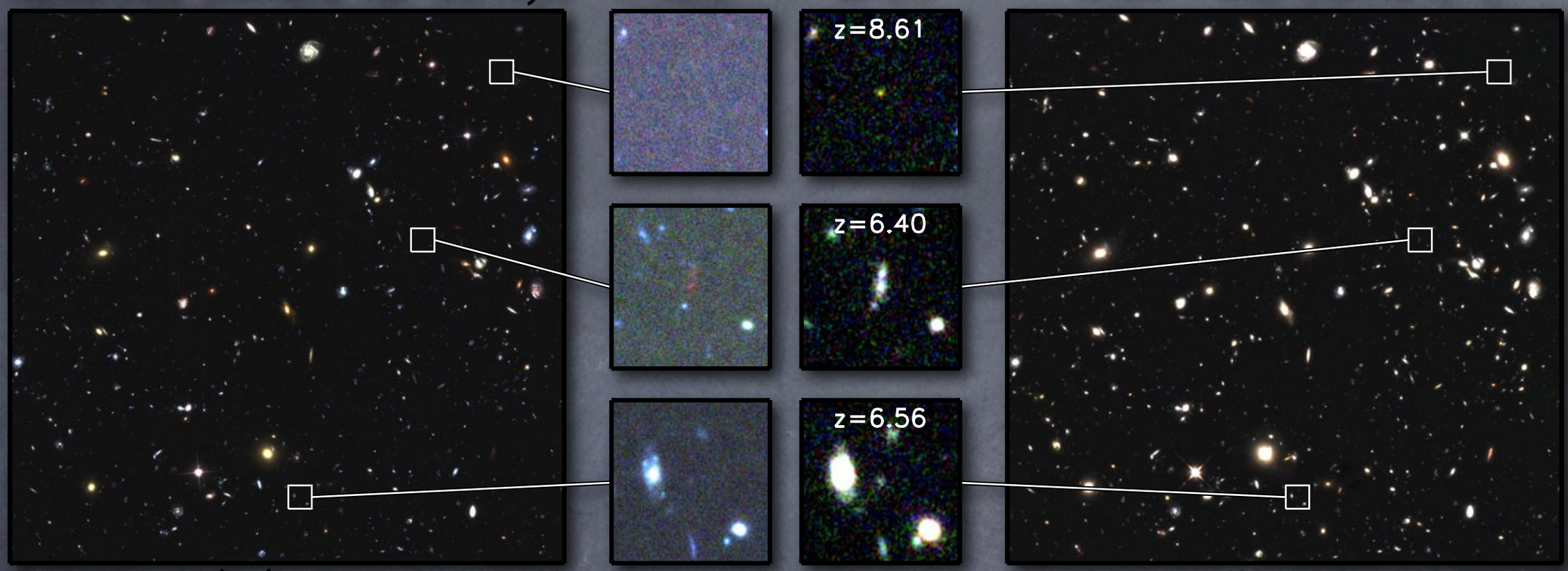
Stellar Populations of Galaxies at 6.3 < z < 8.6



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astroph/0912.1338
http://astronomy.tamu.edu/highz

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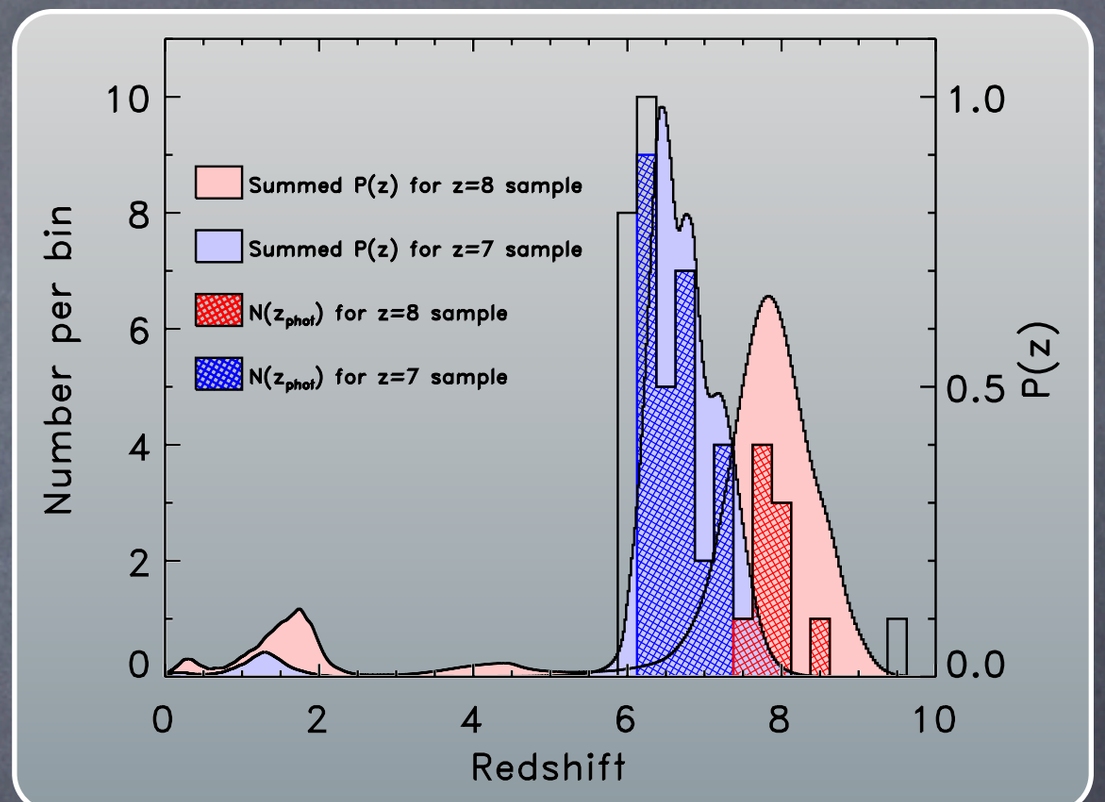
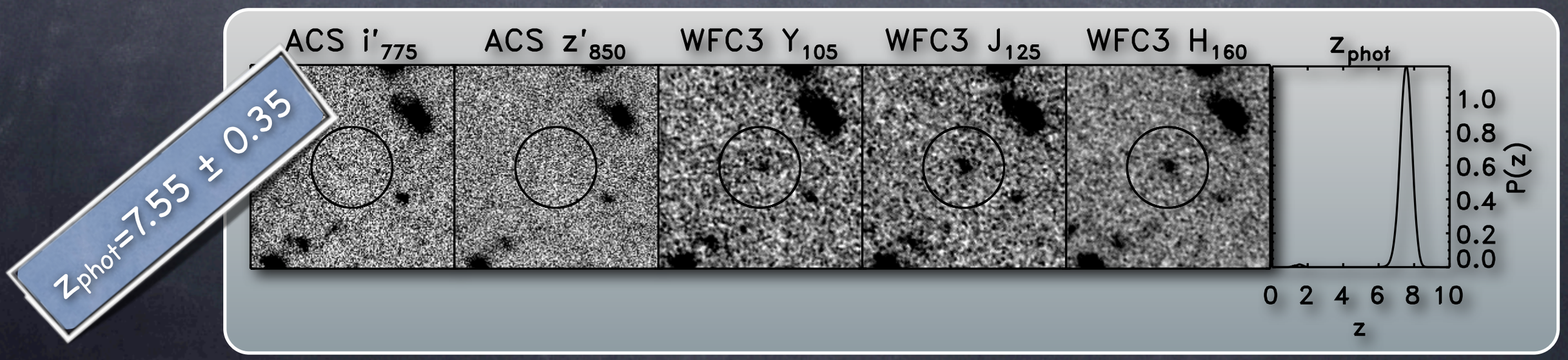
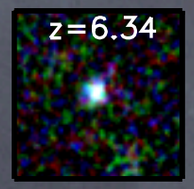
The University of Texas at Austin - March 11th, 2010

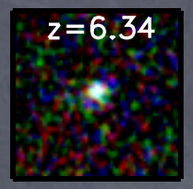
Sample Selection

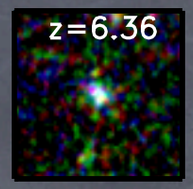
- Using the WFC3 HUDF data, detected ~ 3000 objects in a J+H-band detection image.
- Computed photometric redshifts of all objects detected at ≥ 3.5 σ (~ 2500) in both J_{125} and H_{160} using EAZY (Brammer+08).
- Our sample consists of 35 galaxies with $6.3 < z_{phot} < 8.6$.
  - 26 at $6.3 < z_{phot} \leq 7.5$, and 9 and $7.5 < z_{phot} < 8.6$.

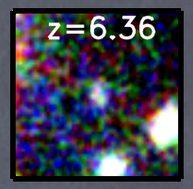


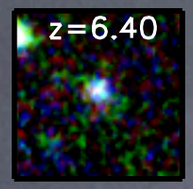


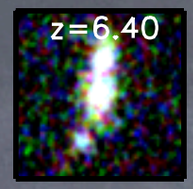


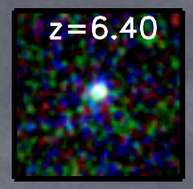


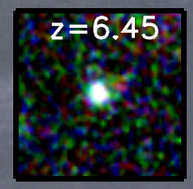


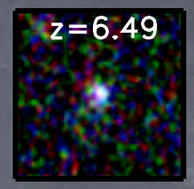


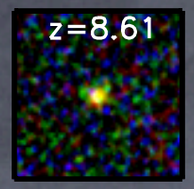


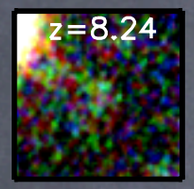


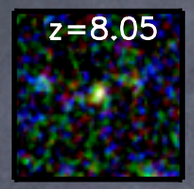


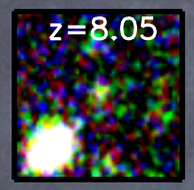


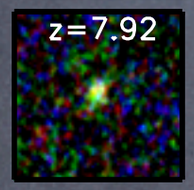


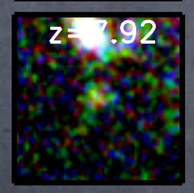


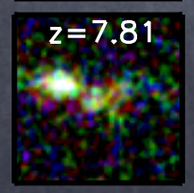


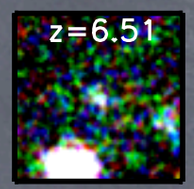


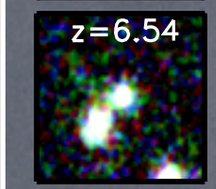


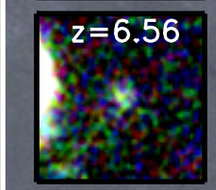


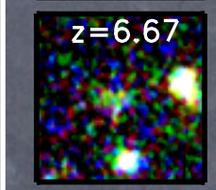


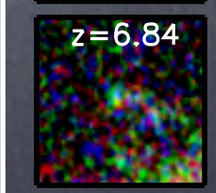


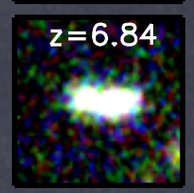


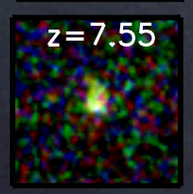


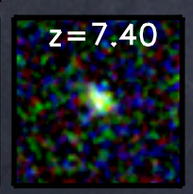


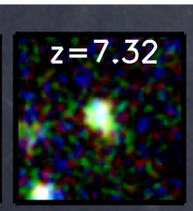


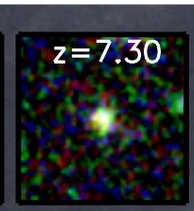


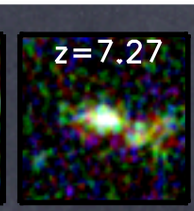


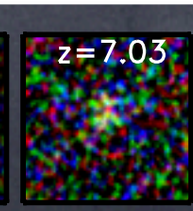


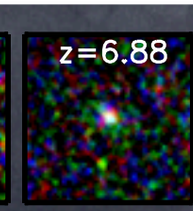


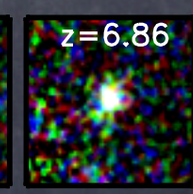


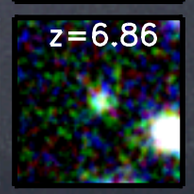










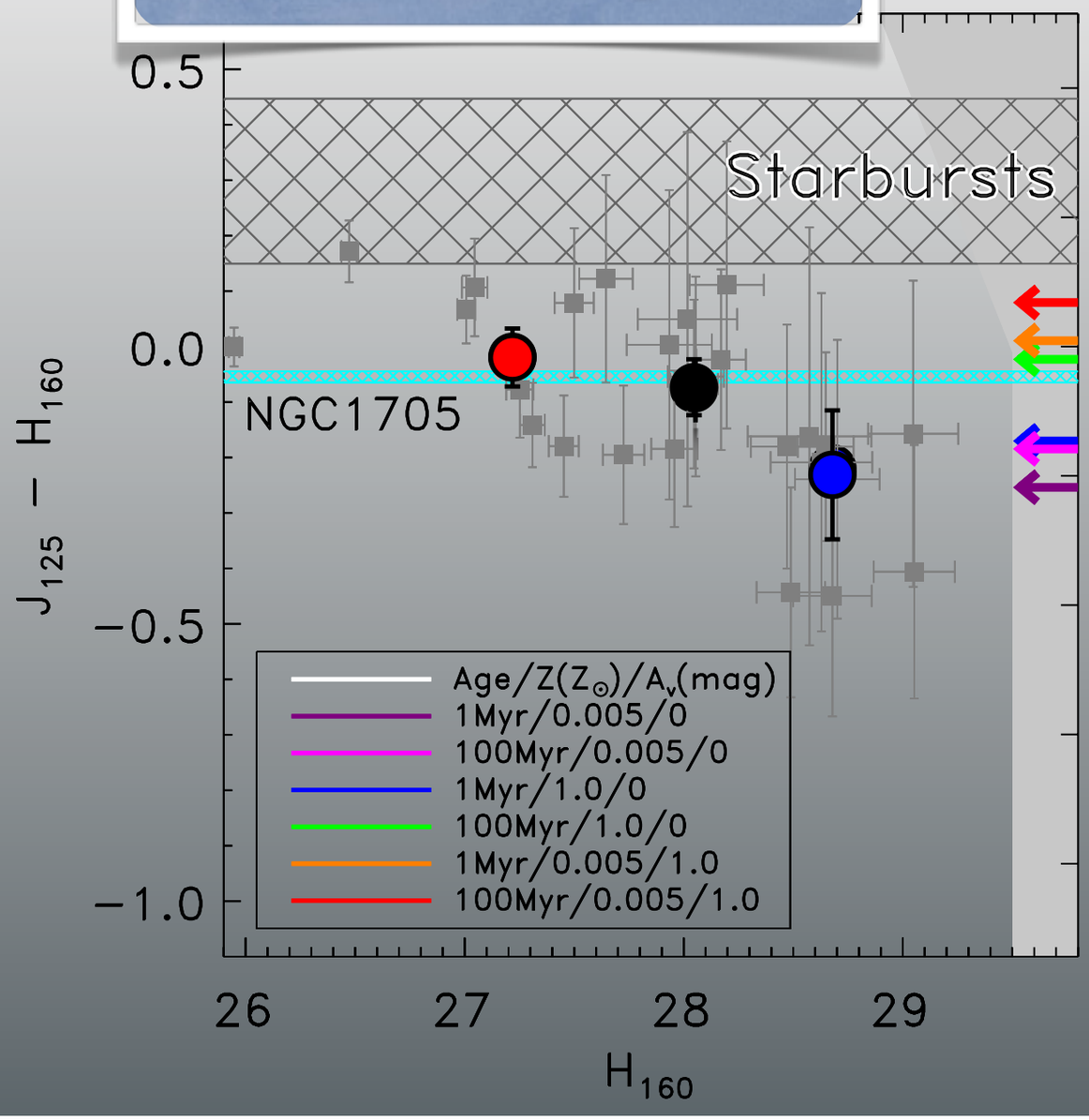


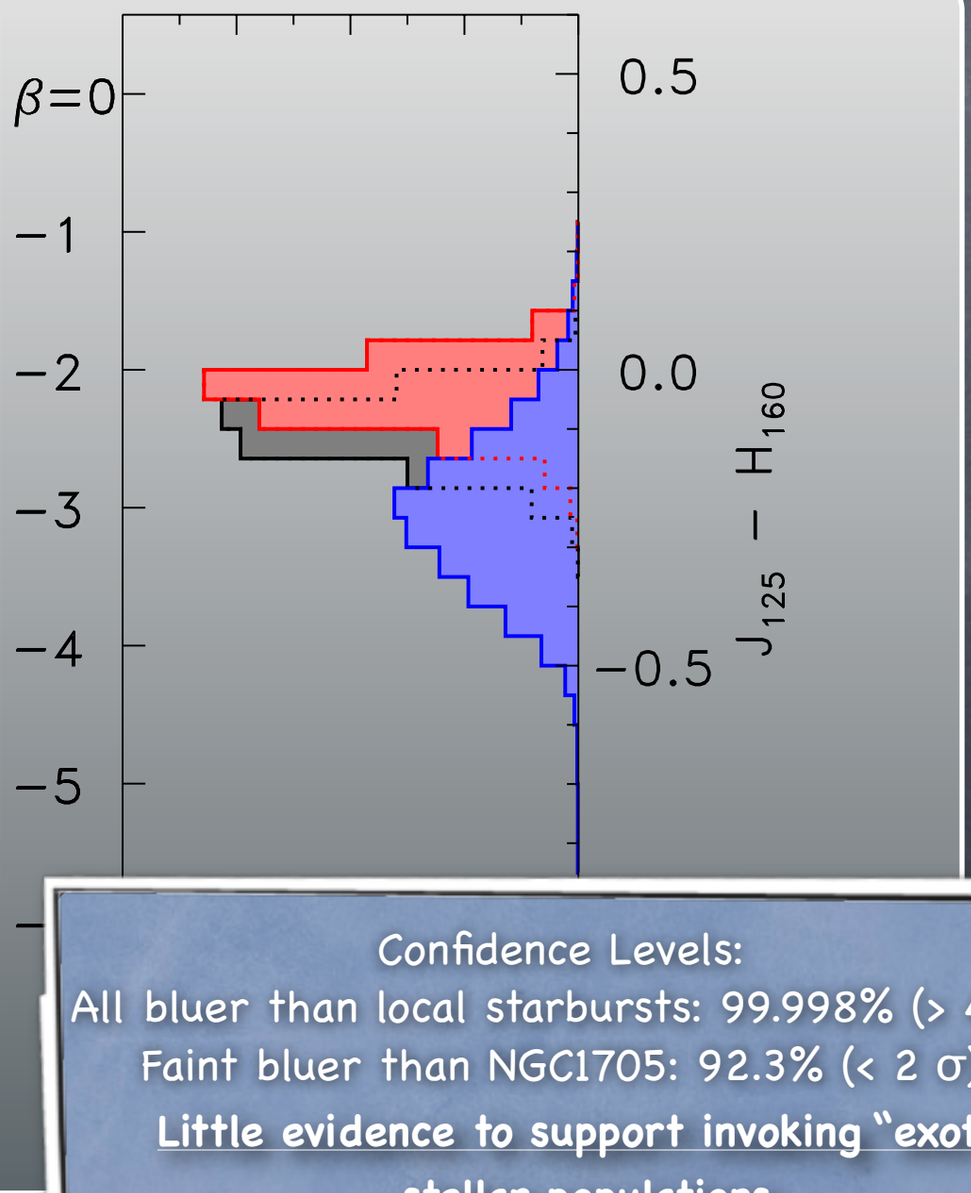
Motivation

- Study their colors
  - Can we rule out the null hypothesis that these objects are no different than galaxies at z ~ 3?
  - If so, can we say anything about more exotic stellar populations?

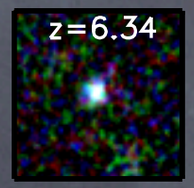
Rest-UV Colors

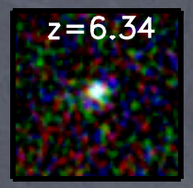
26 z ~ 7 objects

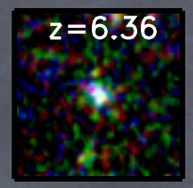


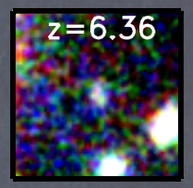


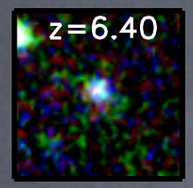
Confidence Levels:
All bluer than local starbursts: 99.998% (> 4 σ)
Faint bluer than NGC1705: 92.3% (< 2 σ)
Little evidence to support invoking "exotic" stellar populations.

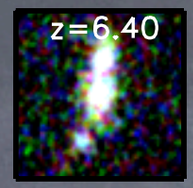


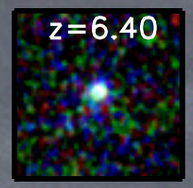


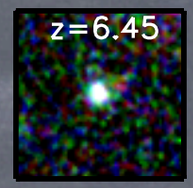


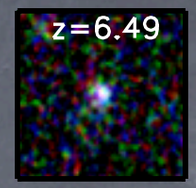


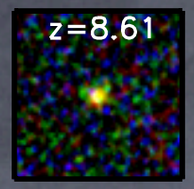


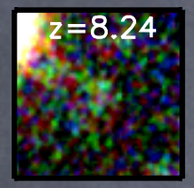


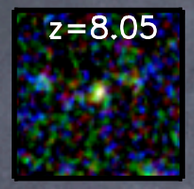


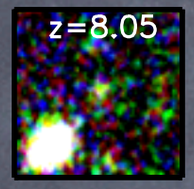


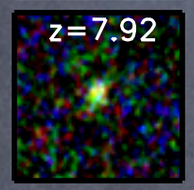


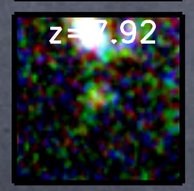


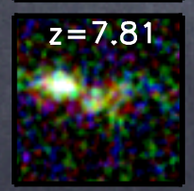


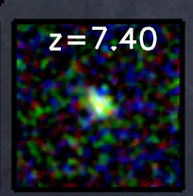


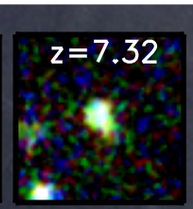


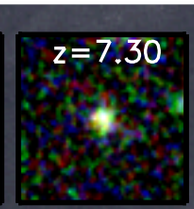


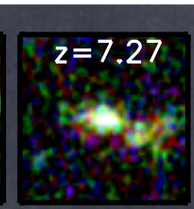


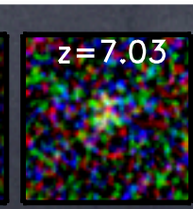


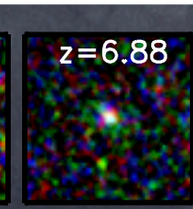


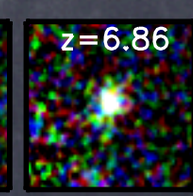


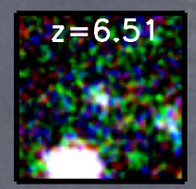


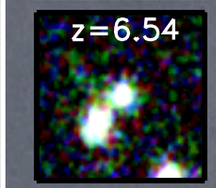


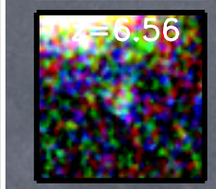


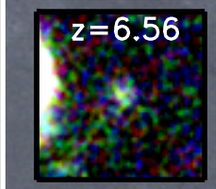


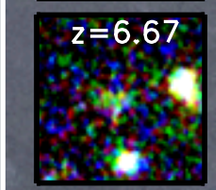


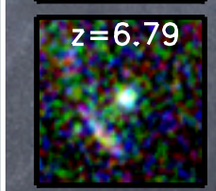


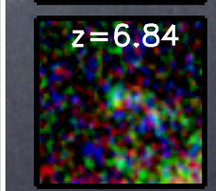


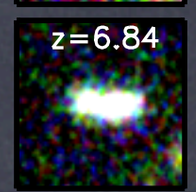












Motivation

✓ Study their colors

✓ Can we rule out the null hypothesis that these objects are no different than galaxies at z ~ 3?

✓ If so, can we say anything about more exotic stellar populations?

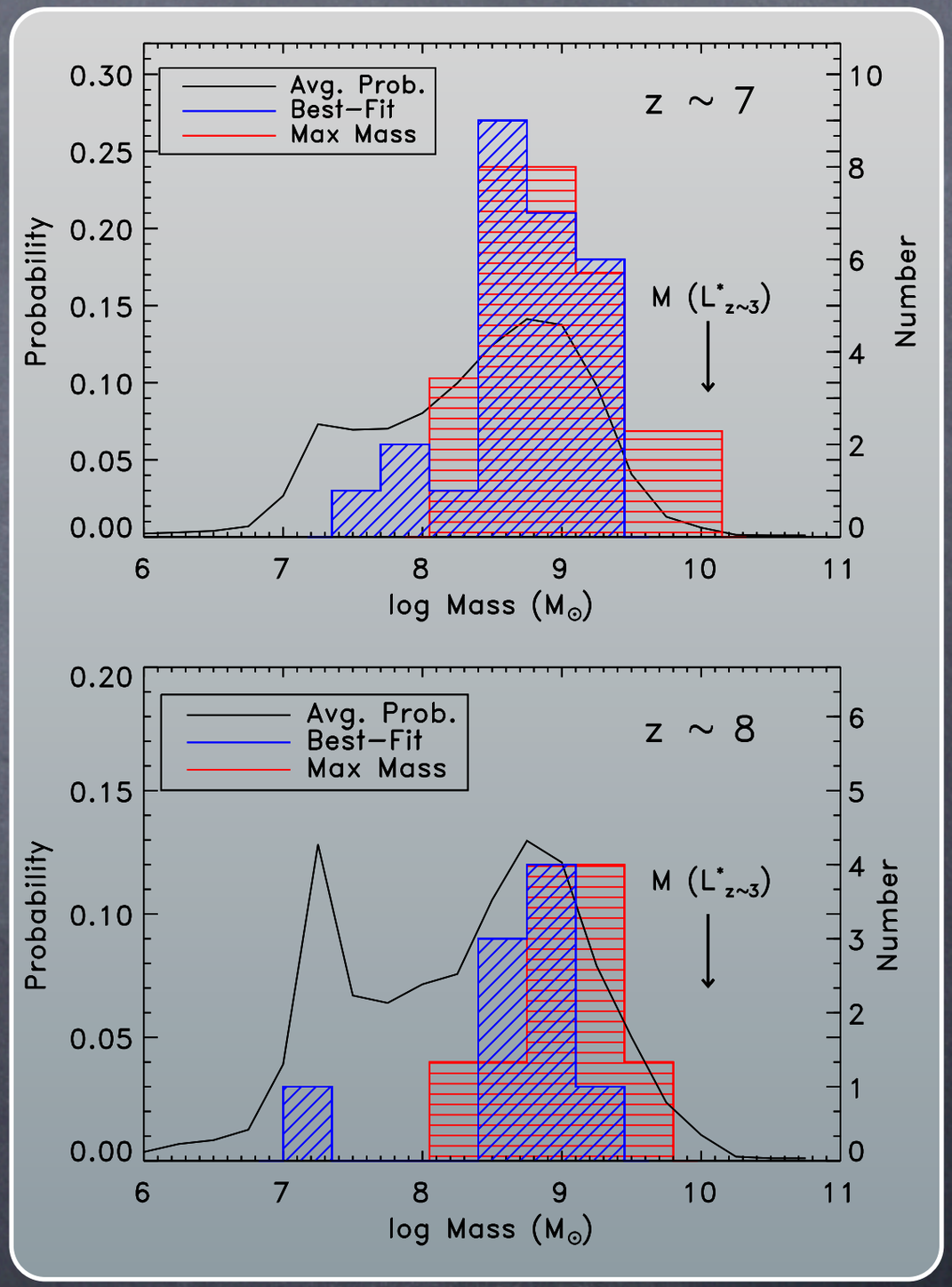
- Examine the remaining stellar population properties?
- What can we confidently say, and what is guesswork?

Stellar Populations

- We investigated the stellar populations in these galaxies by comparing our observations to CB07 models.
- We fit data from ACS, WFC3 and Spitzer, assuming that $z = z_{phot}$.
  - Included Lyα emission in the models (see Finkelstein+07,08,09), as it can significantly affect the Y_{105}/J_{125} fluxes at these redshifts, as the line EW increases as (1+z).
    - Results imply that current NIR NB surveys are not deep enough to see majority of objects.
- We computed 68% confidence ranges on each fitted parameter simulations.
  - We included the uncertainty on the photometric redshift in these simulations - increases uncertainties significantly!
- Age and dust are not well constrained with WFC3 fluxes alone - average of 200 Myr and A_V = 0.4 mag - though majority are consistent with very young ages and low/zero extinction.
  - While metallicity is traditionally poorly constrained, the blue colors of these objects rule out $Z > Z_\odot$ at 95% confidence, and $Z > 0.1\ Z_\odot$ at 68% confidence.

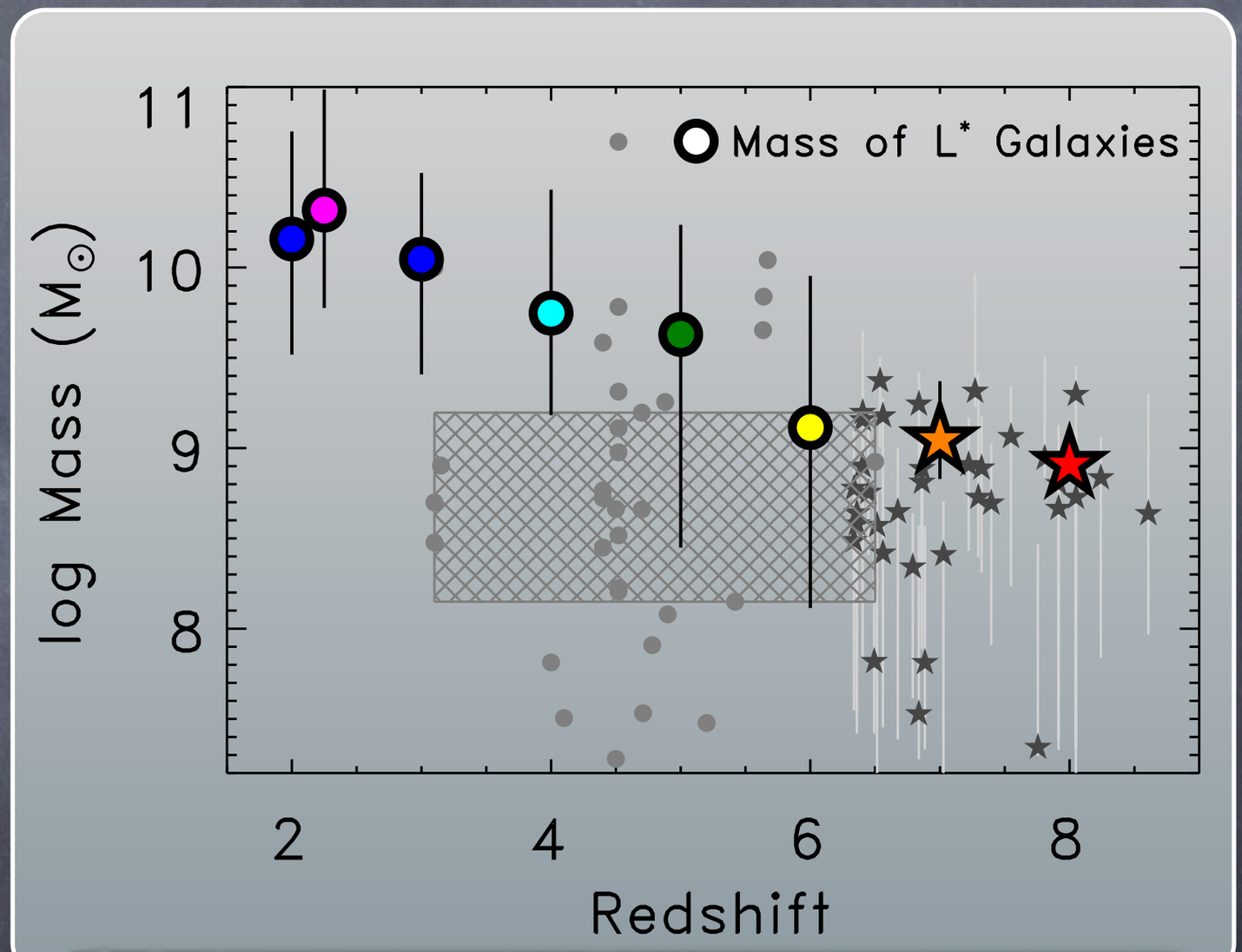
Stellar Masses at z > 7

- Stellar masses ~ 10^8 - 10^9 $M_\odot$ (~10^9 at L*), compared to M ~ 10^{10} at z ~ 3
  - Solid line is the joint probability distribution of mass from the bootstrap simulations.
    - Overall uncertainty on mass is a factor of ~ 10, BUT is a factor of only +2 and -5.
      - The upper limit on mass appears to be well constrained.
      - Test this by fitting a two-population model, where 90% of the mass is forced to form at z = 20.
- The young age of the Universe at these redshifts limits the amount of mass in old stars - more so than Spitzer.
  - At t_{Uni} ~ 500-800 Myr, M/L ratio dominated by stars with M > 3$M_\odot$, or O, B and early A stars.



Mass Evolution of L* Galaxies

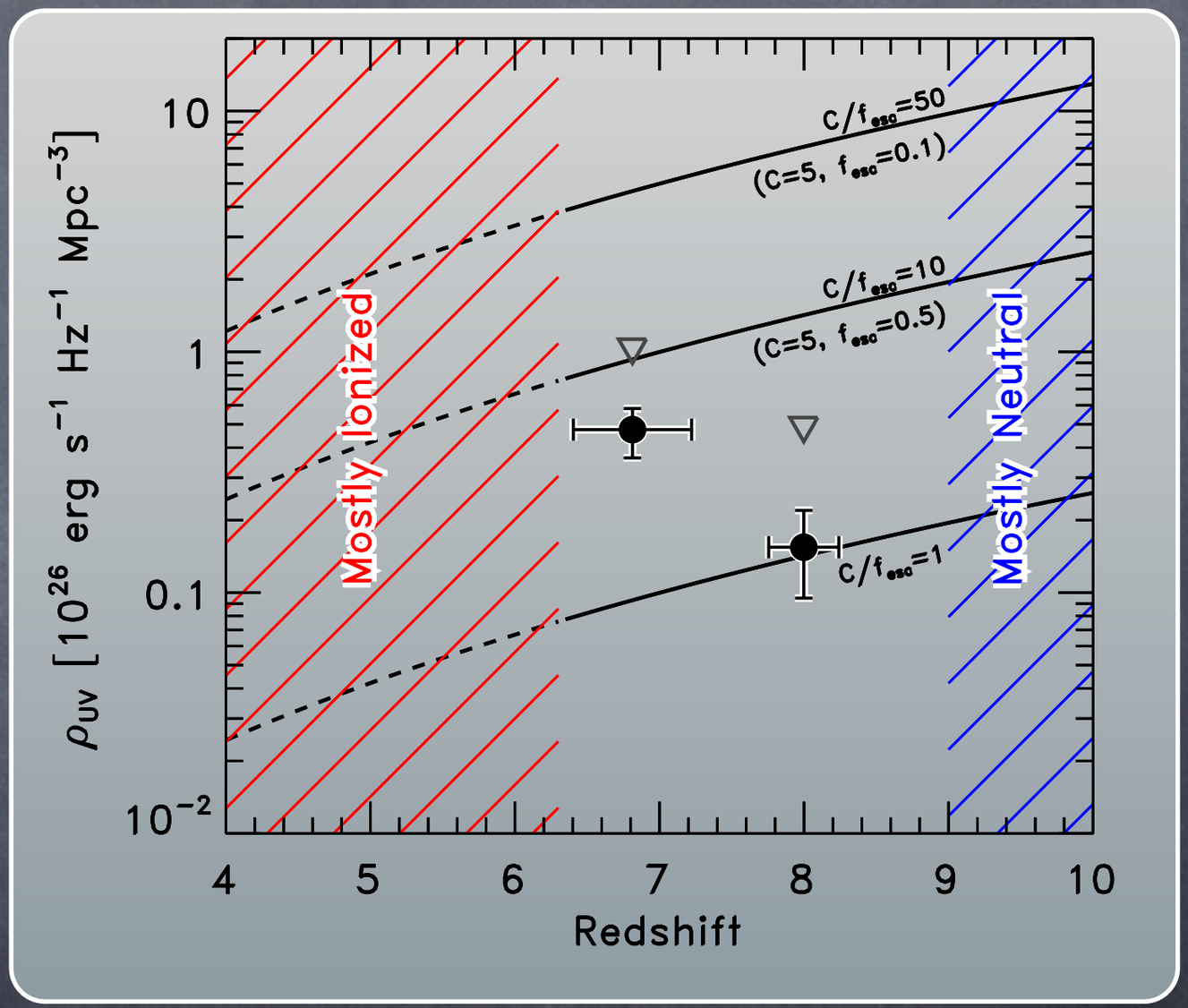
- Typical (L*) galaxies are lower mass at higher redshift.
  - We confirm a drop in typical galaxy stellar mass, first hinted at, at z ~ 5-6.
- Gray dots are Lyα emitters (LAEs)
- z ~ 7-8 galaxies look more like LAEs at all redshifts than LBGs at any redshift.
  - Young ages, low extinctions, and possibly low metallicities confirm the LAE-esque nature of these galaxies.
- At z ~ 3-6, LAEs appear to be the building blocks of lower-z galaxies.
  - At z > 7, it appears to be the "era" of these building blocks, in that the evolved LBGs seen at lower-z are extremely rare.



Lower-z data from Reddy+06, Shapley+05 and Stark+09
Error bars are 80% ranges.

Cosmic Reionization

- By adding up the rest-UV fluxes of our objects, we can examine how they would impact reionization.
  - We computed the specific luminosity density for the z ~ 7 and 8 samples.
  - With no correction for dust or incompleteness, our objects come within a factor of a few of sustaining reionization for high escape fractions (~ 50%).
    - Assumes low clumping factors (Pawlik +09, Finlator+09).
  - Accounting for unseen faint galaxies brings us a factor of ~ 2-3 closer.
    - Escape fractions of ~50% might be reasonable (e.g., Siana+10).



Summary

- HST+WFC3 allows us to peer within 500 Myr of the Big Bang, discovering some of the earliest galaxies in the Universe.

- These early galaxies appear very blue, consistent with normal, young, low-dust populations, less evolved than LBGs at z ~ 3 (> 4σ result).

  - Little evidence for exotic stellar populations, i.e. Z=0, top-heavy IMF.

- Their stellar populations are consistent with z ~ 3-6 Lyman alpha emitters, which are thought to be galactic building blocks.

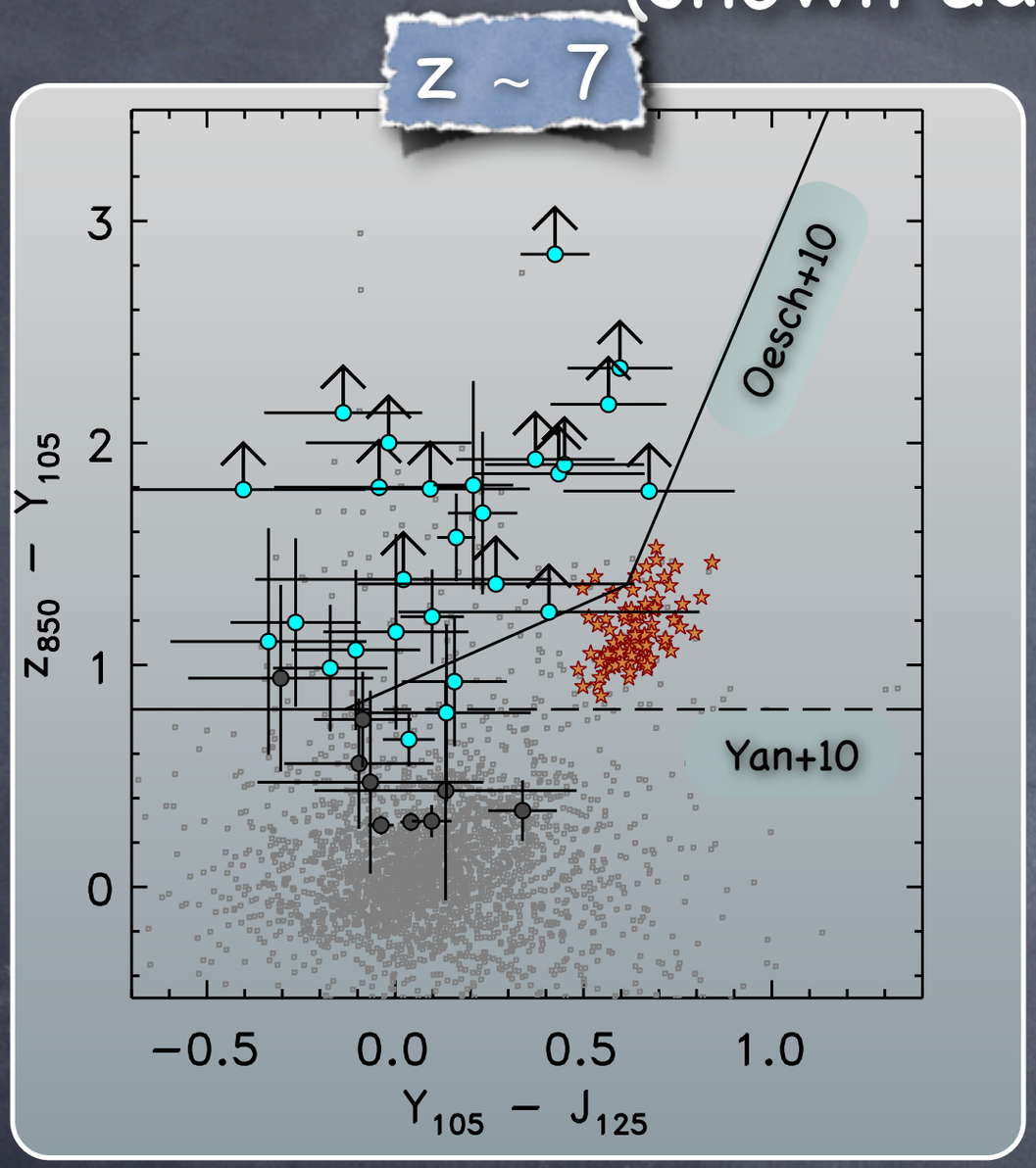
  - At these high-redshifts, it thus looks like we have entered the era of baby galaxies, where the more evolved LBGs common at lower-redshift have not yet had time to form.

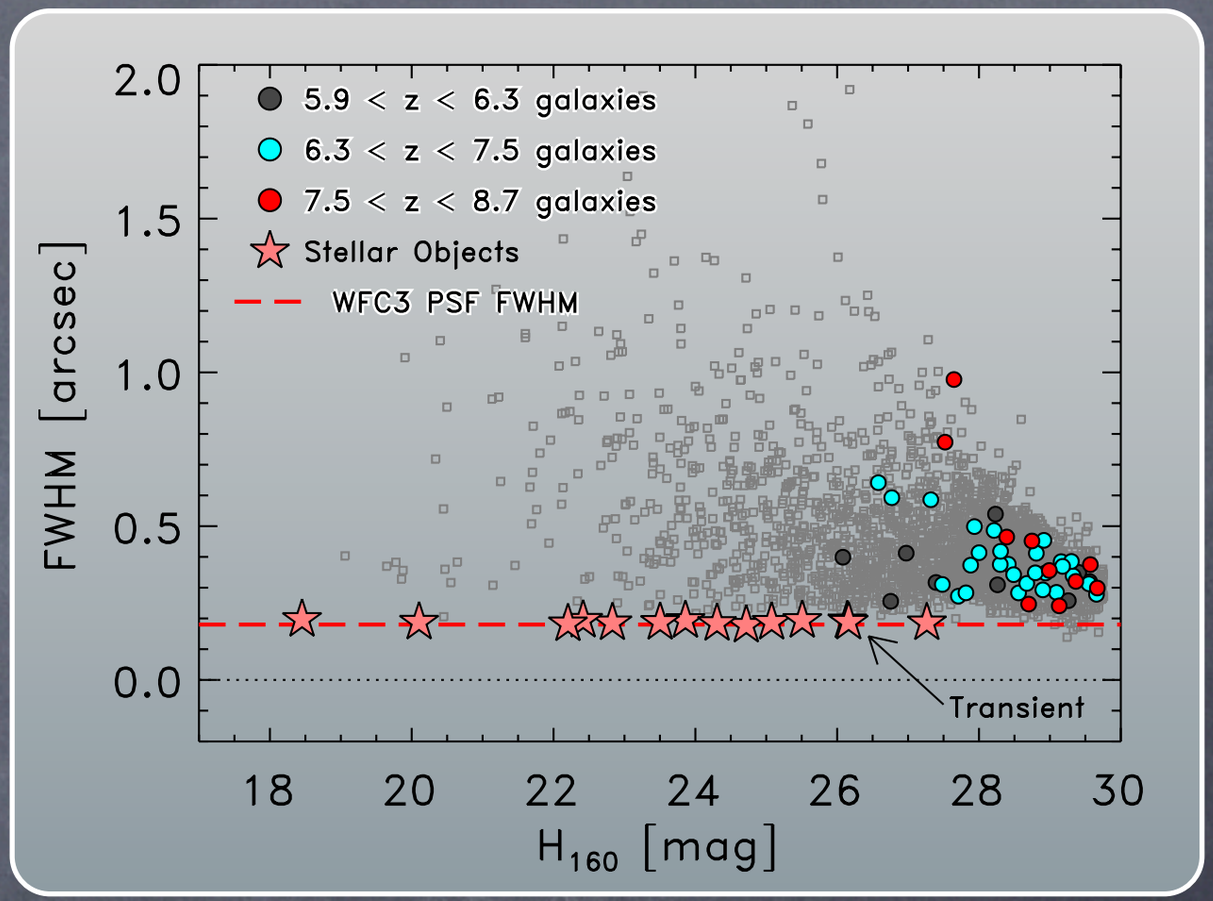
- If escape fractions are high, galaxies at these redshifts may be able to sustain reionization.

More information at: http://astronomy.tamu.edu/highz

Comparison to LBG Criteria

(shown during questions)





- Circles: Gray = z < 6.3, Cyan = 6.3 < z < 7.5, Red = 7.5 < z < 8.6.
- Brown symbols represent synthesized colors of brown dwarfs, from empirical spectra.
  - Using stars in the WFC3 image, we measured $FWHM_{PSF}$ = 0.18″
    - All of our 35 objects are resolved.