The Lyman Continuum Escape Fraction at Moderate Redshift

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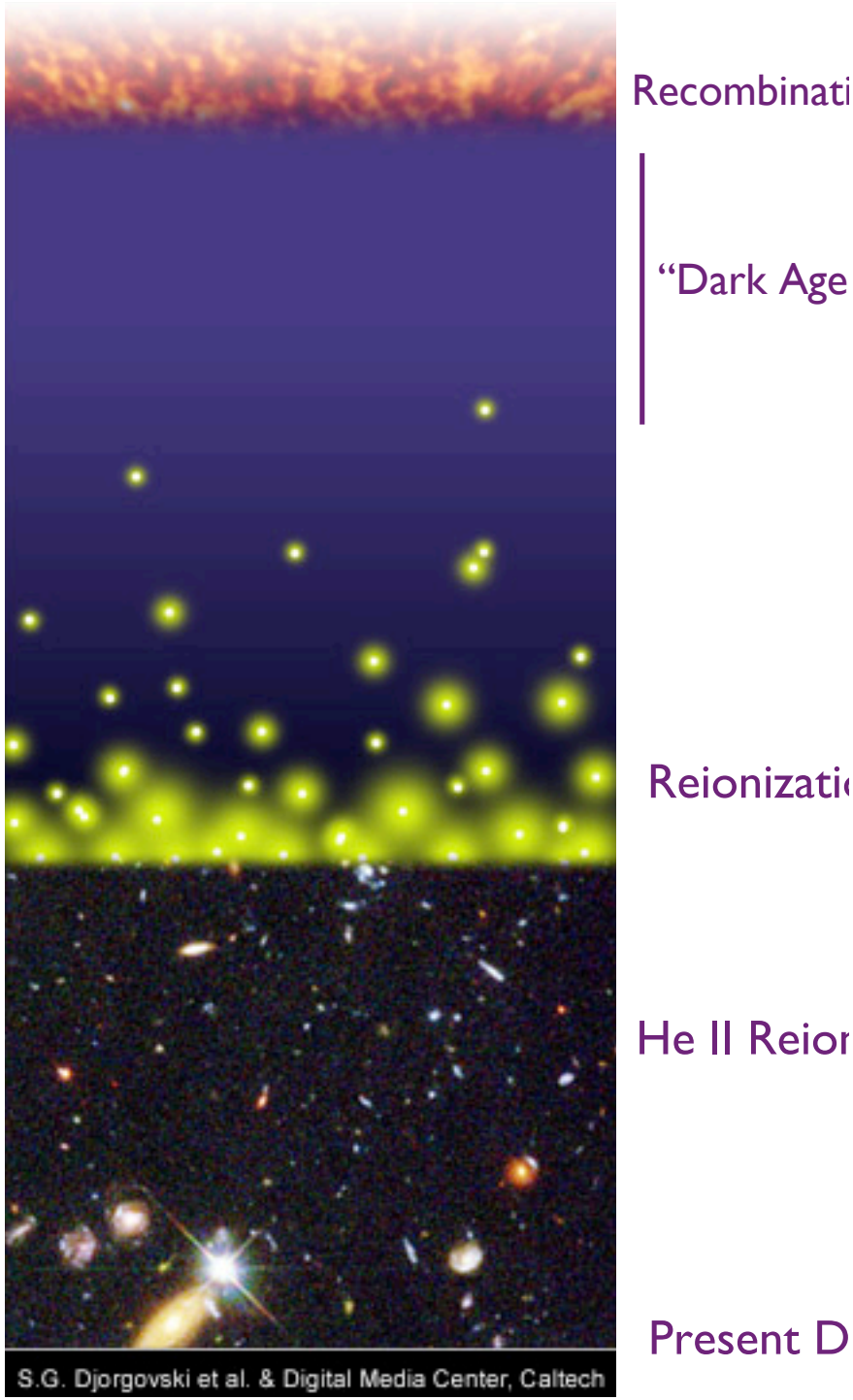
Motivation

- Reionization: What is the galaxy contribution to the HI-ionizing background ?
  - QSOs do not dominate at z > 3. (Willot et al. 2007, Siana et al. 2008)
  - Star-formation
- How/when do ionizing photons escape galaxies ?
  - Mergers? --> Morphology dependence
  - SNe chimneys? (eg. Fujita et al. 2003) --> Luminosity Dependence
  - Dwarf Satellites? --> Luminosity Dependence
  - Redshift dependence?



Measuring f_{esc}

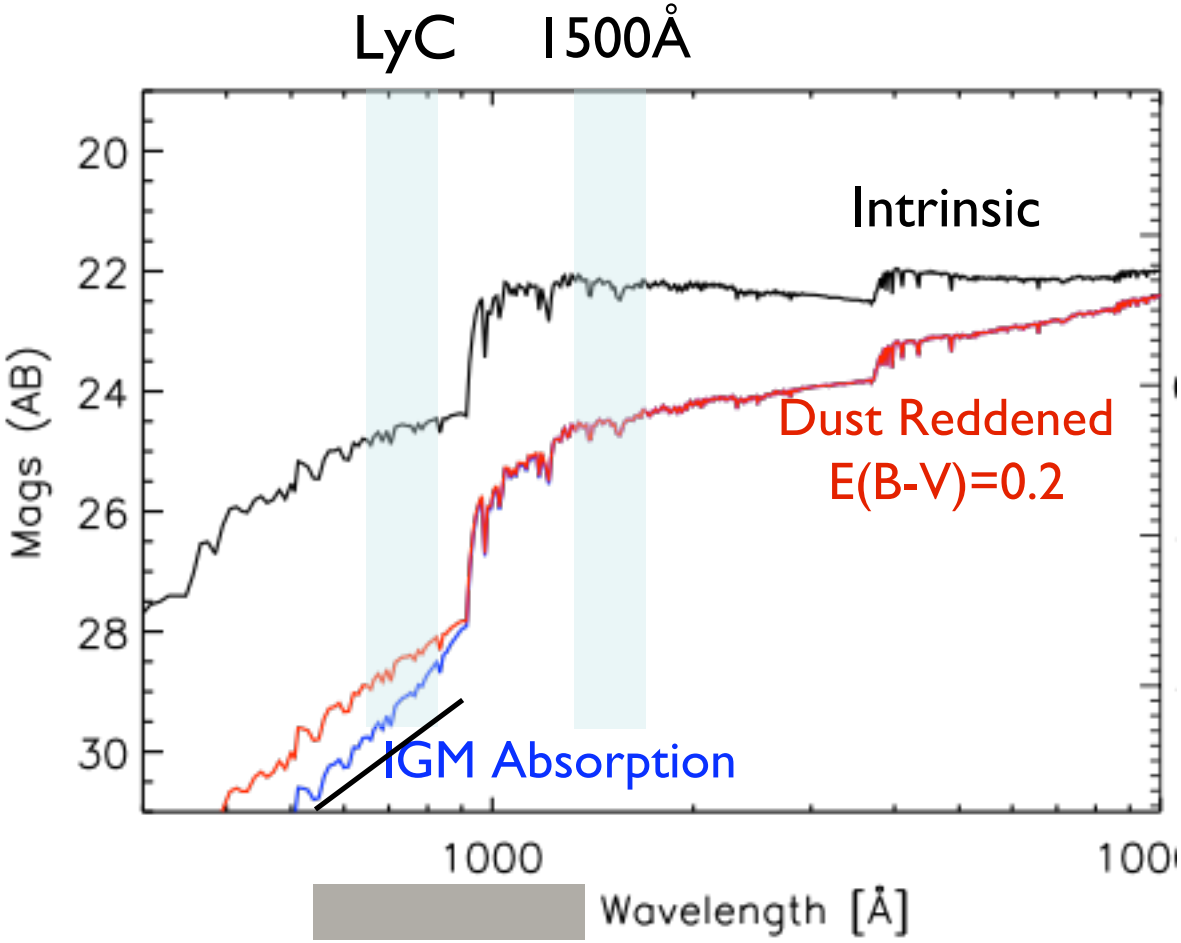
"The UV escape fraction remains problematic" (Fan et al. 2006)

1. f_{esc} = fraction of lyman continuum photons which escape galaxy.

2. $f_{esc,rel}$ = fraction of lyman continuum photons which escape galaxy divided by fraction of 1500Å photons escaping galaxy.

3. Can't measure f_{esc} at z~6 because of intervening IGM

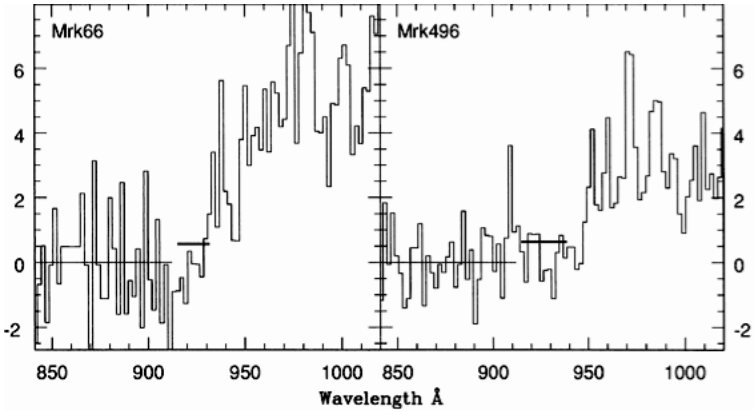
4. Lower z LC-emitters would be easier to study



Measuring the Relative Escape Fraction

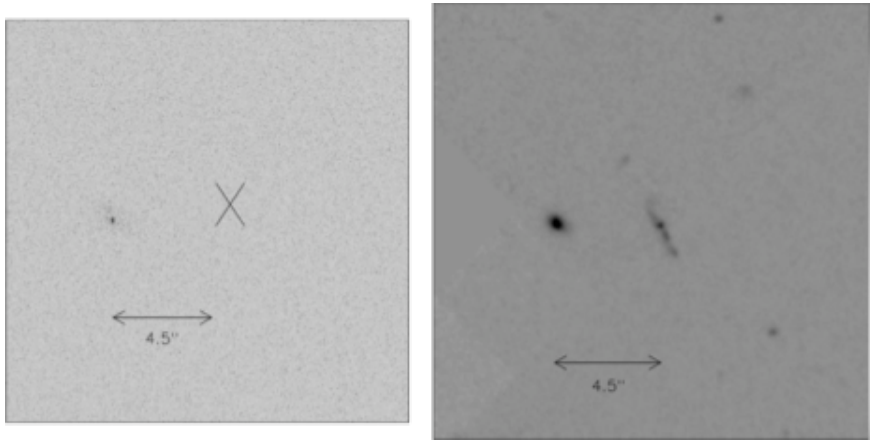
z=0

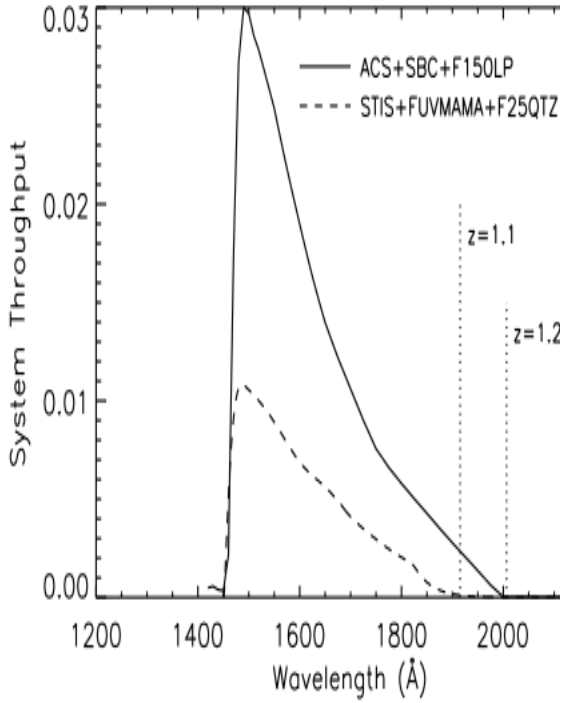
Leitherer et al. (1995)



z=1

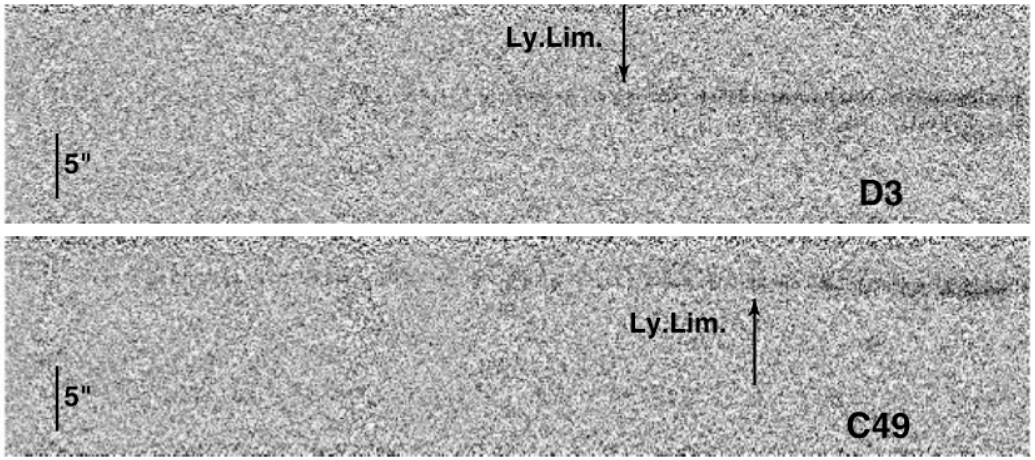
Malkan et al. (2003)

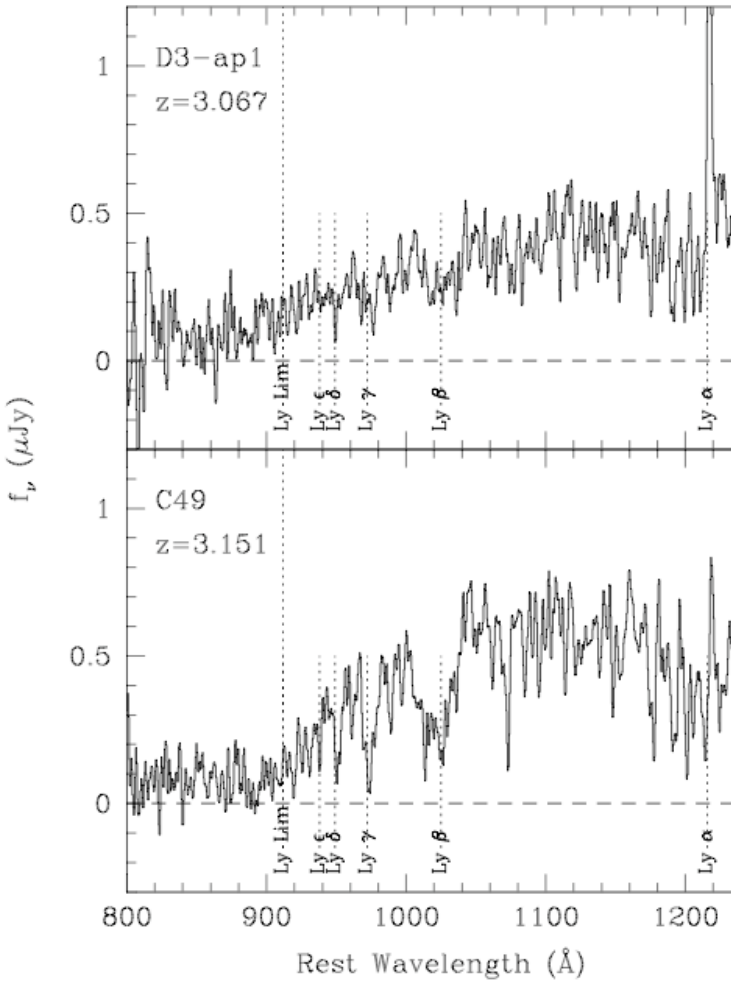




Measuring the Relative Escape Fraction, z~3

- Steidel et al. (2001) stack of 29 LBG spectra at <z>~3.4
  - Biased toward blue LBGs
  - Very high $f_{esc,rel}$
- Shapley et al. (2006) 14 spectra of z~3 LBGs
- 2/14 have high $f_{esc,rel}$ ~ 1





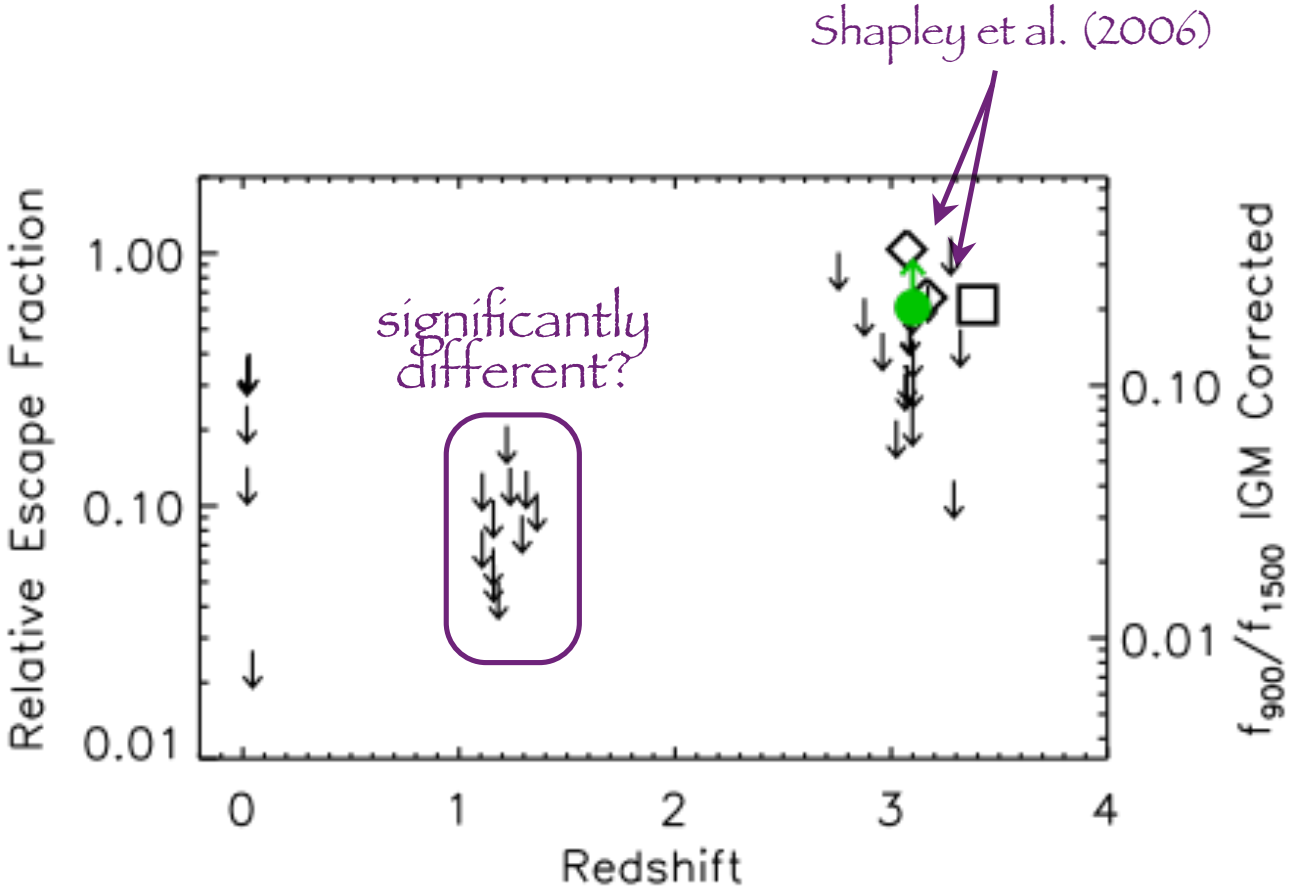
Shapley et al. (2006)

Previous f_{esc} Measurements

Spectroscopy at z~0, z~3, Imaging at z~1 with HST

⇒ Detection of LC in LBGs at z=3.09 (Shapley et al. 2006 ◊)

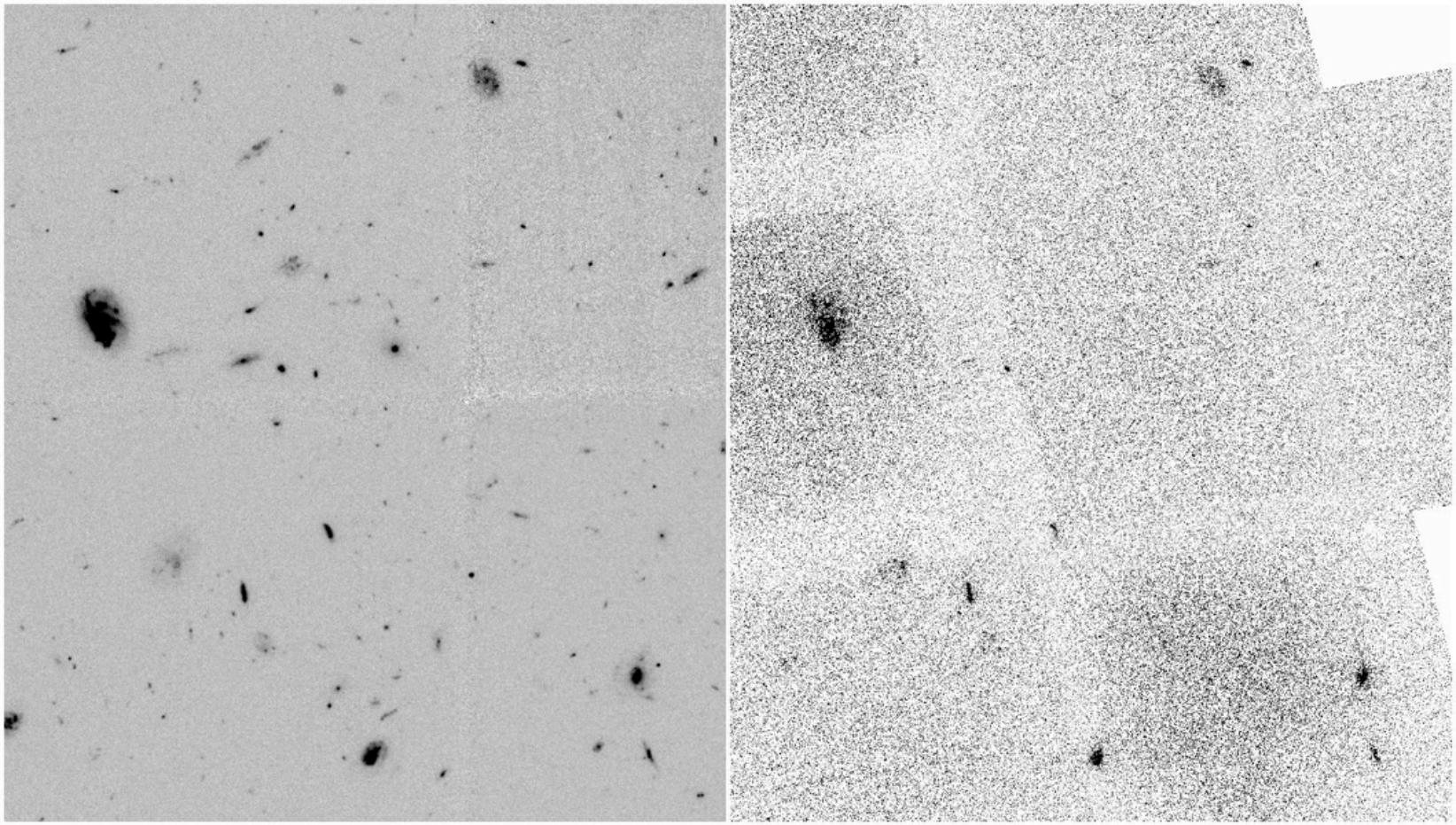
⇒ High f_{esc} only in rare objects



New Search at z = 1.3

- 1600 Å Imaging of HDF-North and HUDF
- Rest-frame Lyman continuum at 1.2 < z < 1.5

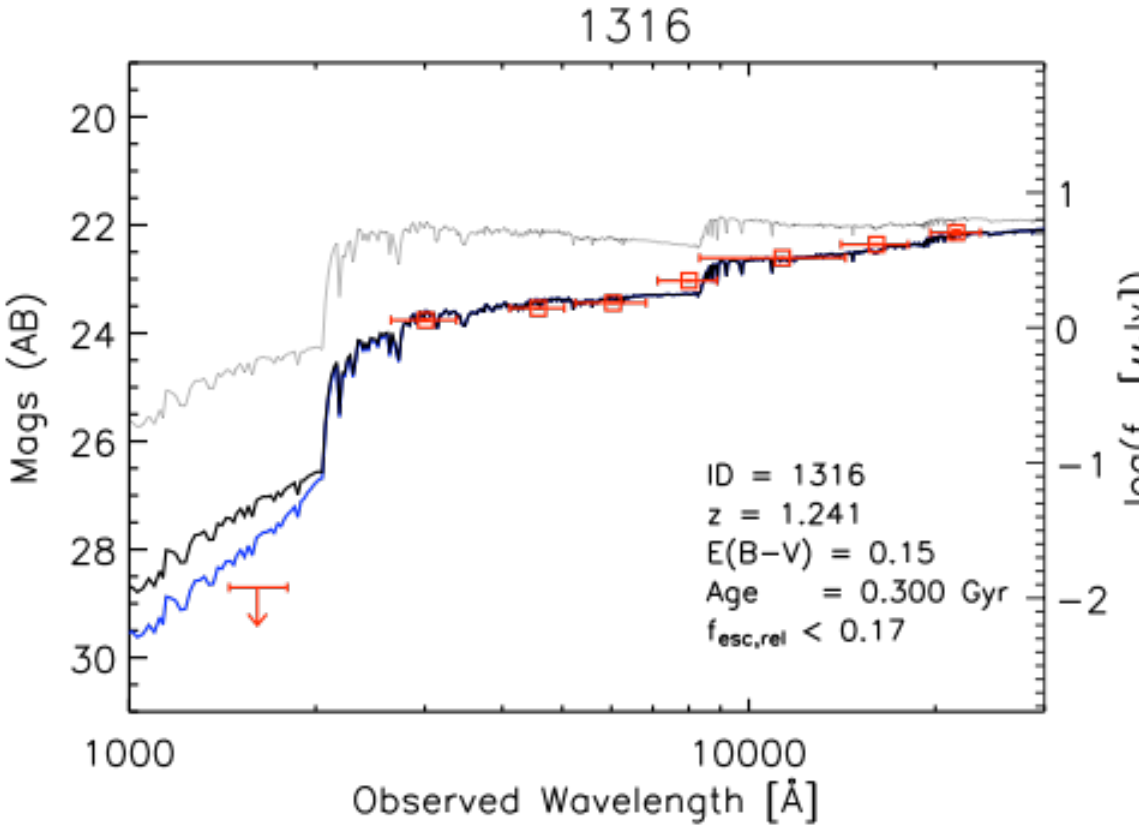
FUV (3σ)~ 29-29.5 (AB)



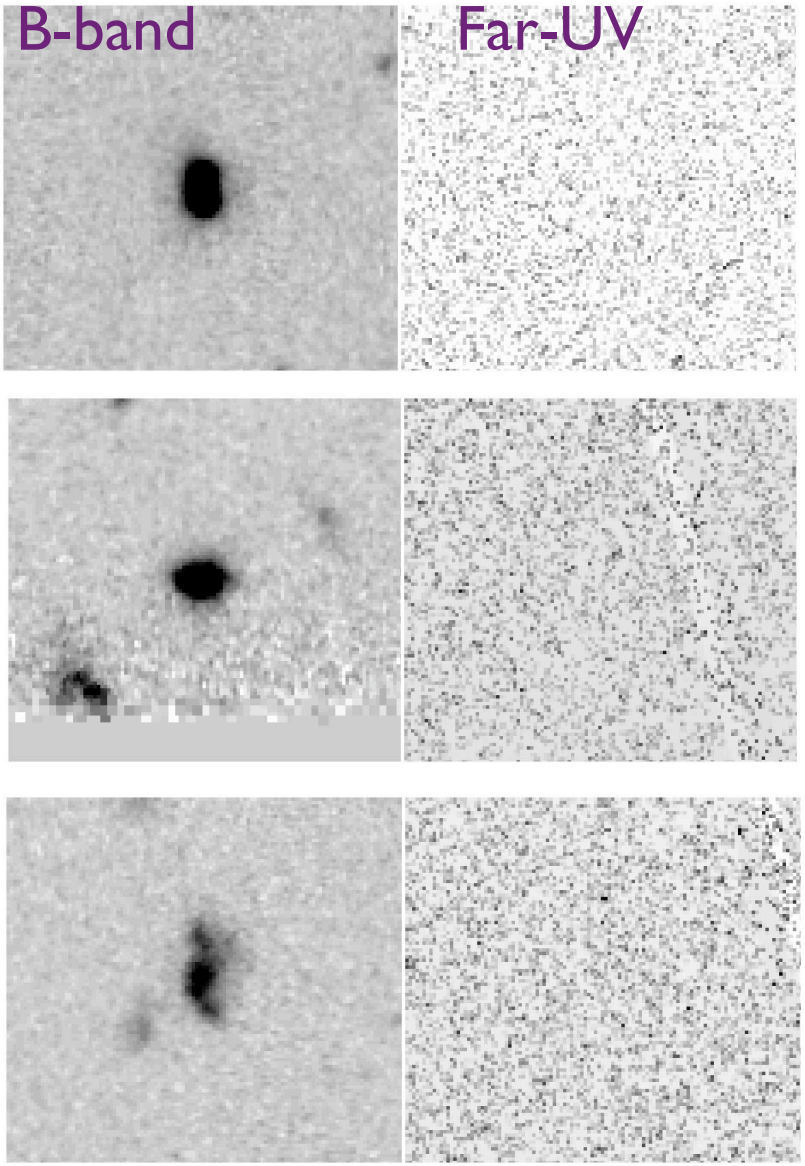
Estimating the Instrinsic Lyman Break

- Fit to SED
  - best fit is constant SFR
  - includes reddening at 1500
- Apply average IGM opacity at z

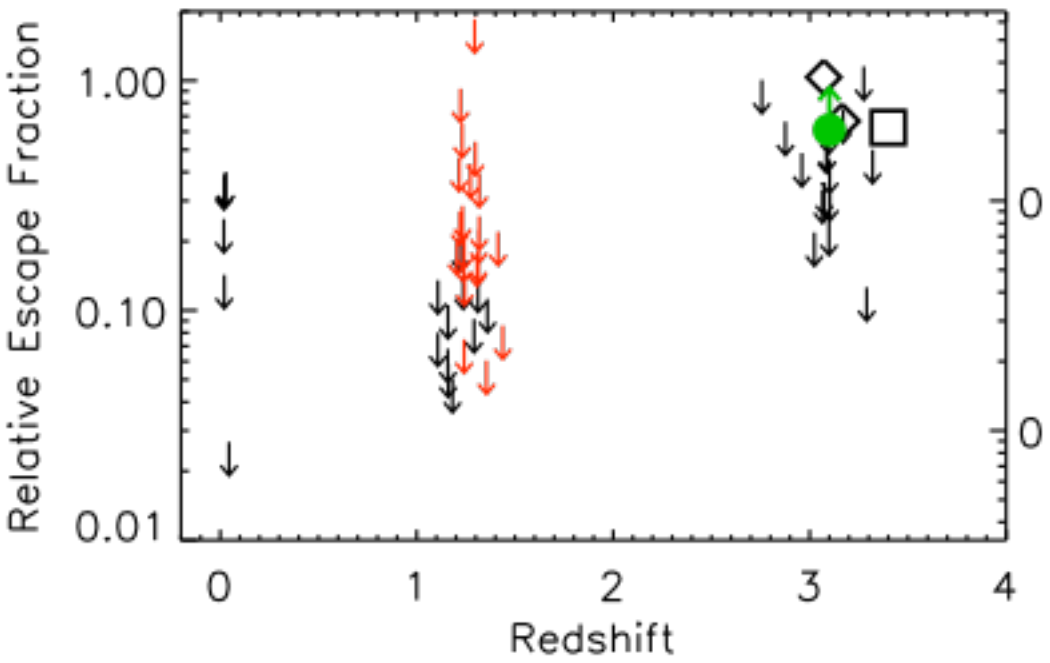
- Break is typically factor of 6--10



Results



Siana et al. (2007)



Caveats

- Lower L galaxies
- Rest-Frame 700 Å

New Survey: brighter sources, deeper images

Imaging of 14 luminous, blue galaxies at z~1.3

as luminous as LBGs

ACS FUV imaging

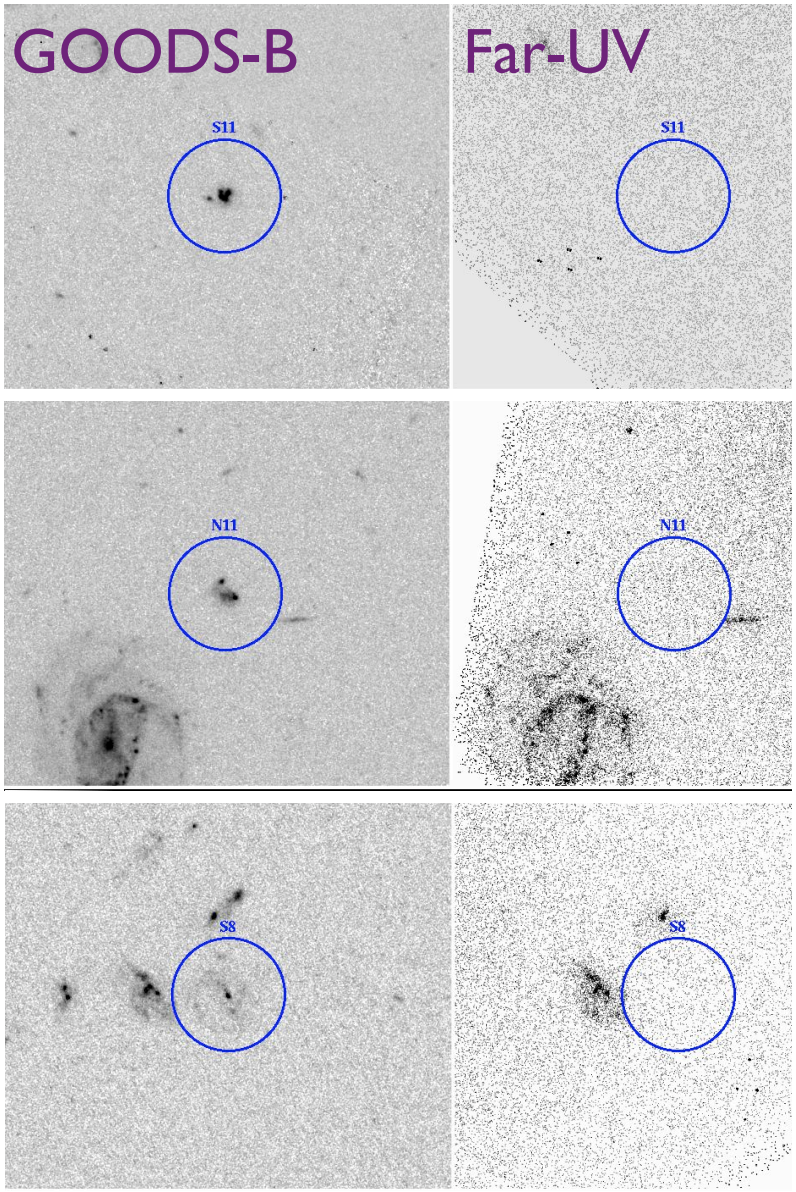
positioning of targets on dark region of MAMA detector

observing strategy minimizes dark current by avoiding detector warming

5 orbits per target; AB>29, 3sigma

⇒ deepest f_{esc} survey to date

Would detect $f_{esc,rel}$ of 5%



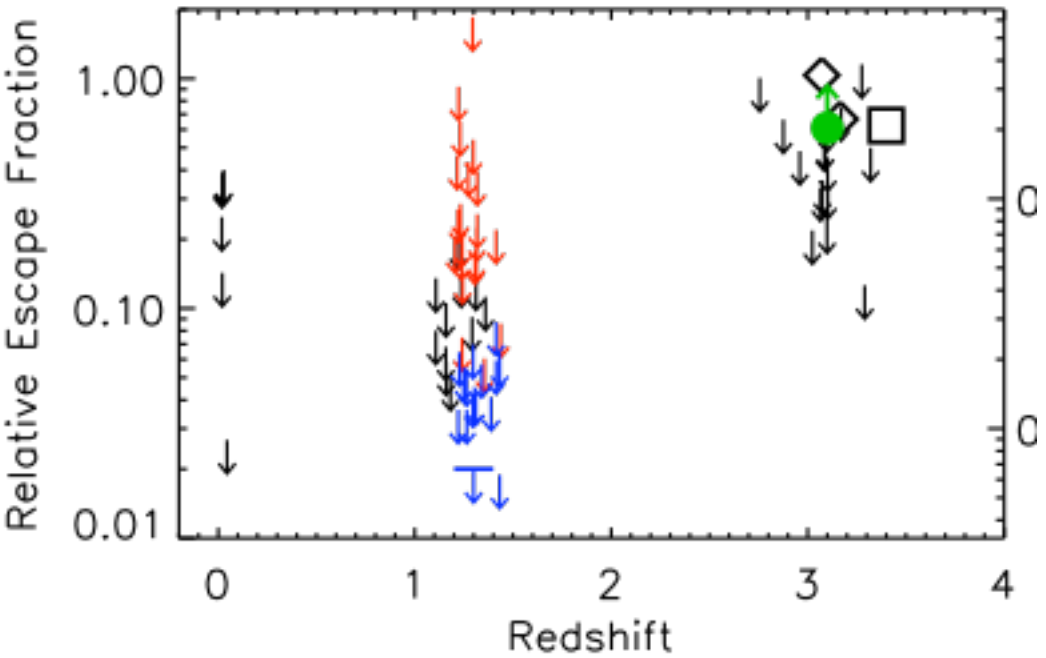
New Results

No detections!

Consistent comparison of rest wavelengths
factor of 1.33 from 750 to 900

Stacking of limits
previous stack limit < 5%
working on stacking of new data; new limit will be under 2%

Siana et al. (2008b, in prep)

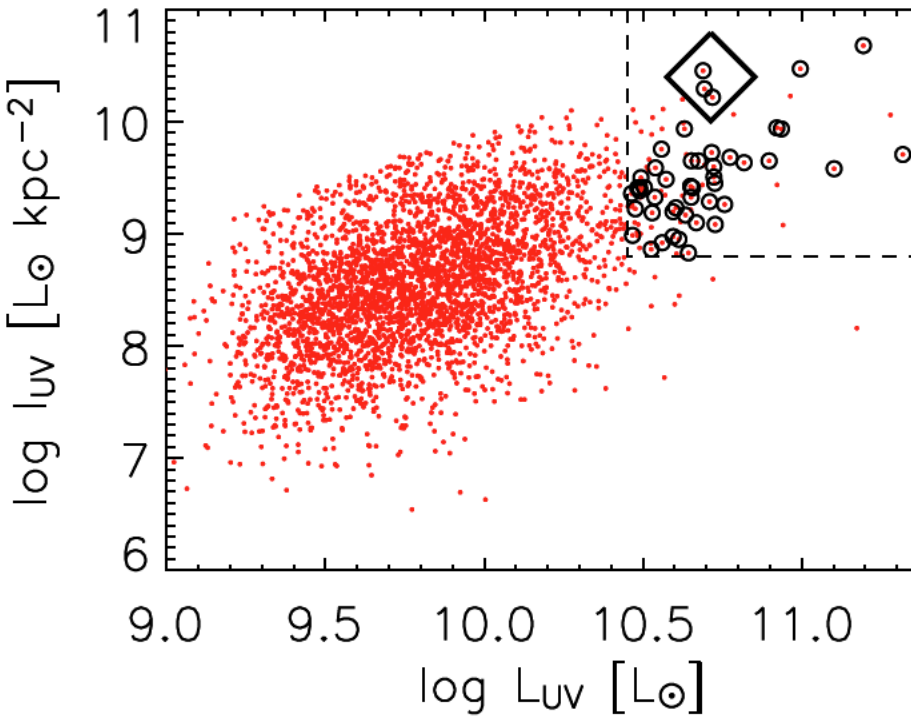


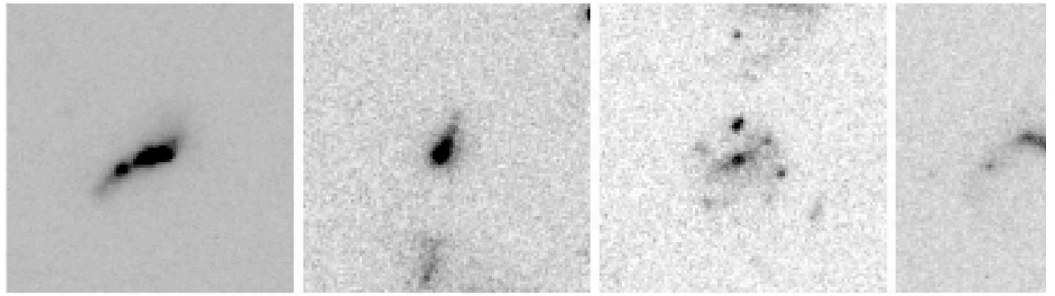
Caveats

- ~~Lower L galaxies~~
- Rest-Frame 700 Å

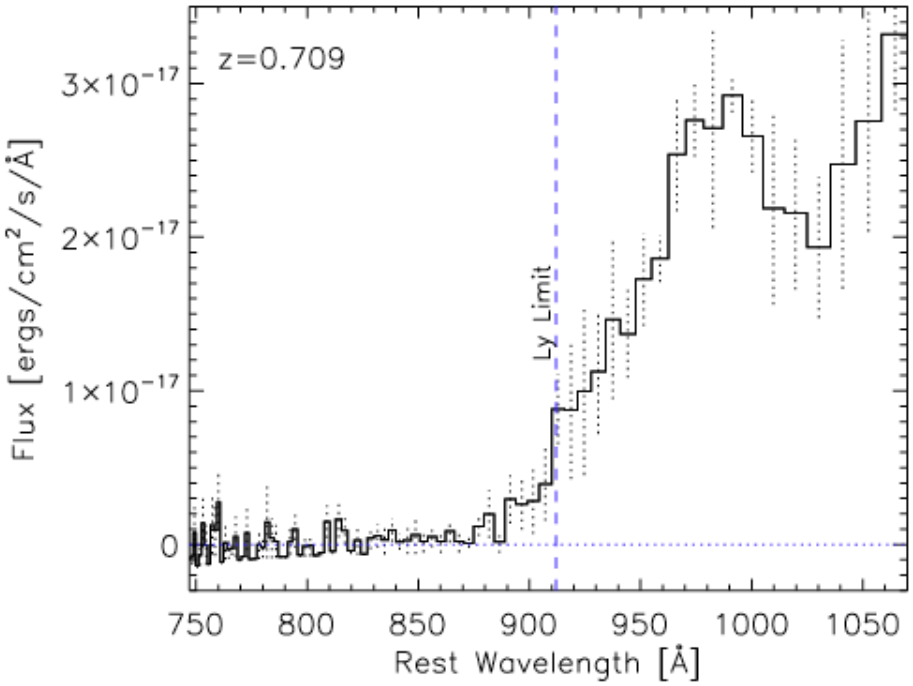
HST Far-UV Prism z=0.7 LBG Analogs

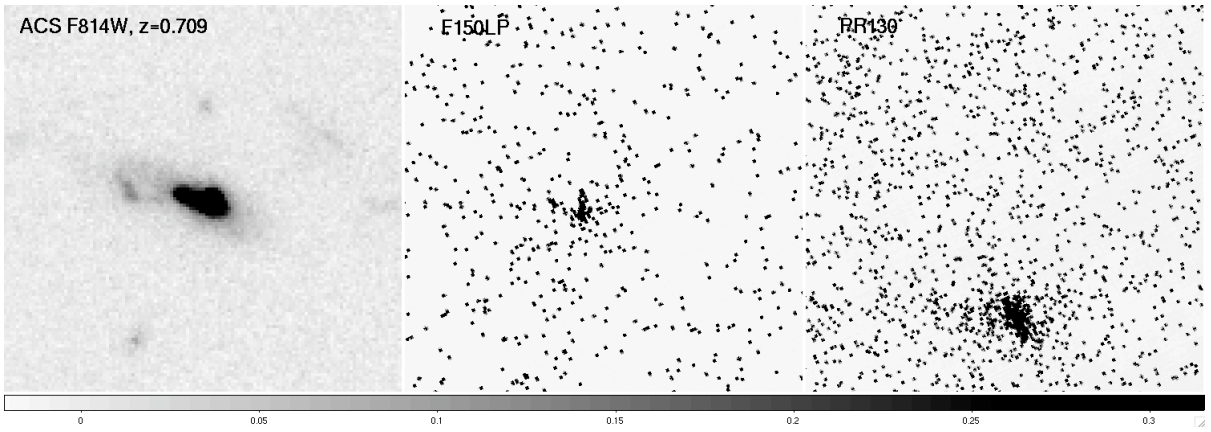
- LBG Analogs (L_{UV} and Surface Brightness, Hoopes et al. 2006)
- Get Spectrum near Lyman Break
  - LC shifts into FUV prism bandpass at z~0.7
- Target selection
  - 32 Objects (3-5 orbits each) selected in COSMOS
  - Selected with photo-z, confirmed at Palomar
  - Range of morpohologies
- Observations began Jan 2008
- Measure f_{850}/f_{1050}
  - scale FUV to f_{1500} with fit to SED





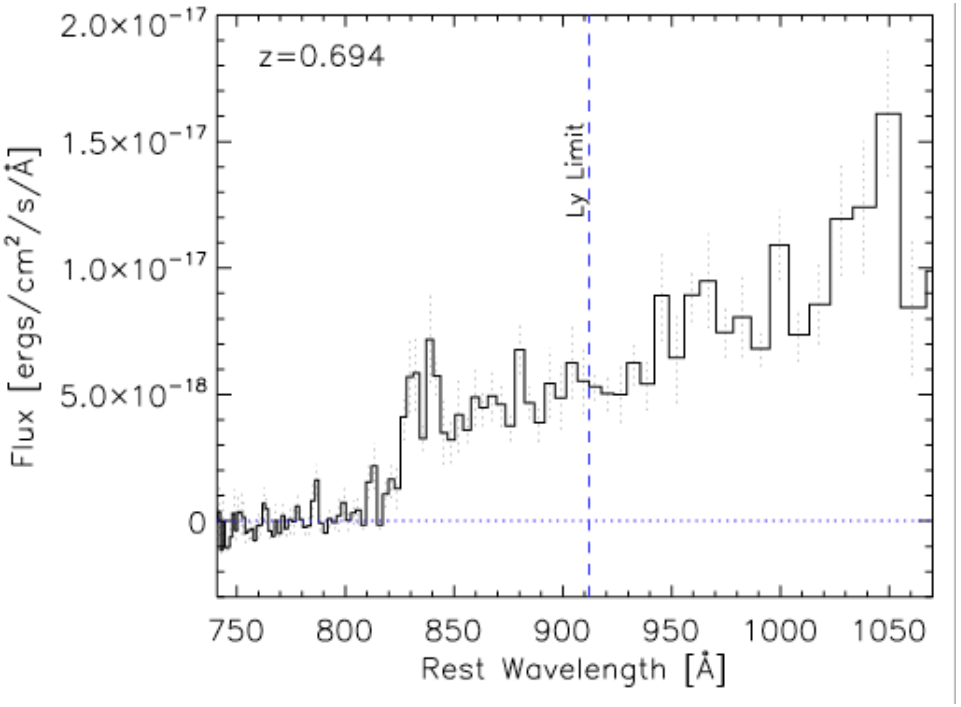
HST Far-UV Prism z=0.7 LBG Analogs

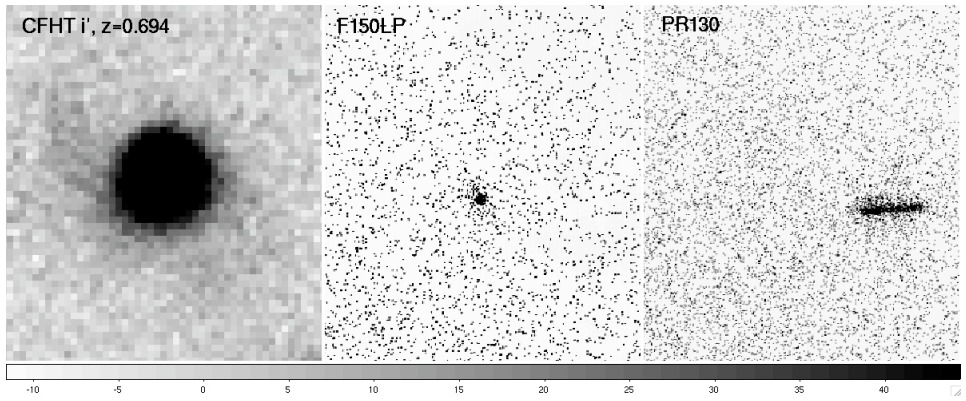




HST Far-UV Prism z=0.7 LBG Analogs

AGN -- proof of concept





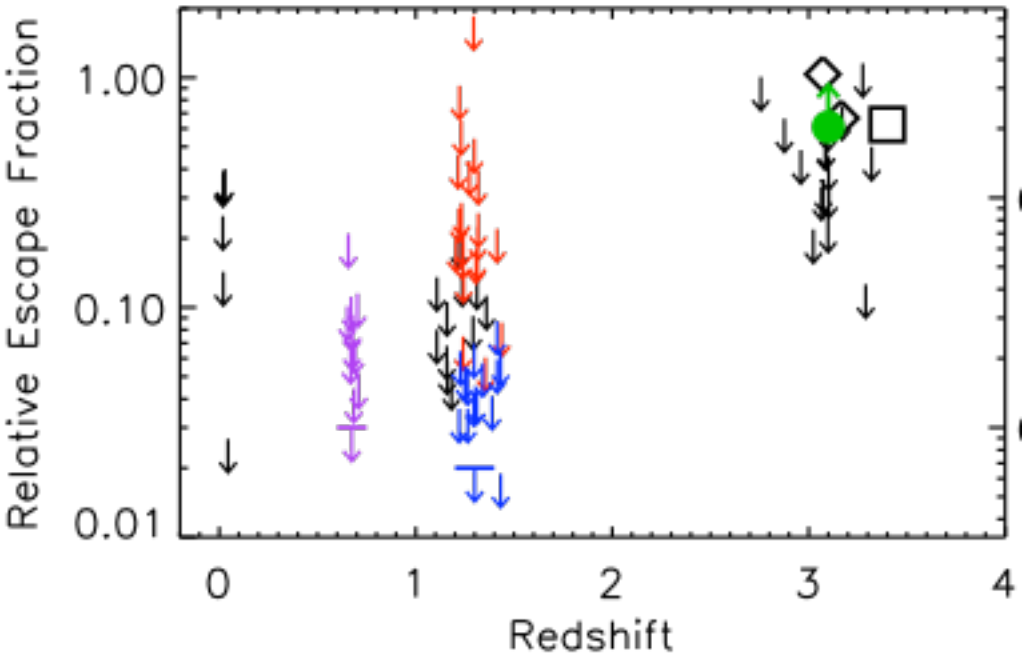
Prism Results

Bridge et al. (2008) in p

- No detections from 11 spectra to date
- Limits of 5-21%
- Stack of spectra gives $f_{esc,rel} < 3\%$

No detection of escaping LC at moderate redshift despite large surveys

Evidence for evolution with redshift

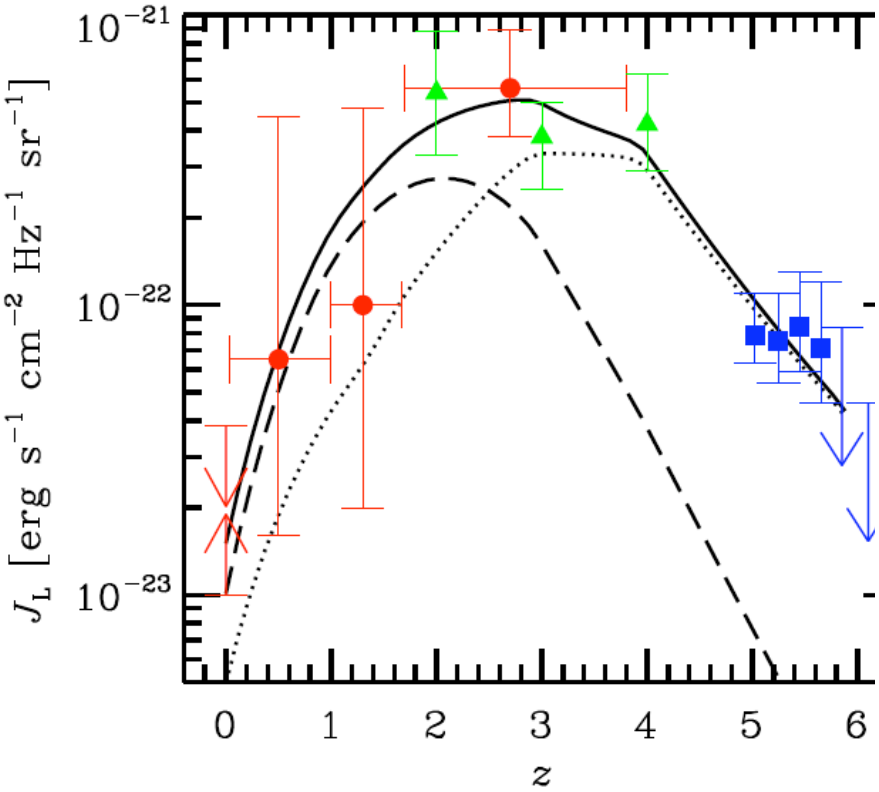


Caveats

- ~~Lower L galaxies~~
- ~~Rest-Frame 700 Å~~

Evolving Escape Fraction?

- QSOs can produce ionizing background at z < 2 (Inoue et al 2006)
- ... but not at z > 3 (Siana et al. 2008, Fontanot et al. 2007)
- Young stars must pick up the slack!



Conclusions

- We now have very strict limits on the relative escape fraction at z~1.3 and 0.7
  - 56 objects with a range of luminosity, morphology; new targets analogous to LBGs
  - Limits below 4% (below 2% in the stack)
- Ionizing emissivity at λ_{rest} = 750 Å is VERY low in z=1 starbursts!
- Lack of detections implies an evolving escape fraction for very luminous starbursts (eg. SFR > 10)
- Consistent with decreasing QSO contribution of ionizing background at low-z.
- Future Work: investigate z=3 LBG with known LyC