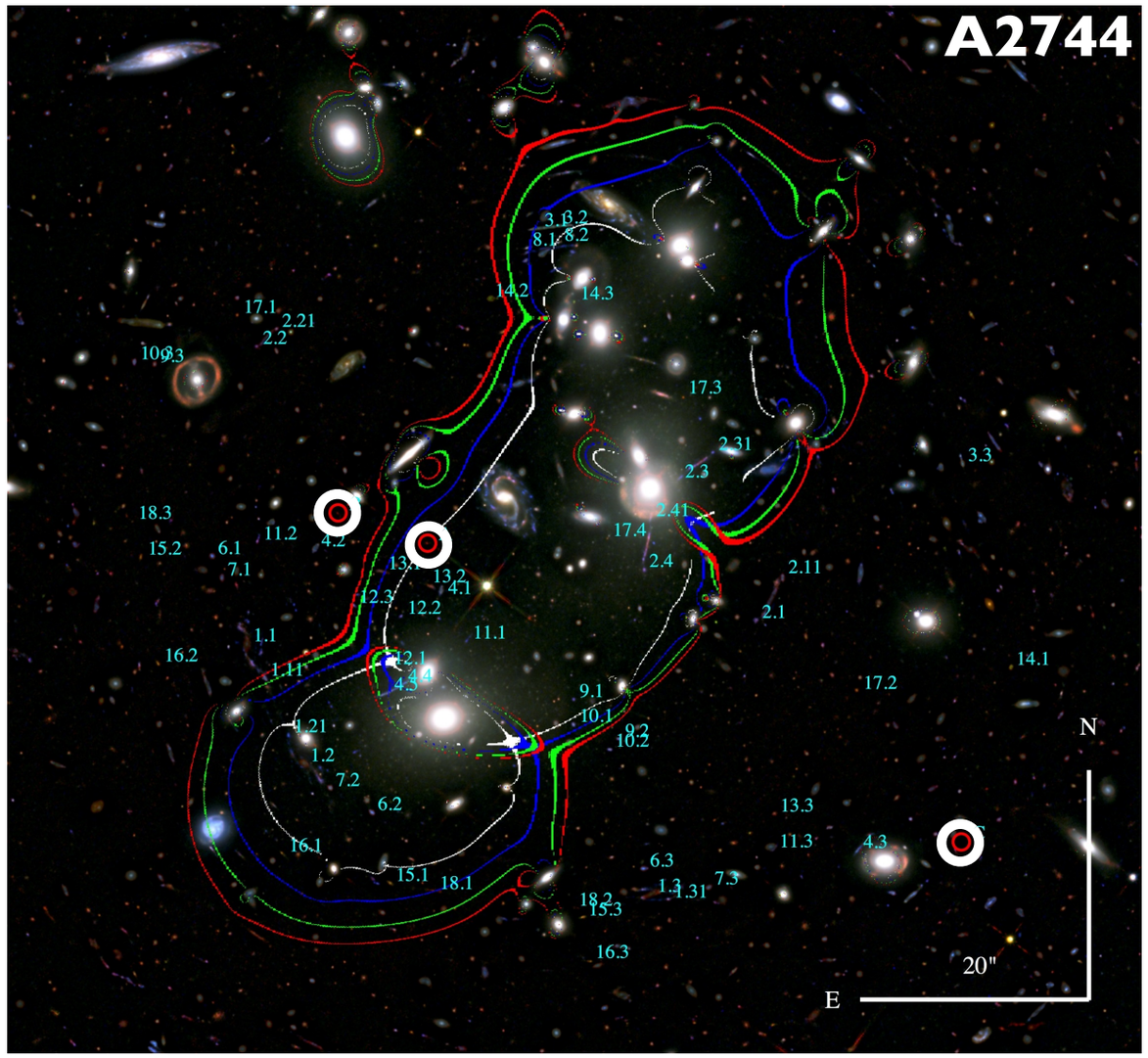

expected number of z~10 galaxy candidates reduced by ~1.6x

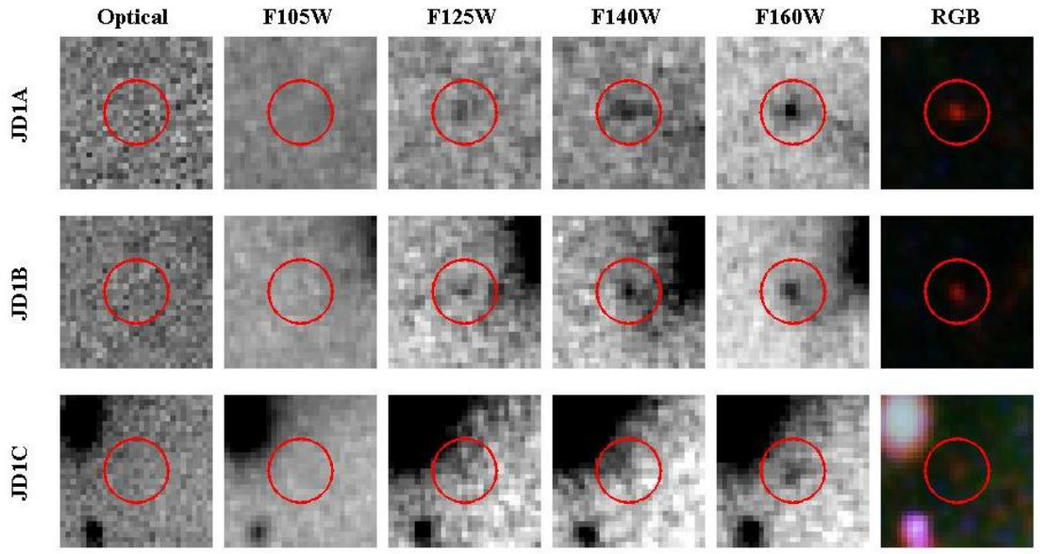
| Nexp z~10 | ϕ* evolution | M* evolution |
|---|---|---|
| A2744 cluster | 0.5 | 1.3 |
| A2744 parallel field | 0.5 | 1.1 |
| **6 FF clusters+parallels** | **6** | **14** |

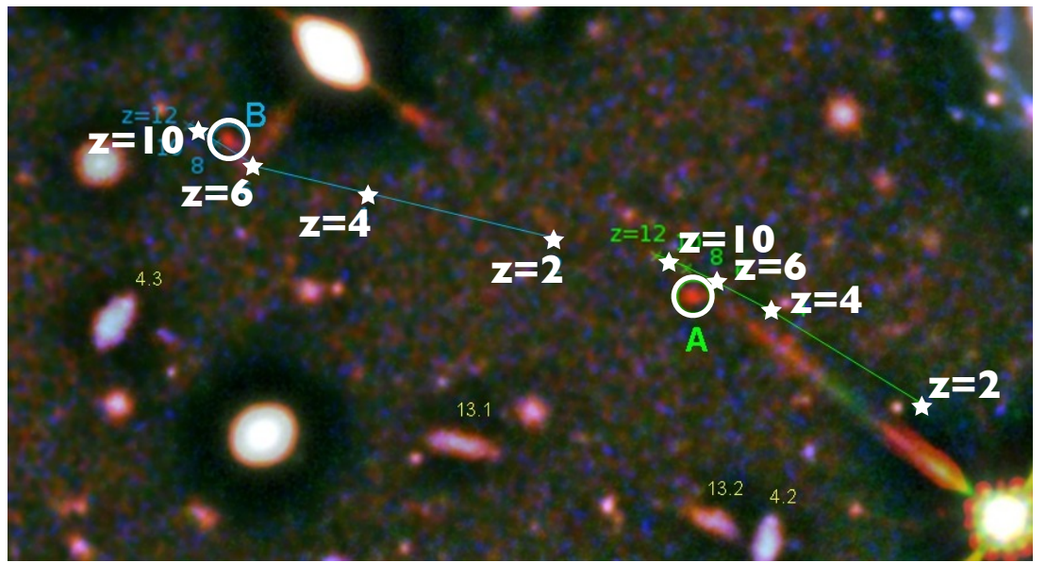
Frontier Field Program is expected to at least double, likely triple current z~10 samples!

# Triply Imaged z~10 Candidate in First FF Cluster

Zitrin+14




H = 29.9 mag (de-magnified)

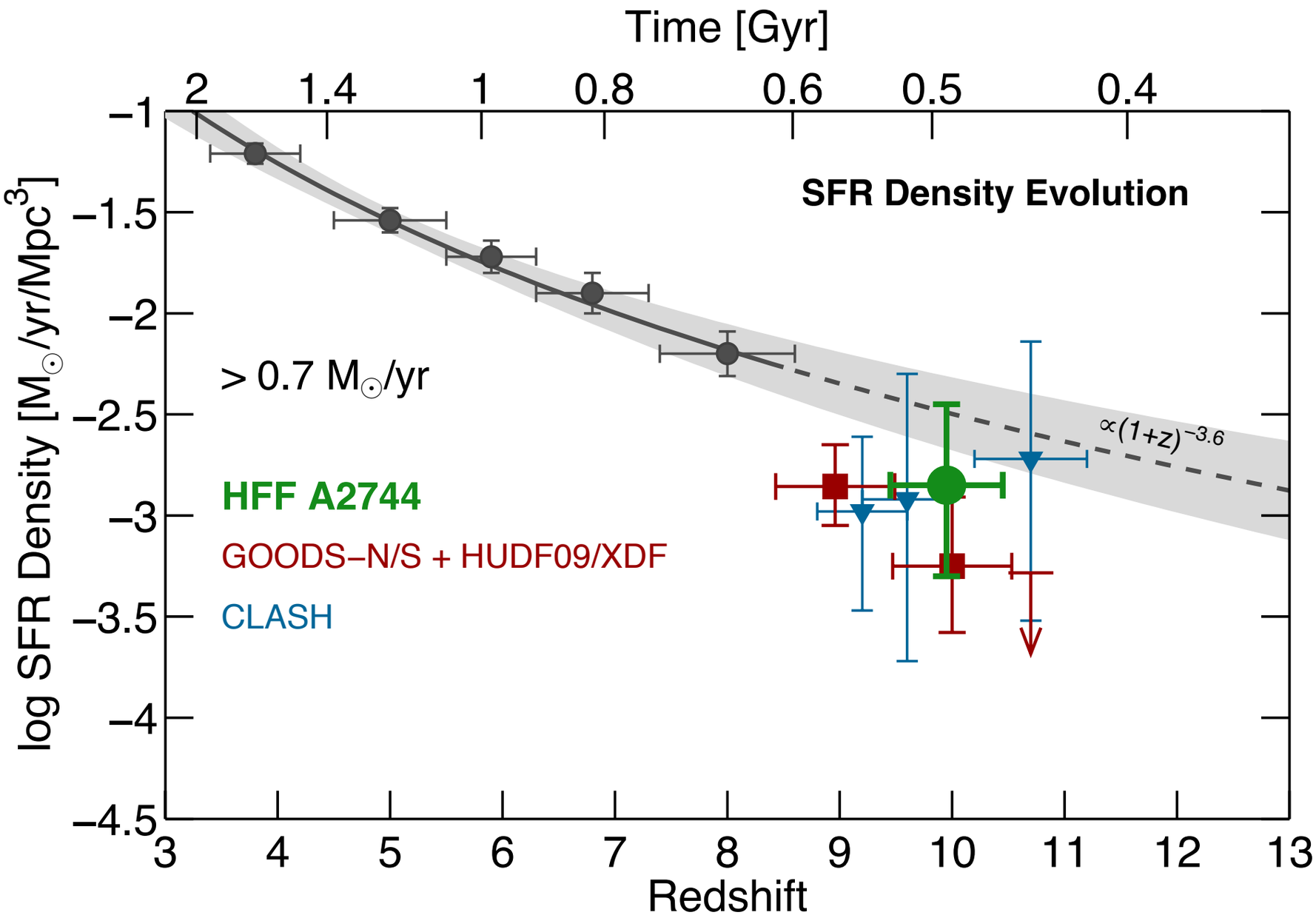
zphot = 9.8+-0.4

magnification: 10-11x

strong geometric support of high redshift solution of photo-z

**No z~10 galaxy candidate found in parallel field!**

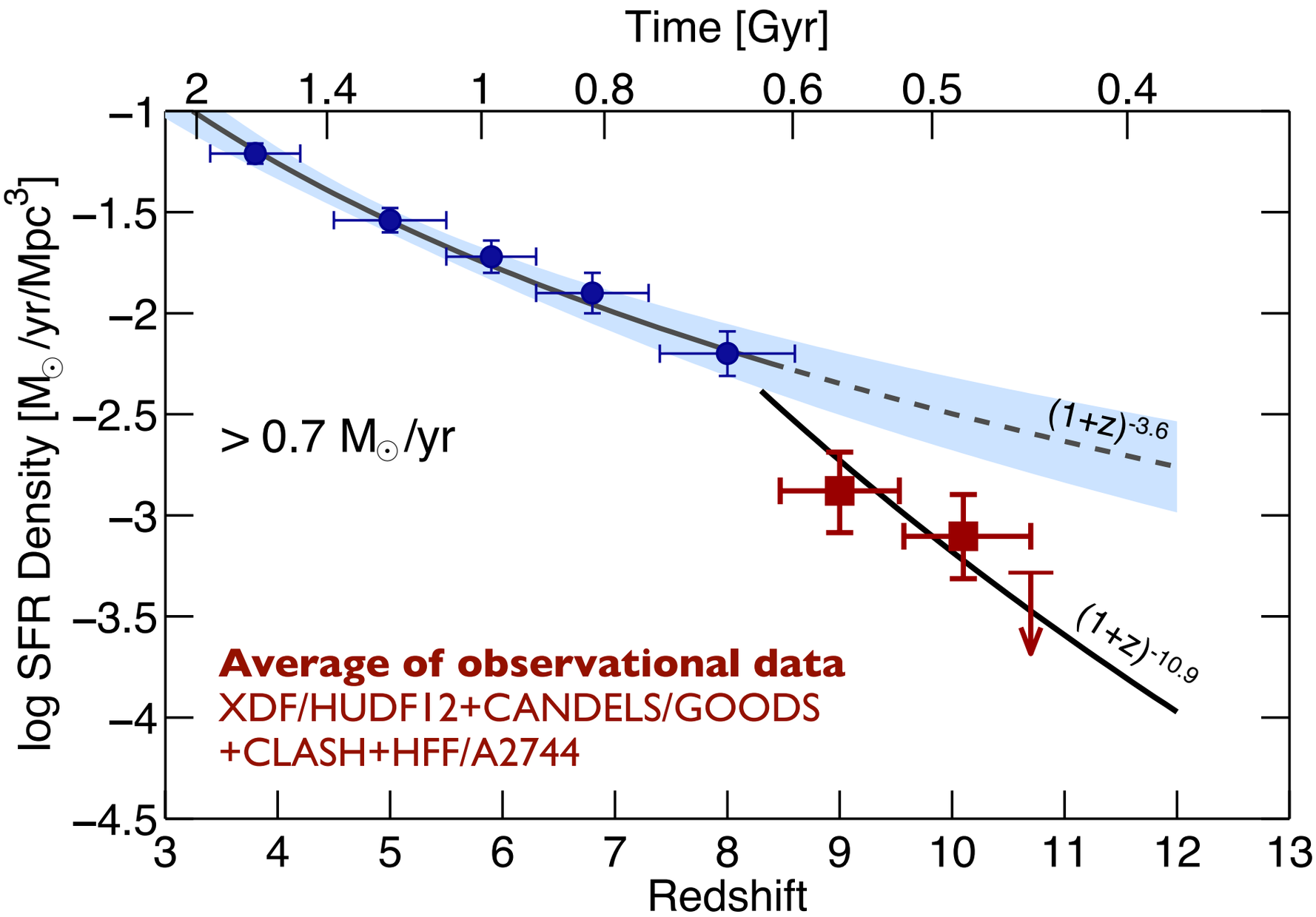
# SFRD Evolution at z>8




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

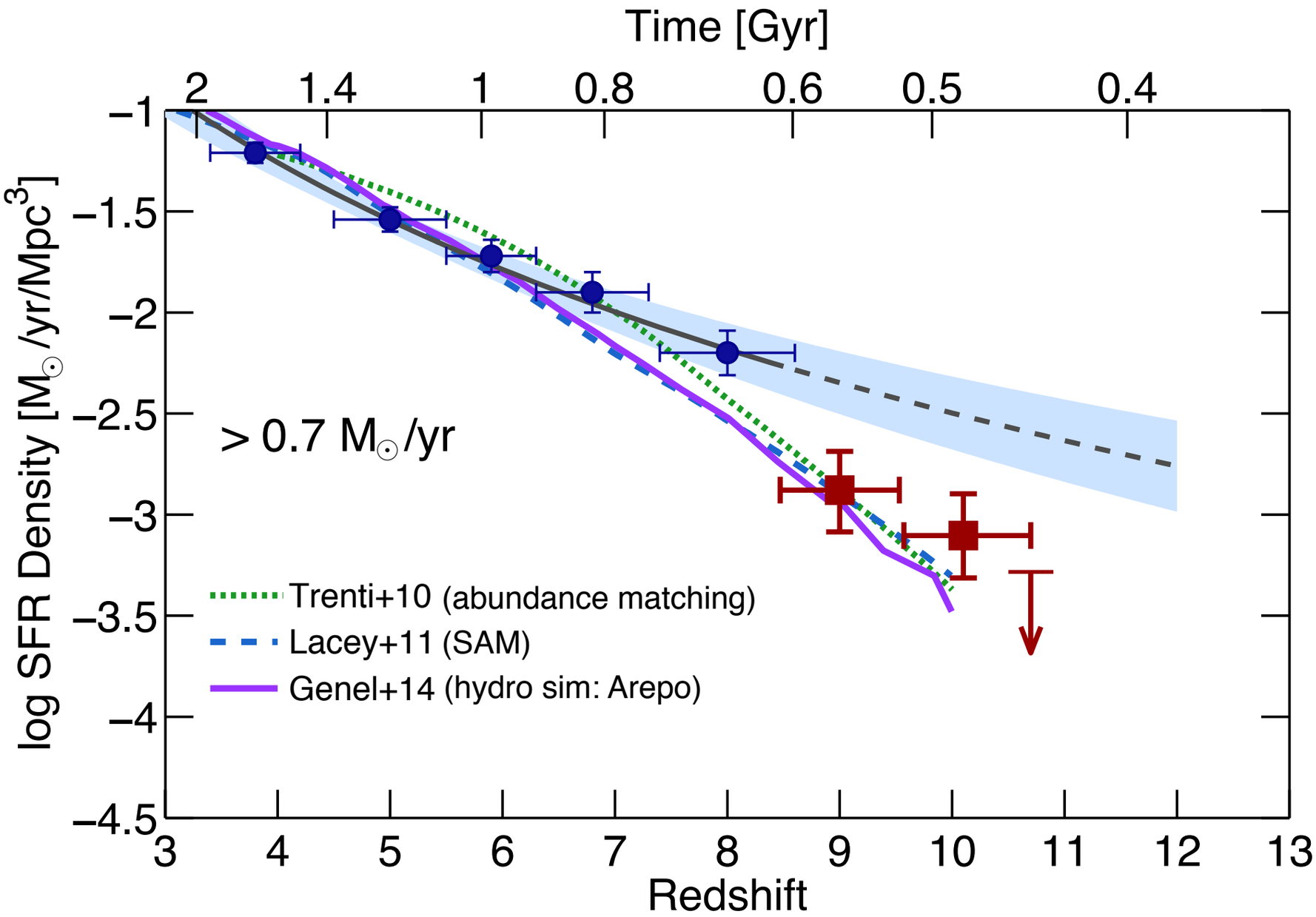
see also: Zheng+12, Coe+13, Bouwens+13/14, Ellis+13, McLure+13, Ishigaki+14

# SFRD Evolution at z>8



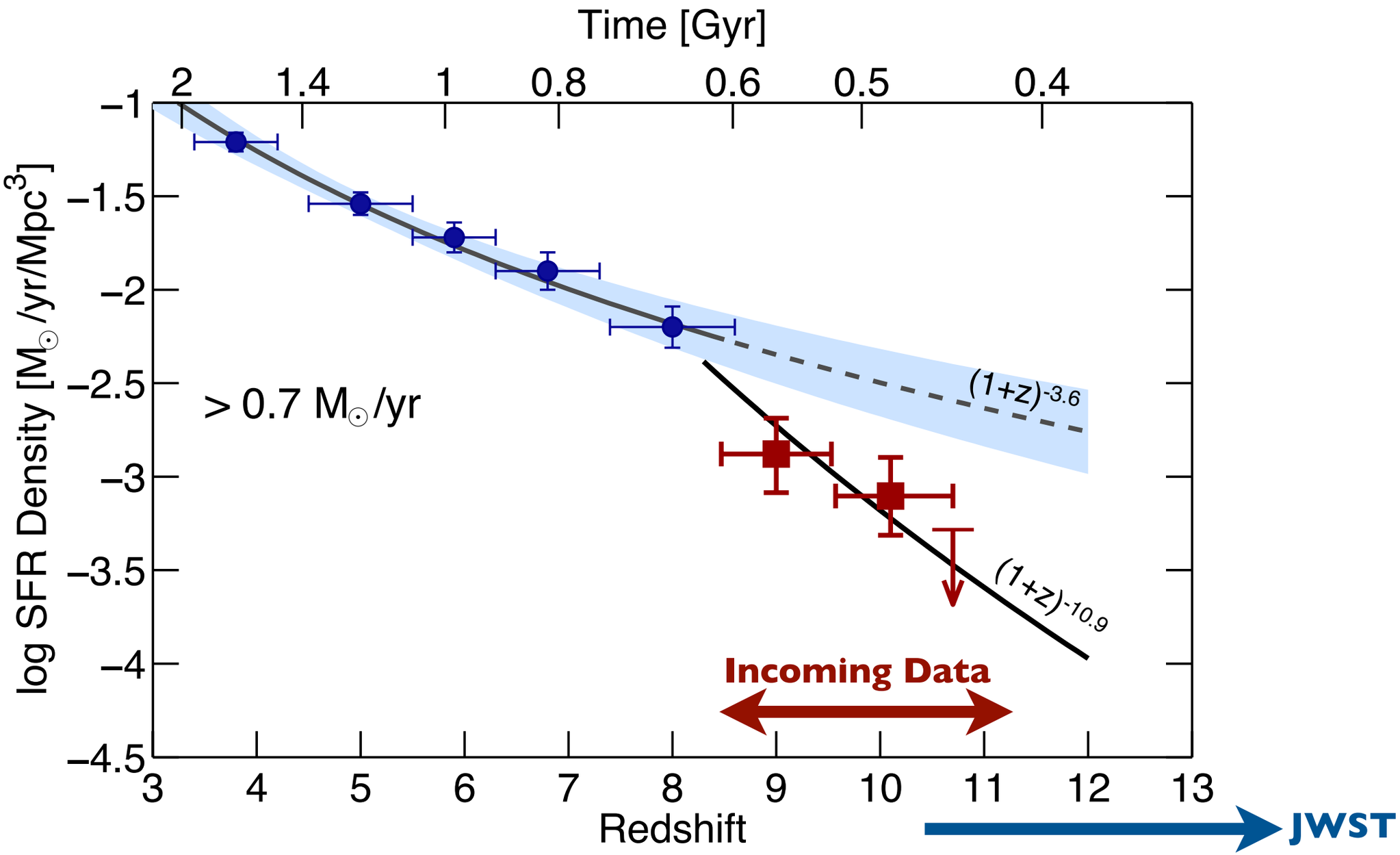

Combining the current constraints from all datasets:
very rapid evolution in the cosmic SFRD at z>8 (factor ~10x in 170 Myr).

# SFRD Evolution at z>8




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

# SFRD Evolution at z>8




**But:** observational result is still uncertain (where are mag 27-29 sources?) confirmation needed with incoming Frontier Field data, in preparation for JWST

# 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**

- Sample sizes at z~9-10 are still very small. UV luminosity function very **poorly sampled** (see talks later today: *Rychard Bouwens + others*)

- Blending and shear result in position and **magnification dependent completeness ➡ size-luminosity** relation is additional source of uncertainty

- Galaxy **SFRD** increases by **~1 order of magitude** in 170 Myr from z~10 to z~8 (consistent with theoretical predictions!)

- Combination of **HST and Spitzer/IRAC** is **extremely powerful** to probe the stellar mass build-up even out to z~10

- Determining evolutionary scenario of UV LF at z>9 is **crucial in preparation for JWST** surveys. HFFs will provide this: double or triple current z~10 samples.