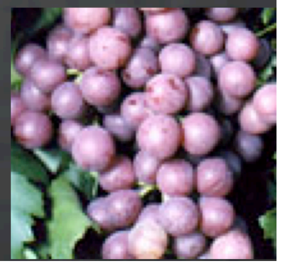
Connection between UV sources and reionization:

- Pop III objects?
- Clustering
- UV escape? Winds? Surface brightness?
- Old stellar populations? Earlier reionization…?
- dwarf galaxies, large galaxies …?

Star-forming galaxies at z~6

Sangeeta Malhotra,
James Rhoads, Nimish Hathi, Nor Pirzkal
Steve Finkelstein, Junxian Wang
GRAPES & PEARS teams



Need to go faint:

- Go back to redshift $z > 6$ and account for photons needed for reionization
- See ordinary galaxies, i.e. fainter than L*, because they make up most of the photons needed.

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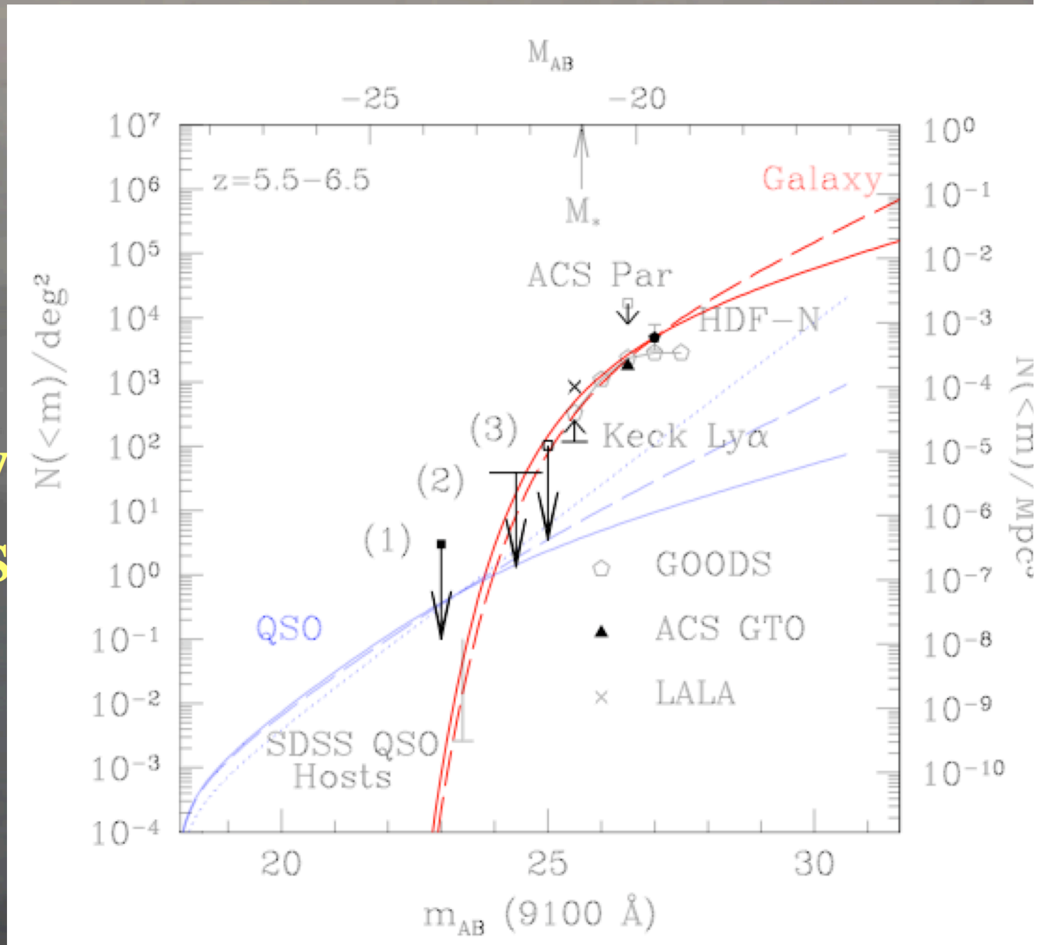

Yan & Windhorst 2004

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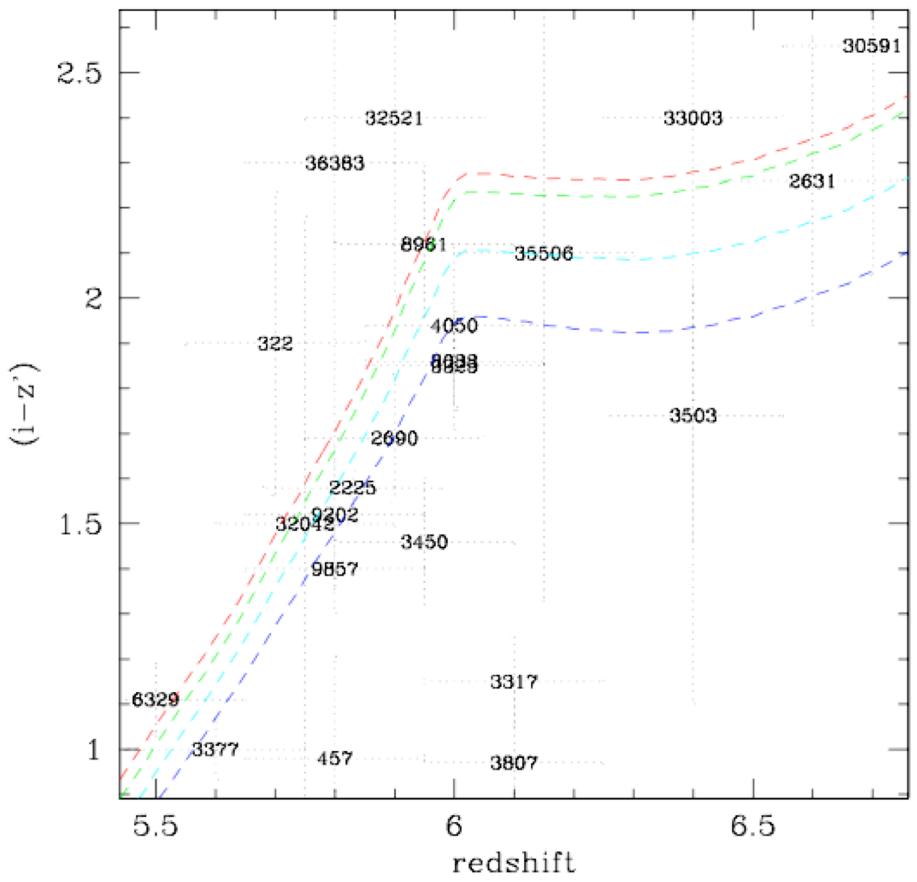
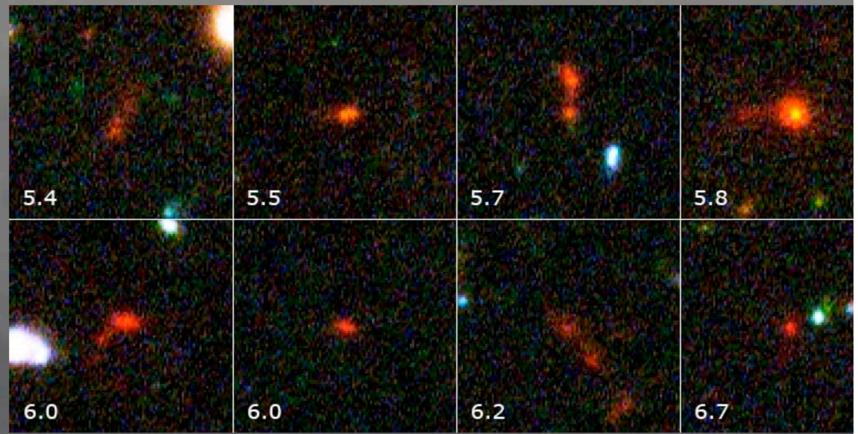
Color selection

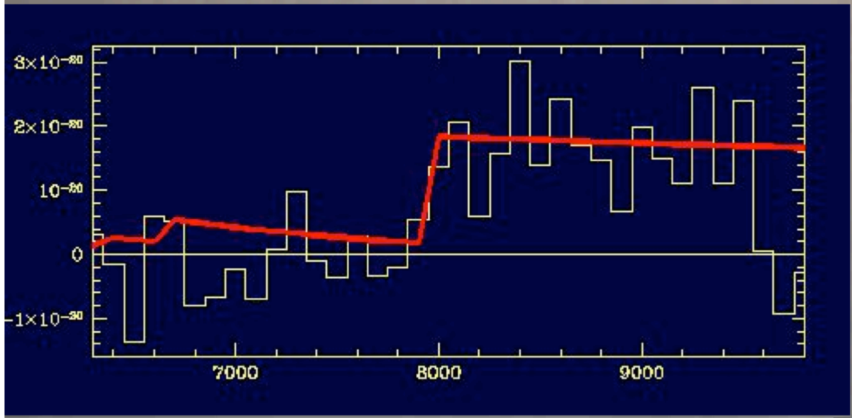




40 orbits of UDF observations with the ACS grism

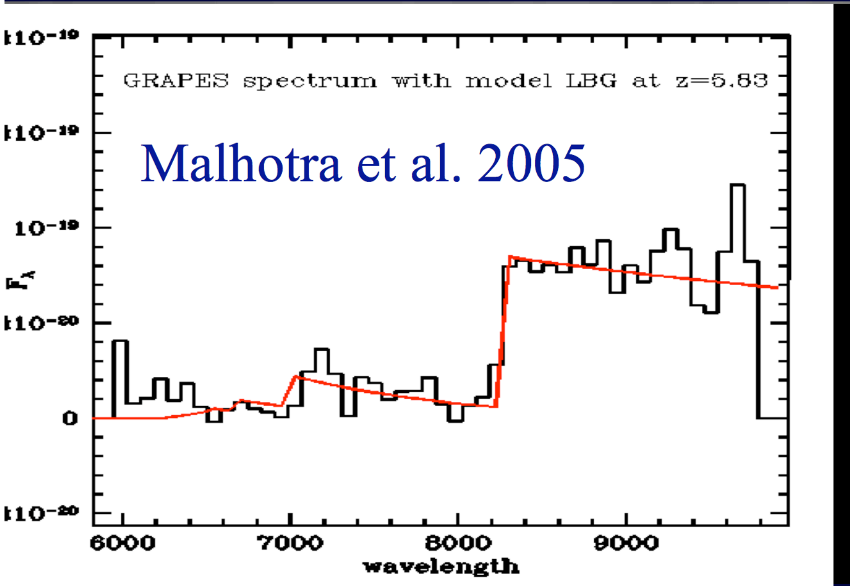
- Spectra for every source in the field.
- Good S/N continuum detections to I(AB) ~ 27 - about 2 magnitudes deeper than ground-based. about 15% of UDF sources ~ 1500 spectra.
- Spectral identification of every 4<z<7 object to I(AB)=27
- Have made reduced spectra public, available from HST archives:
- http://archive.stsci.edu/prepds/udf/udf_hlsp.html
- Clickable map of HUDF at wwwgrapes.dyndns.org

High redshift galaxies

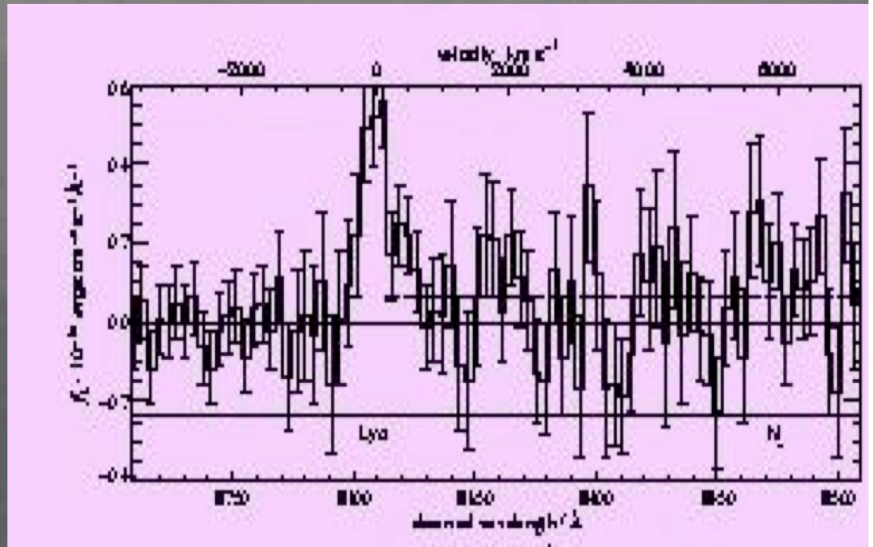


z=5.5, z′ =26.9

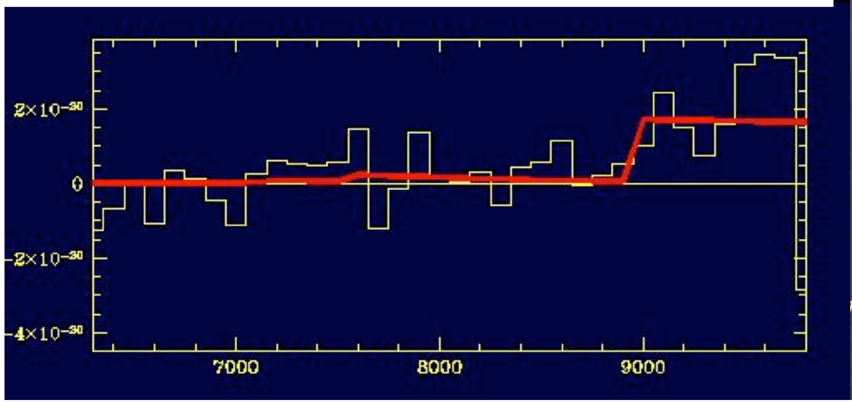
With GRAPES we can spectroscopically confirm LBGs to z’(AB)=27-28 depending on the redshift.



z=5.8, z′=25.1

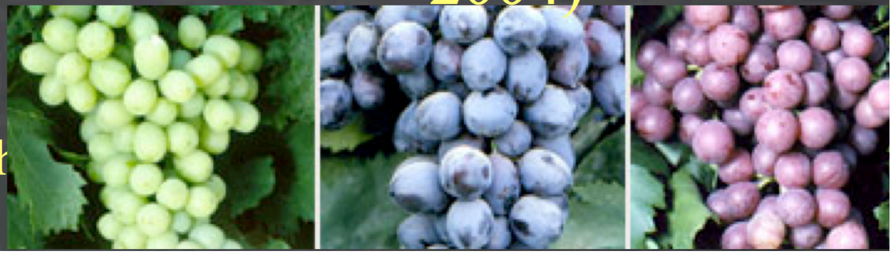


(Stanway et al. 2004)

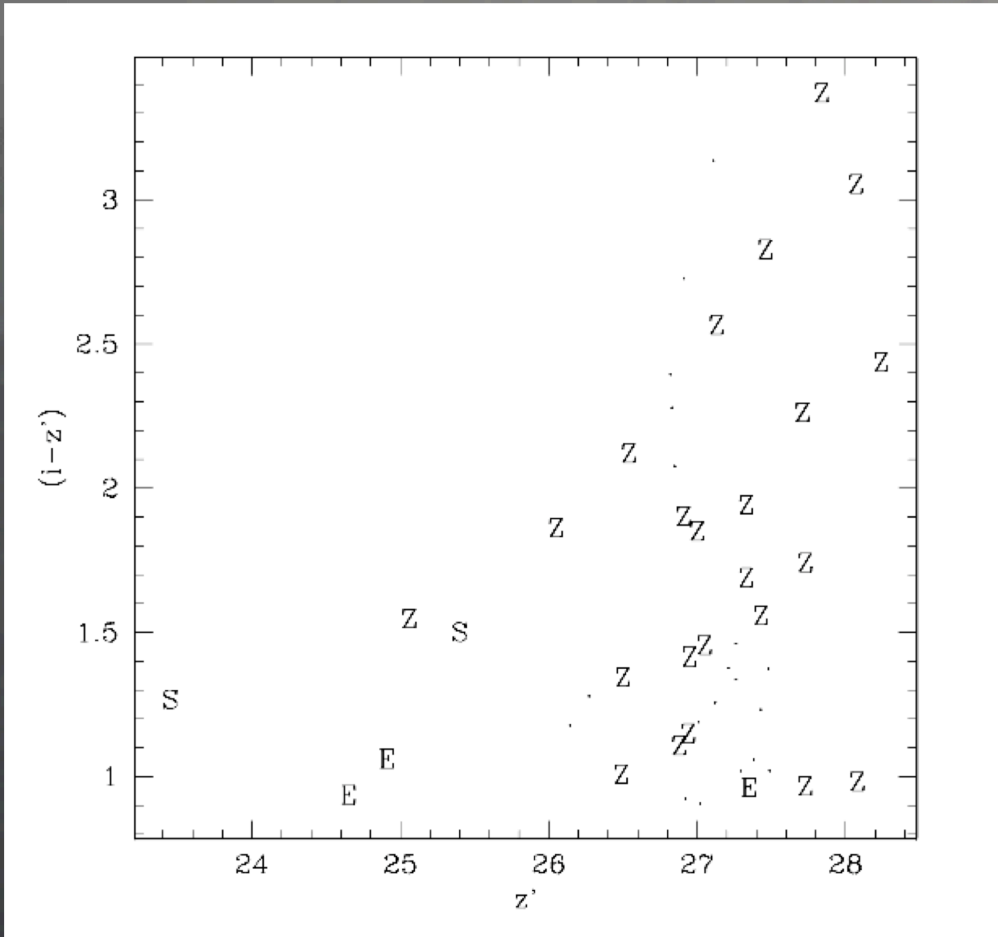


z=6.4, z′ =27.8

al through

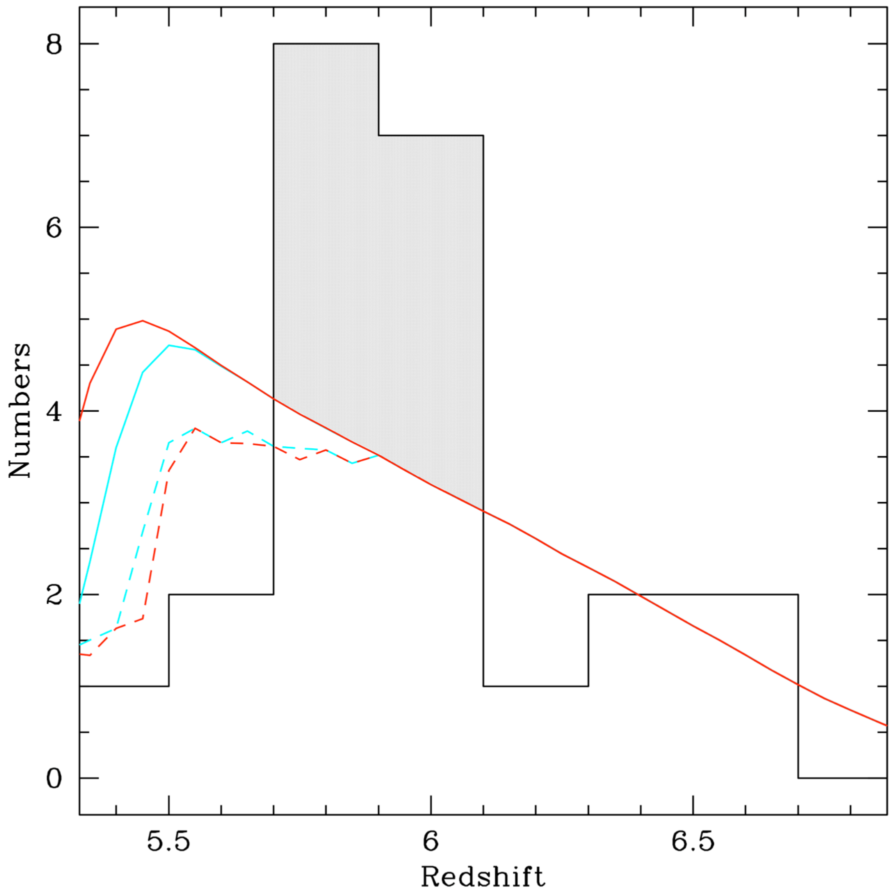


Reliability of (i-z) selection



- 80% for (i-z) > 0.9
- 100% for (i-z) > 1.3

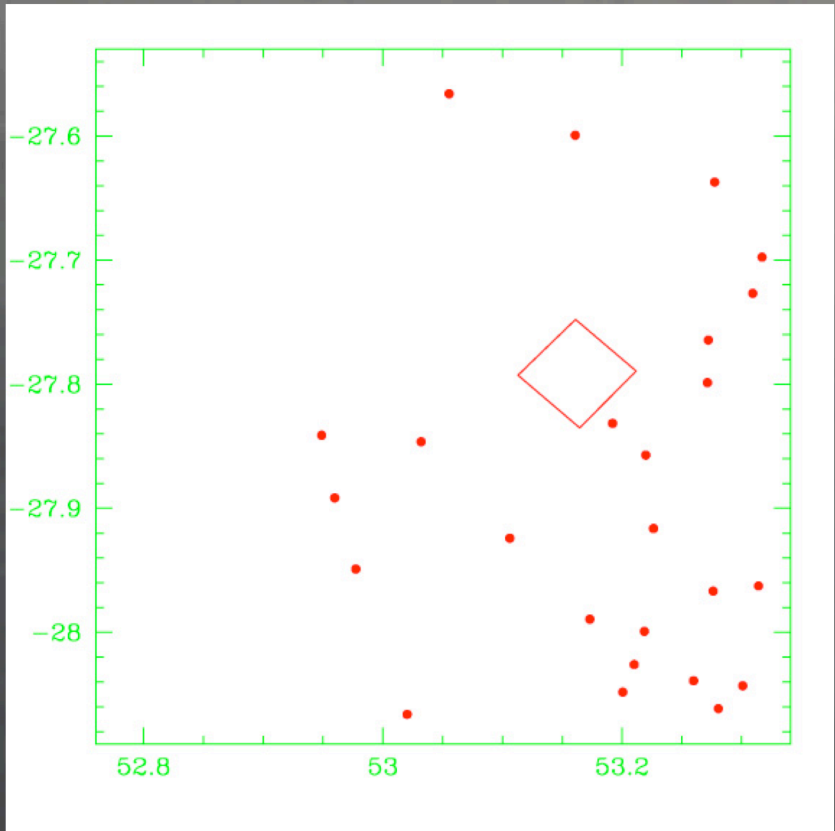
A spike in the Redshift distribution
(Malhotra et al. 2005)



Comparison of observed redshift distribution (histogram) vs. expected numbers

The spike at z~6 is at least a factor of two over-dense.

Deep probe vs. Flat-wide probe

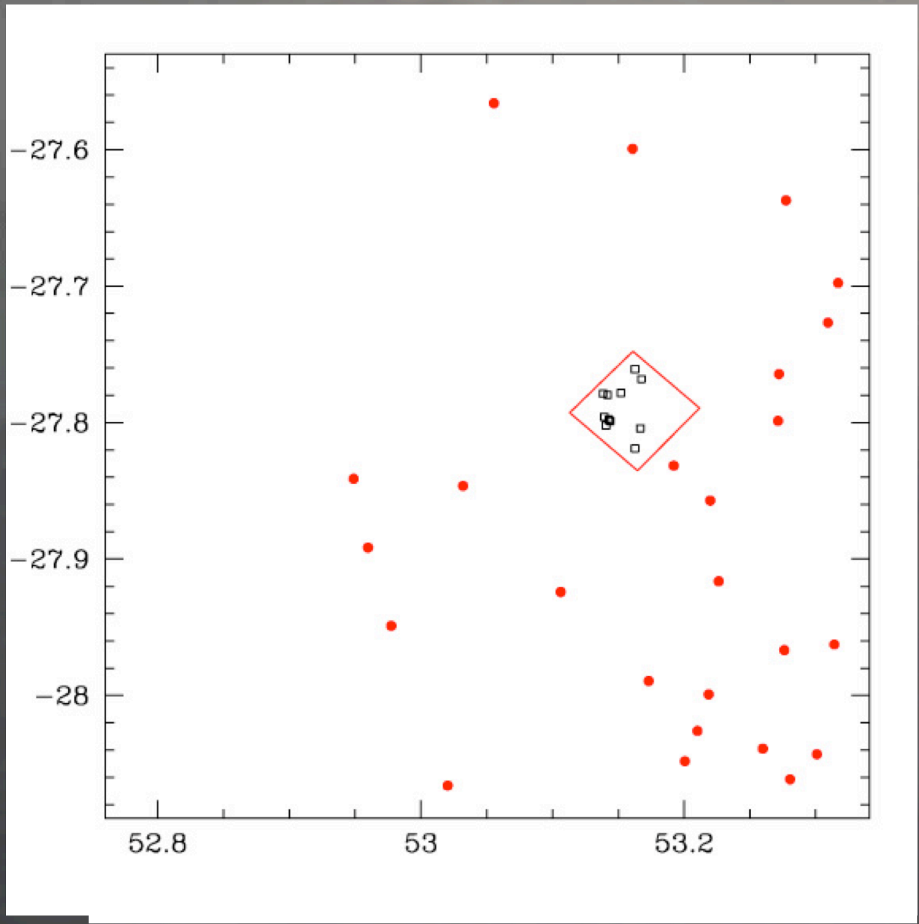


- Ly-alpha emitters at z=5.7-5.77 observed with mosaic at CTIO
  - (36'x36' = 13x13 Mpc)

(Wang, Malhotra & Rhoads 2005)

- Inhomogeneous distribution
  - UDF is at the edge of it

Deep probe vs. Flat-wide probe



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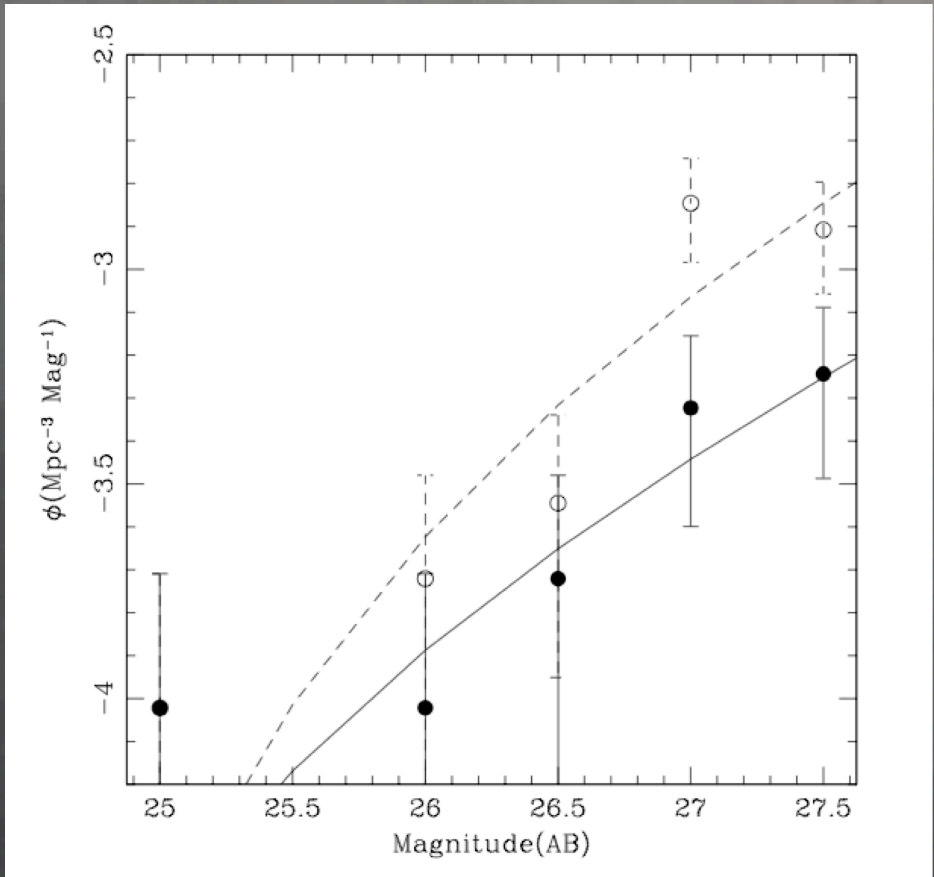
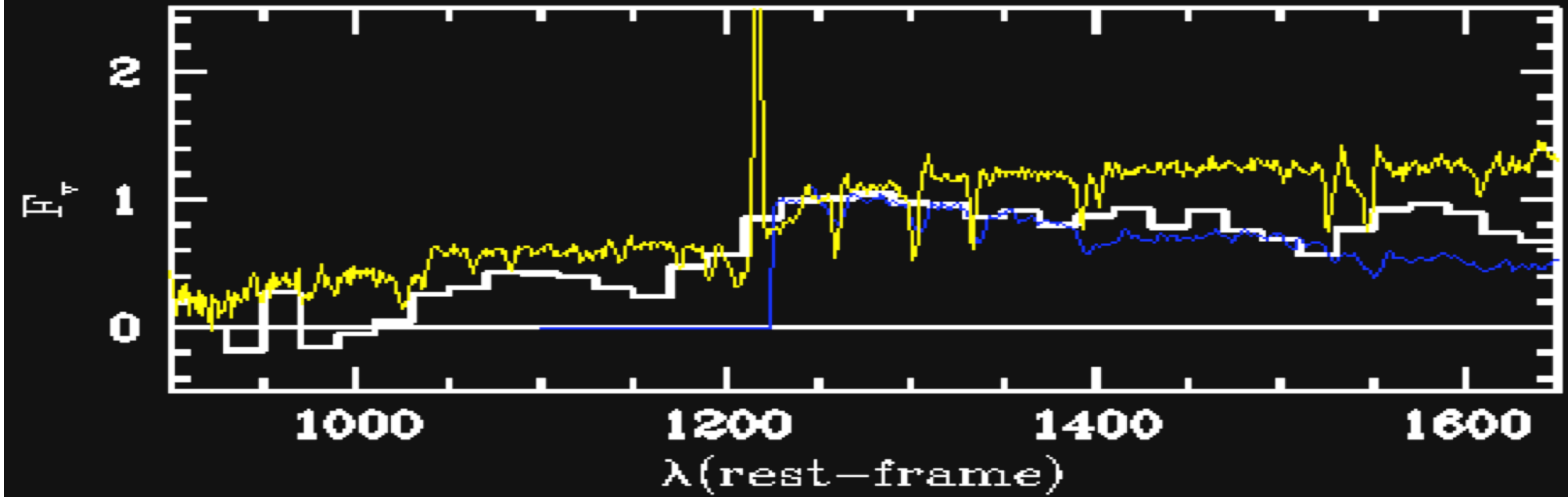
Luminosity function at the overdensity



- Star-formation rate density for this over-dense region is 2-4x10^{-2} M_O/Mpc^3/year
- This is enough to drive re-ionization in this "local" over-density.

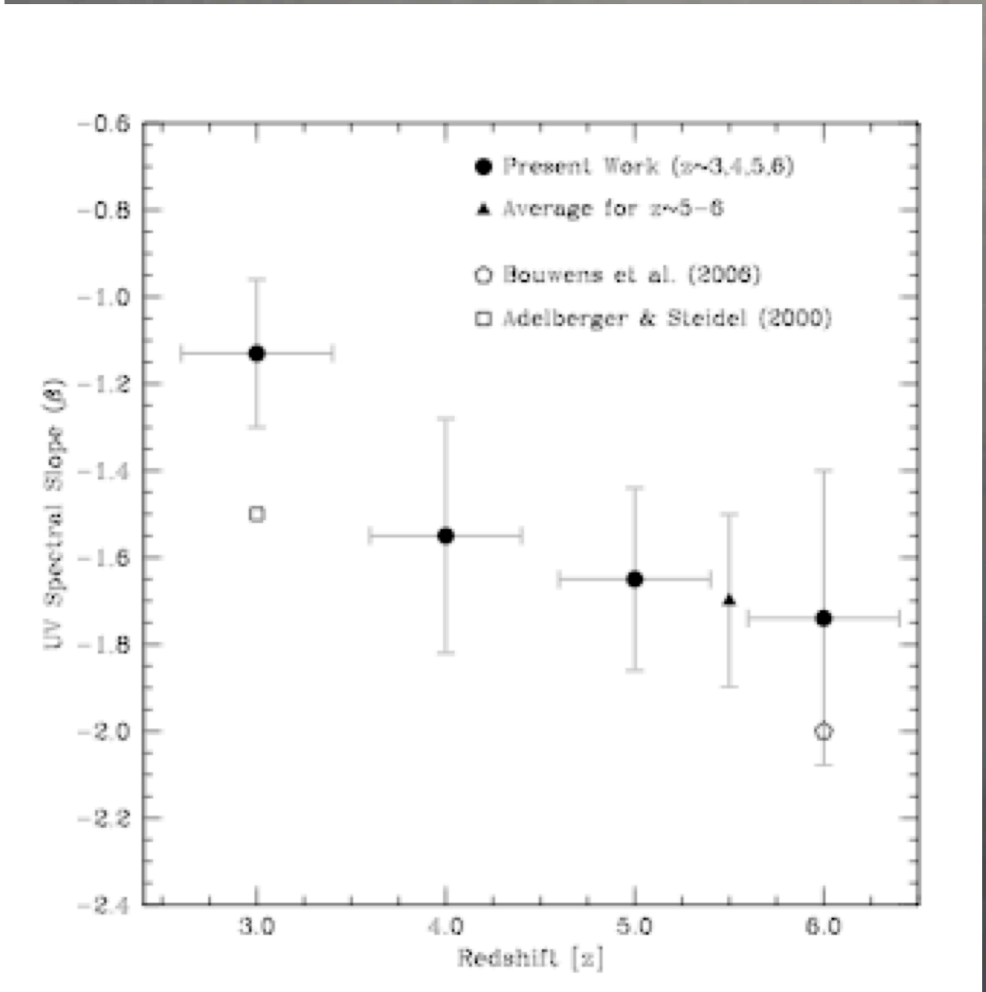
Colors of the galaxies =>
stars that make up these galaxies



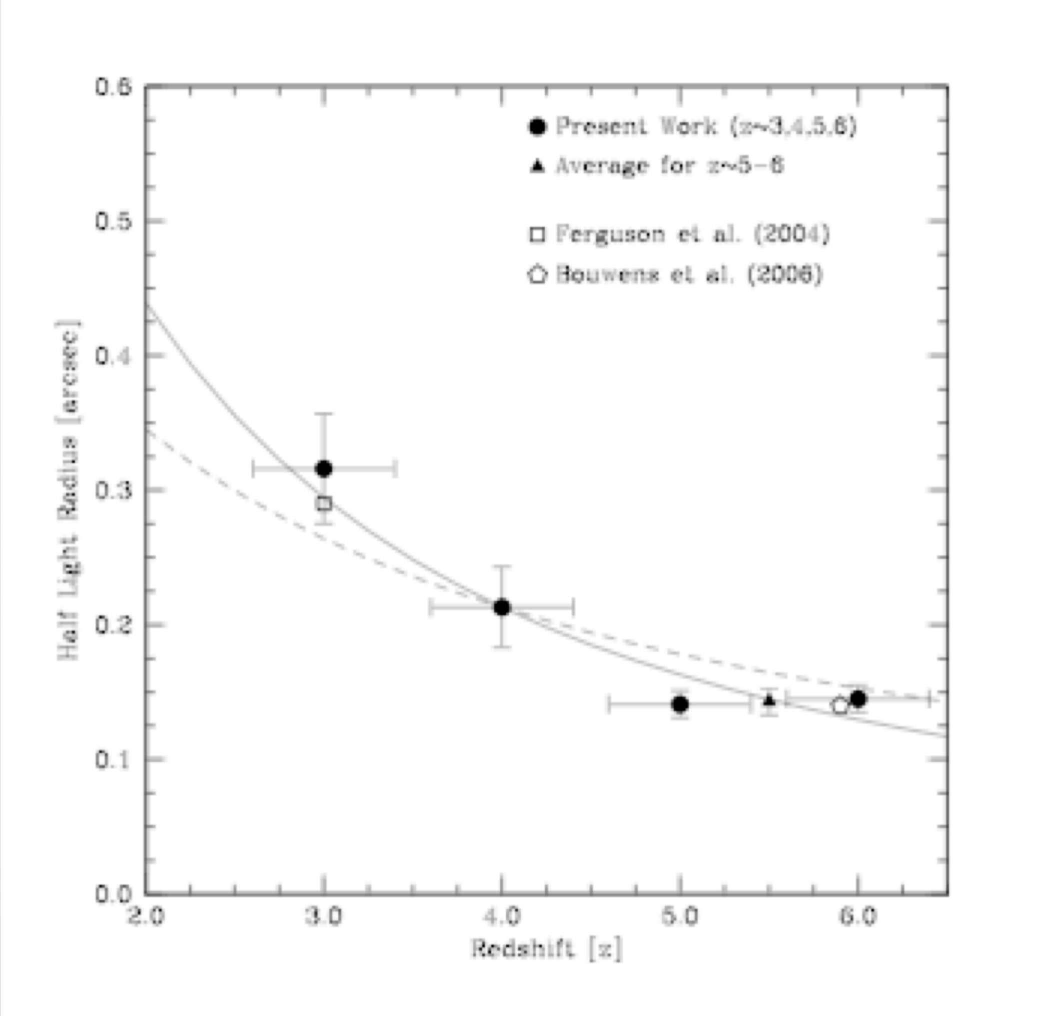
The composite spectrum of z=4-5 objects in the UDF is shown by the white line. The Lyman break sample (Shapley et al.) at z=3 is shown in yellow for comparison and one of the bluest nearby galaxies NGC 1705 is shown in blue.

Surface brightness of z~5-6 galaxies
(Hathi, Malhotra, Rhoads 07)

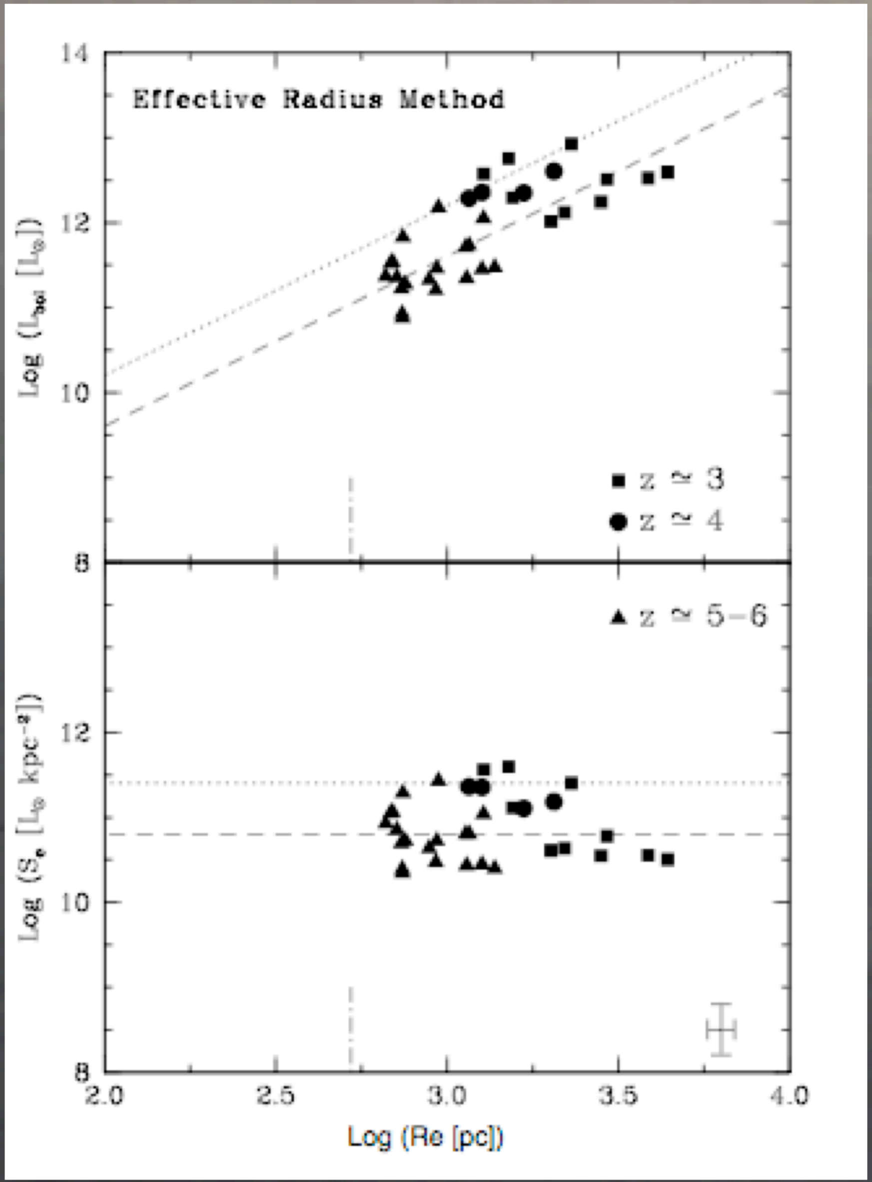
- Surface brightness ➡ star-formation intensity
  - physical quantity regardless of the size of the system
  - Easily comparable to z=0 starbursts or ordinary galaxies.
- Meurer et al . 1997 showed that the star-formation intensity of ~3-4 LBGs is the same as z~0 starbursts.
- We extend the work to z > 6 in the HUDF
  - Higher redshift sample
  - Better surface brightness sensitivity
  - Better spatial sampling with ACS etc.



- Higher redshift sources are bluer!
- Could be due to lower extinctions at high redshifts.

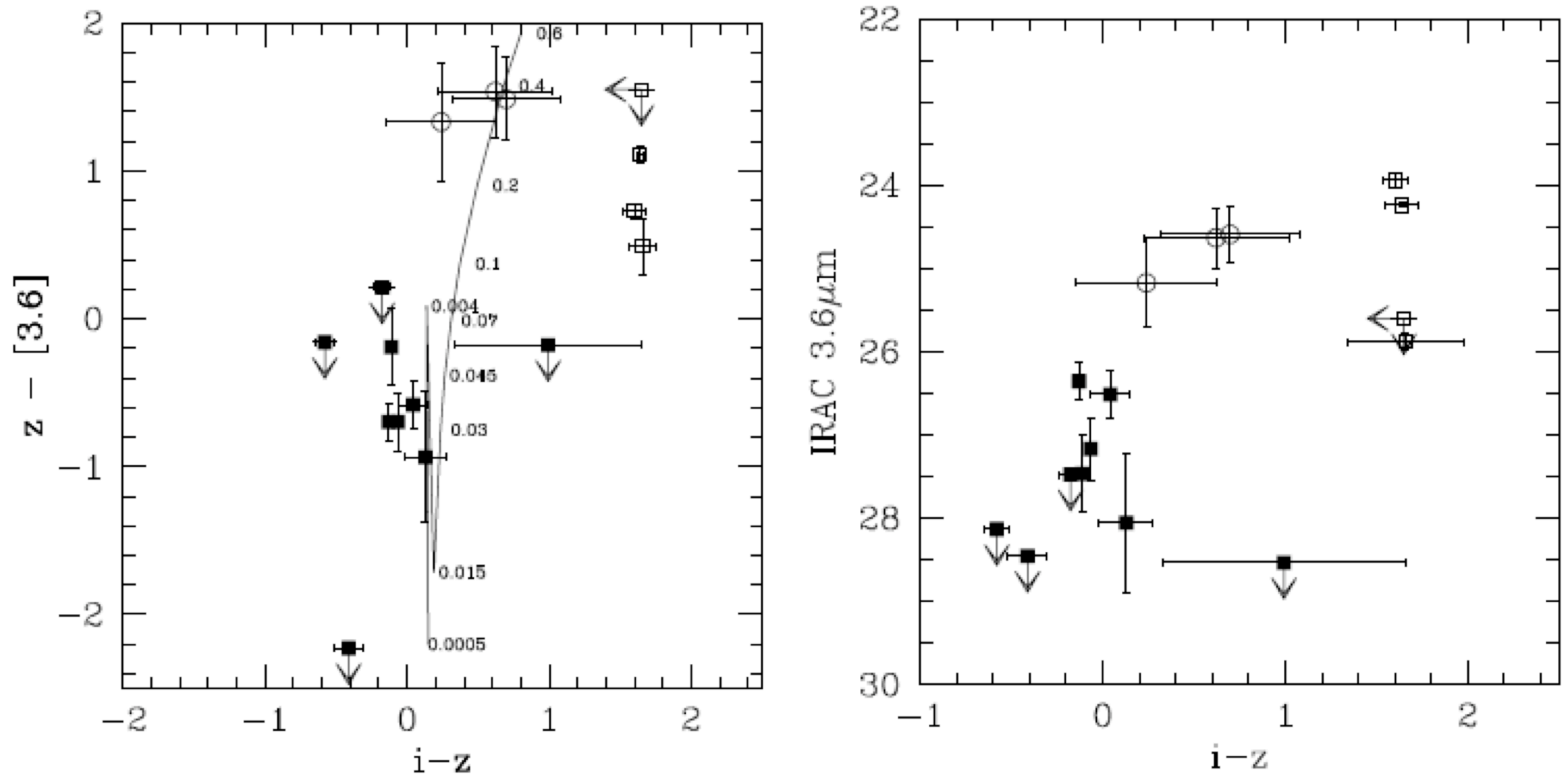


11 June 2007 HI Survival through cosmic time

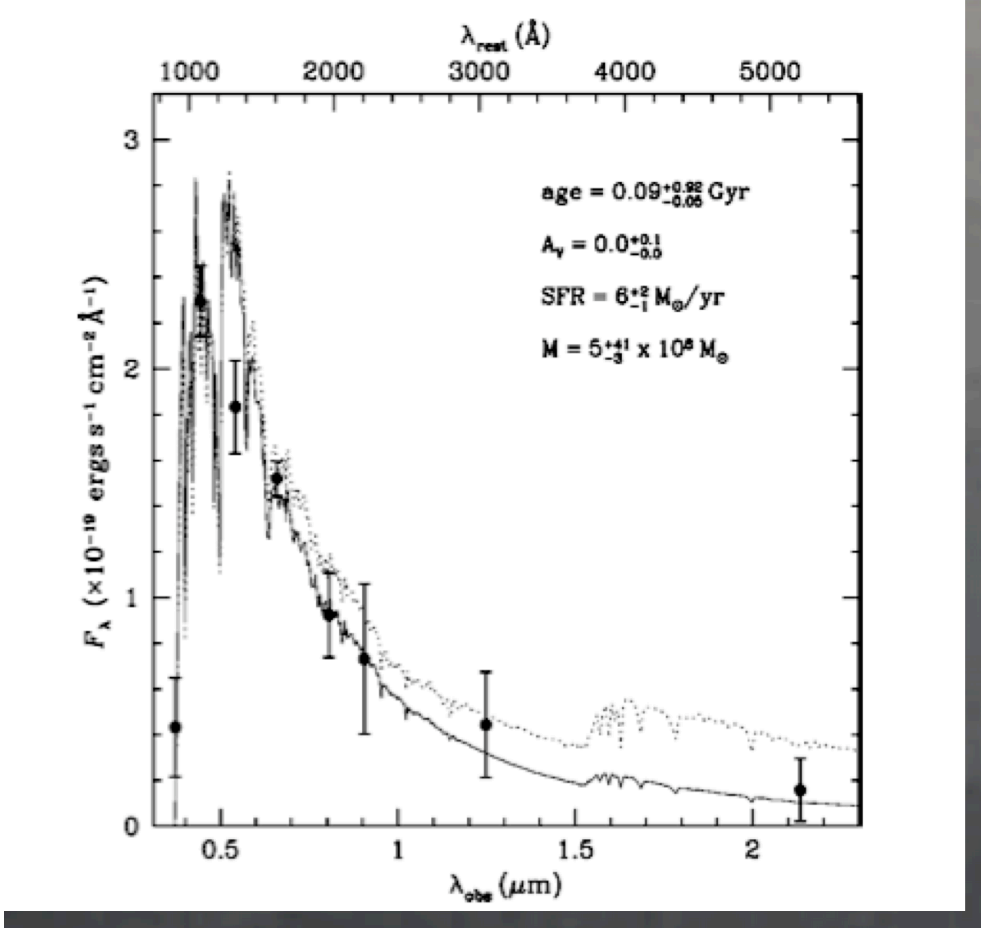


- Z=3,4,5,6
- Surface brightness is the same
- Luminosity goes down with redshift
- Sizes are smaller at higher redshifts

Spitzer observations of lyman- α emitters (Pirzkal et al. 2007, astro-ph 0612513)



More support for young galaxies hypothesis



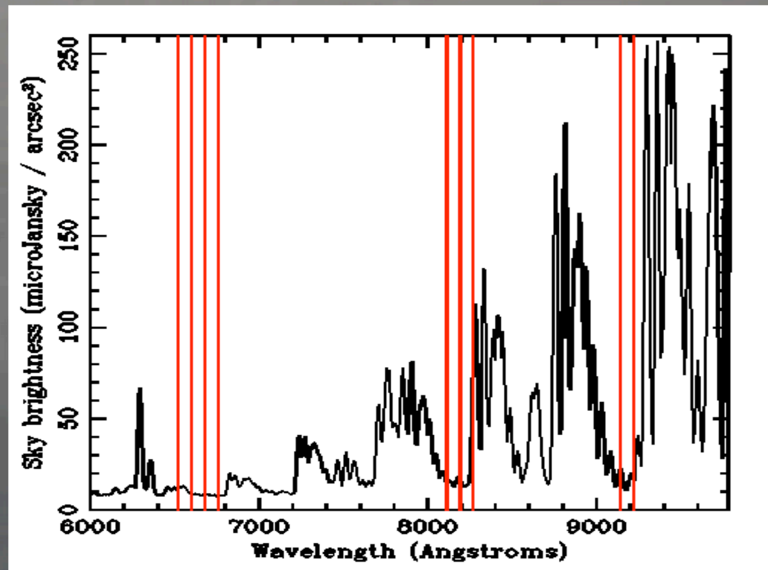
- Blue continuum colors of Ly-a emitters imply ~50% are galaxies in the first 10 $^{6.5}$ years of formation (Veneman's thesis)
- Gawiser et al. 2006, z=3.1 (left)
- Nilsson et al. (submitted)

Summary: what we have learned about z~6 sources

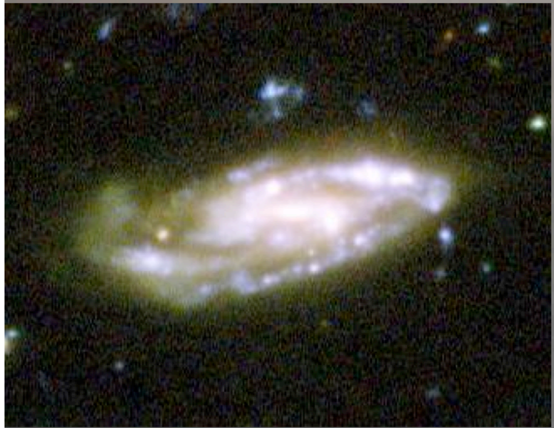
- They can be very strongly clustered
- UV Colors are blue but not abnormally so.
- The surface brightness (or star-formation intensity) of z~6 sources is similar to that of z~0, z~3, z~4 starbursts/LBGs.
- The colors are on the average significantly bluer, and sizes smaller
- Lyman-alpha galaxies, which form about half of known high redshift galaxies show young ages and low masses.

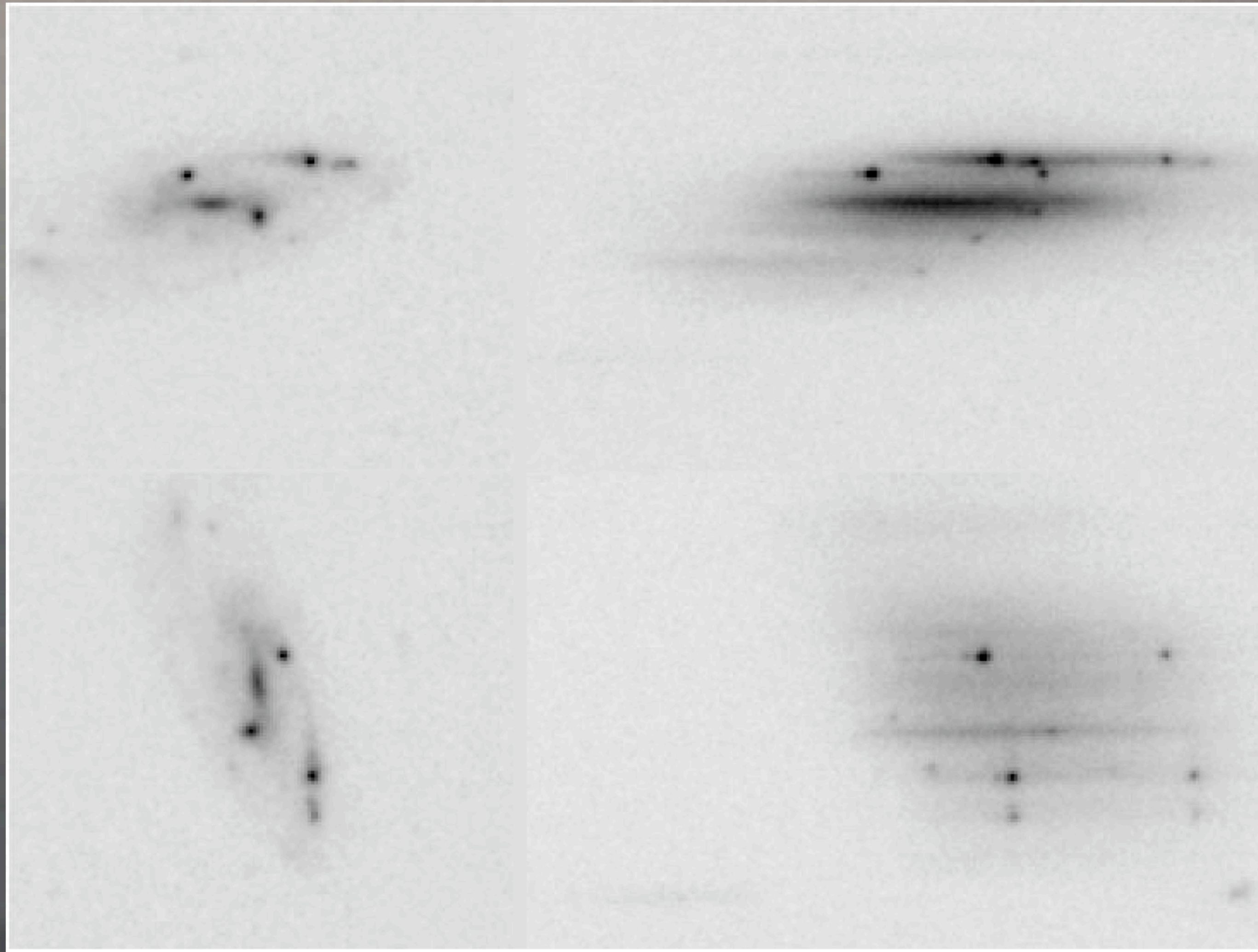
Advantages of HST/ACS combination:

- Low sky background from space
- Red sensitivity of the ACS
- High redshift galaxies are compact, spatial resolution of HST helps.
- Contiguous wavelength/redshift coverage, unlike ground based instruments.
- Spatial resolution shows interesting structures that would be missed with ground based spectroscopy.



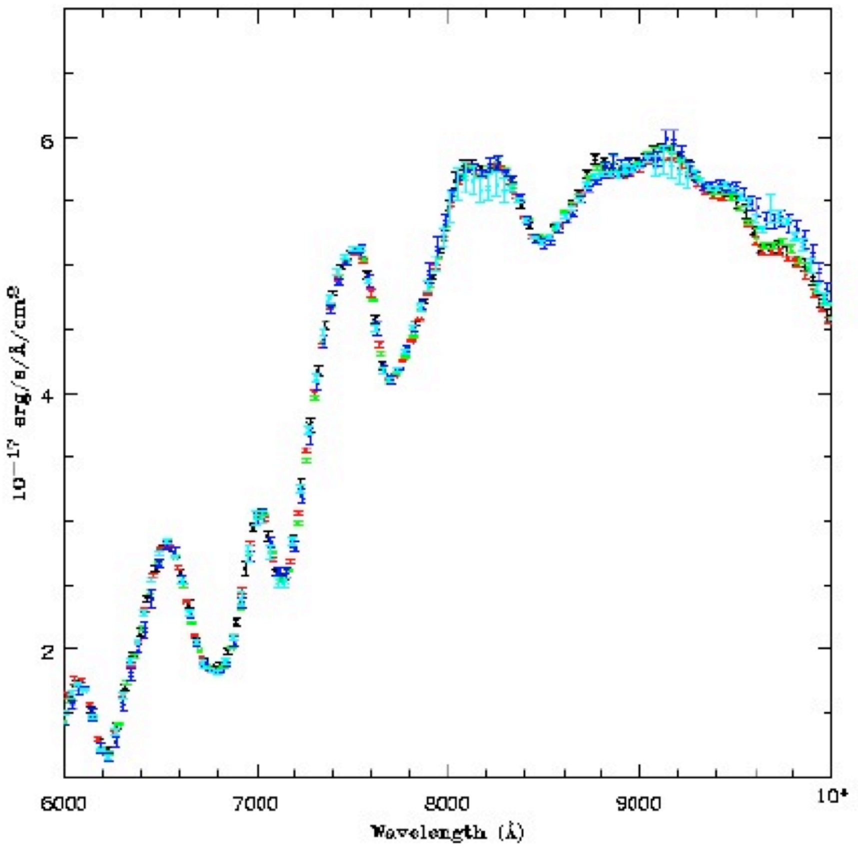
A Spiral galaxy at z=0.3





Direct image | Dispersed image

Experimental design (Pirzkal et al. 2004)

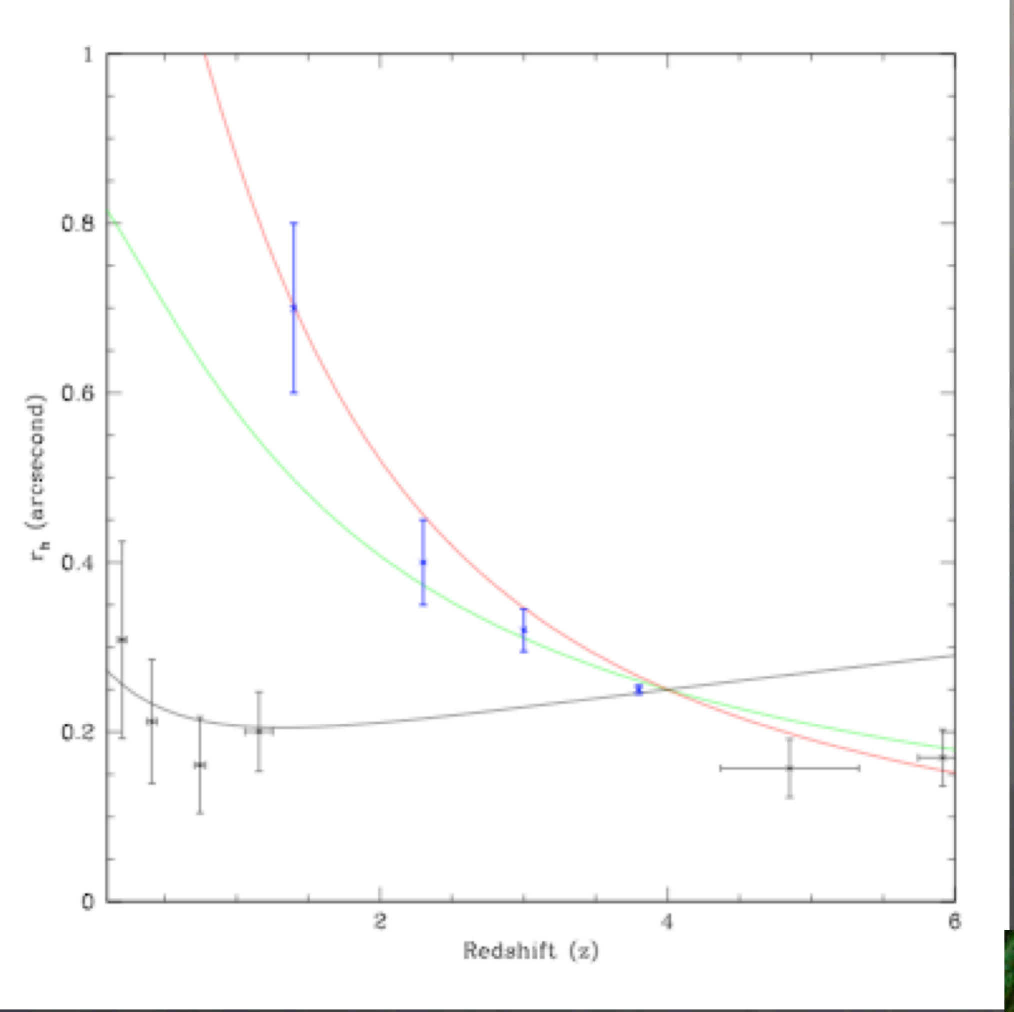


Four orients: large seperation of 90 degrees and small of 8 degrees: 0, 8, 90, 98 degrees orient. To disentangle overlapping spectra.

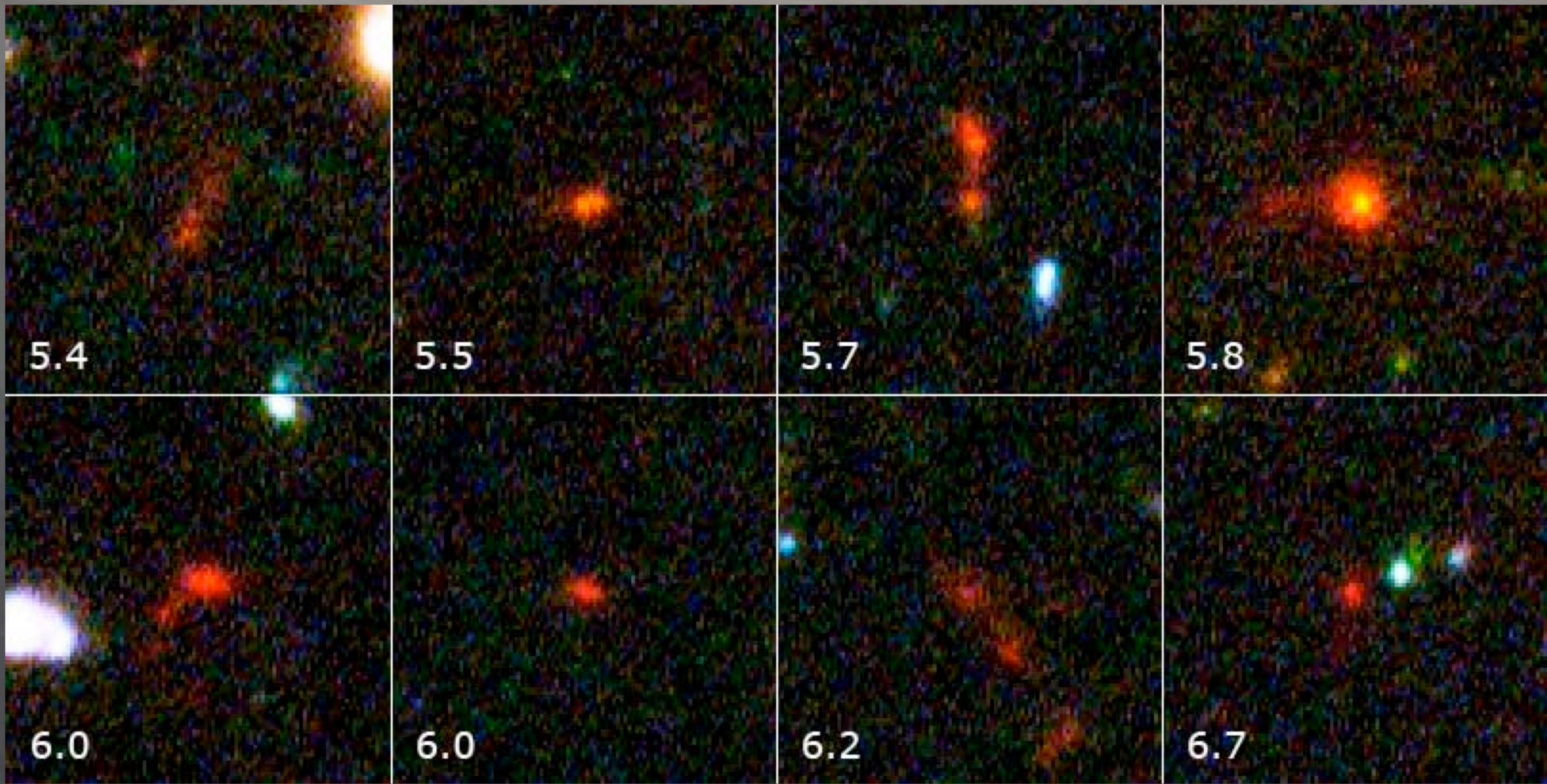
The agreement between the four orients in wavelength and flux demonstrate accurate flat-fielding and wavelength calibration.

Size evolution of emission line selected objects:

Pirzkal et al. 2005b

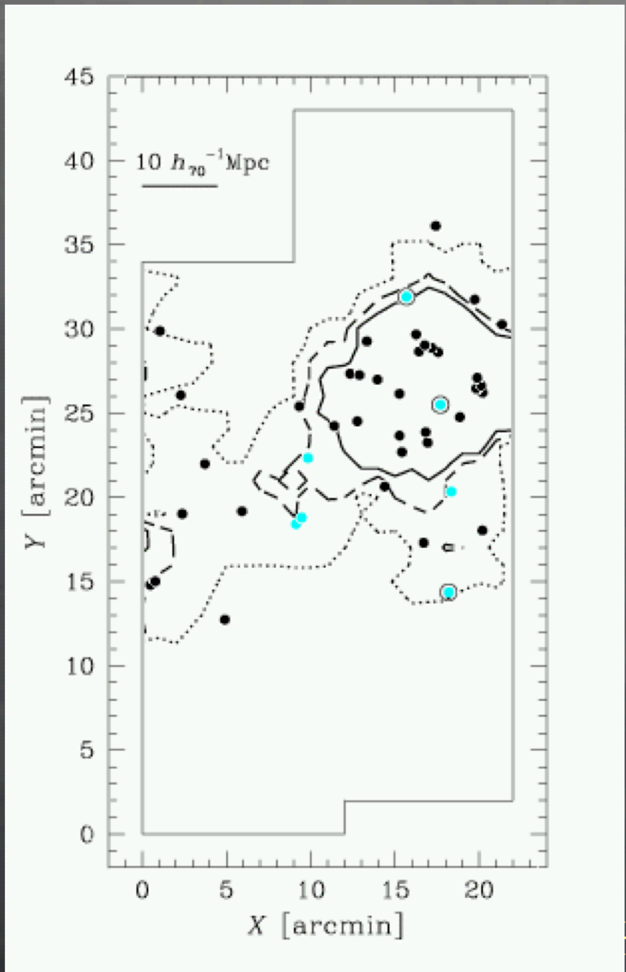


- No discernable size evolution unlike that seen for continuum selected galaxies.
- Selection effect: easy to do spectroscopy of more compact galaxies. But these selection effects cannot account for the difference.

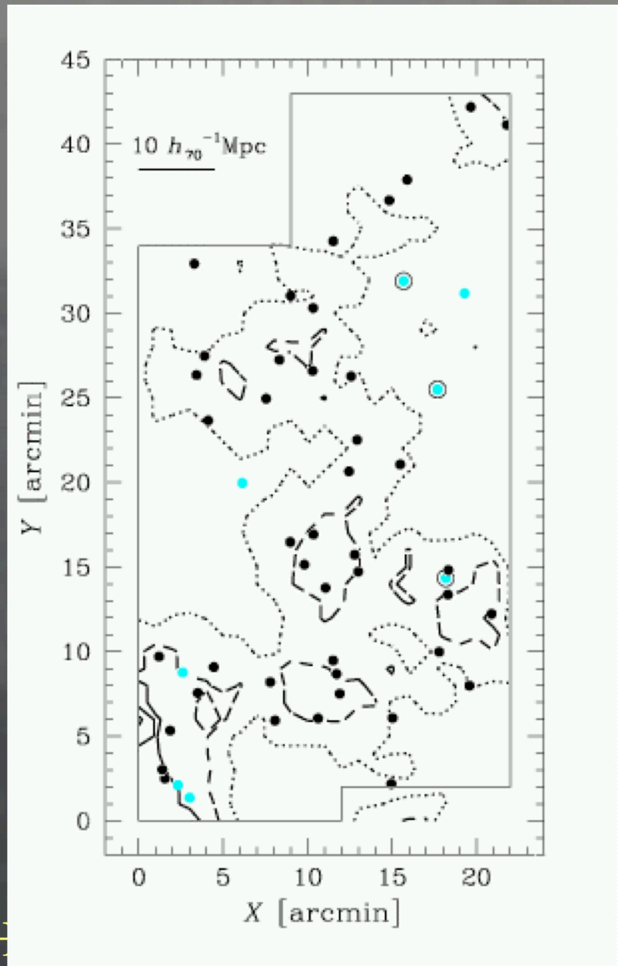


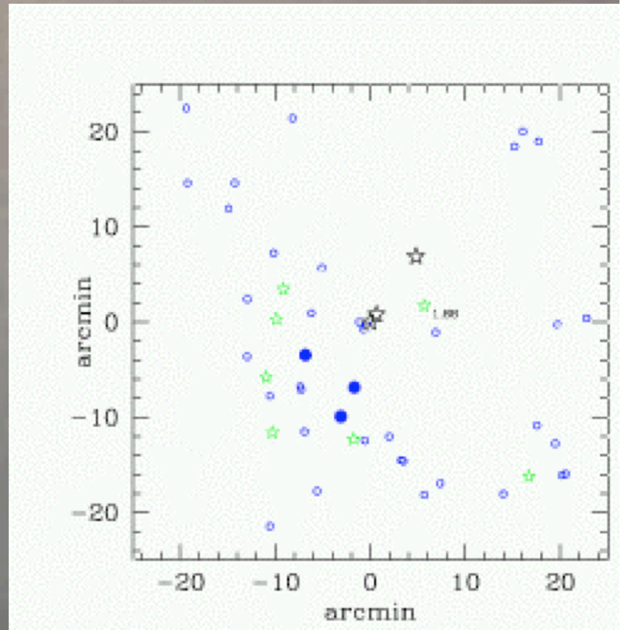
Malhotra et al. 2005

Ouchi et al. z=4.86



Shimasaku et al. z=4.79



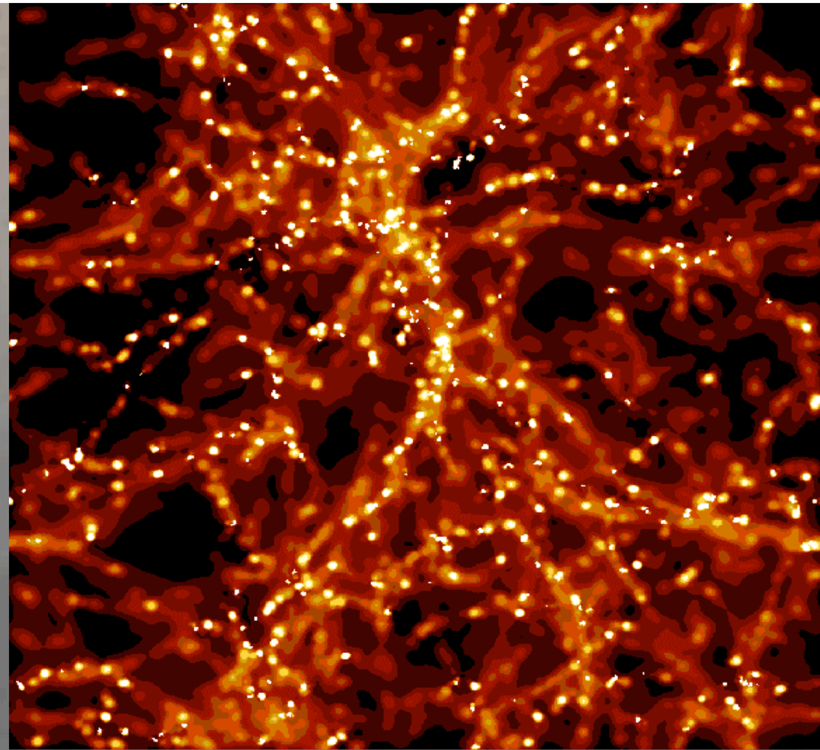


Palunas et al z=3.1

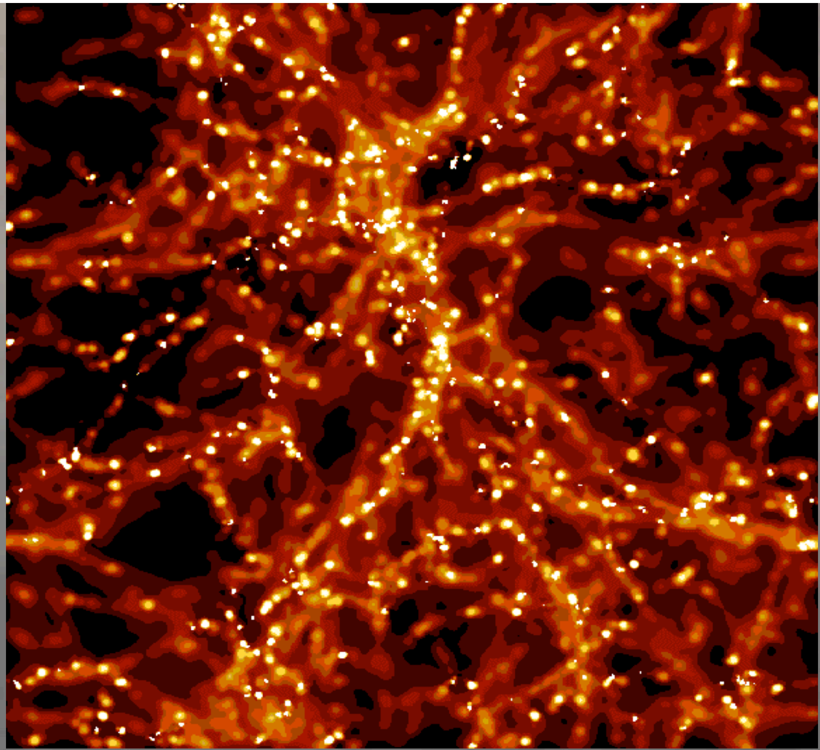
- Steidel et al at z=3.09.
- Campos et al. z=2.4
- Venemans et al. z=4.1

Large Scale Structure at high redshift

Large Scale Structure at high redshift



Large Scale Structure at high redshift



- Cosmological simulations can pinpoint regions of overdensity.

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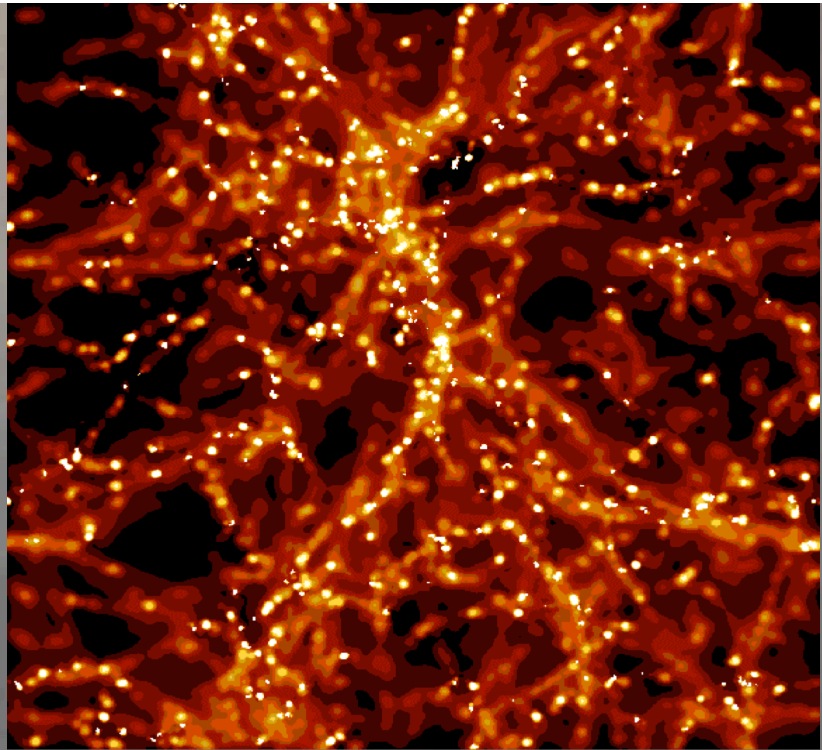
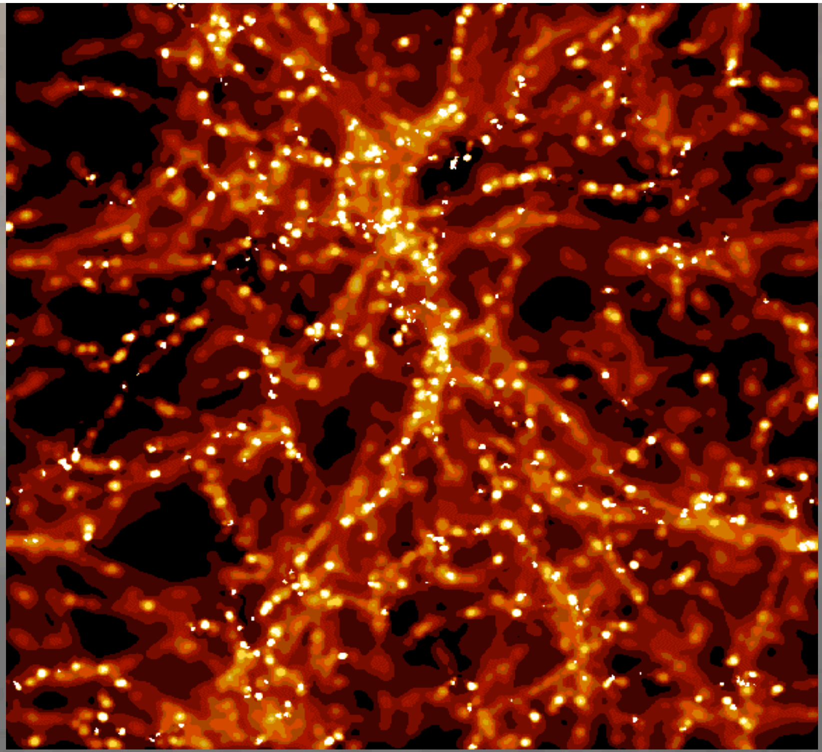


- Cosmological simulations can pinpoint regions of overdensity.
- How does that relate to early star-formation?

Large Scale Structure at high redshift



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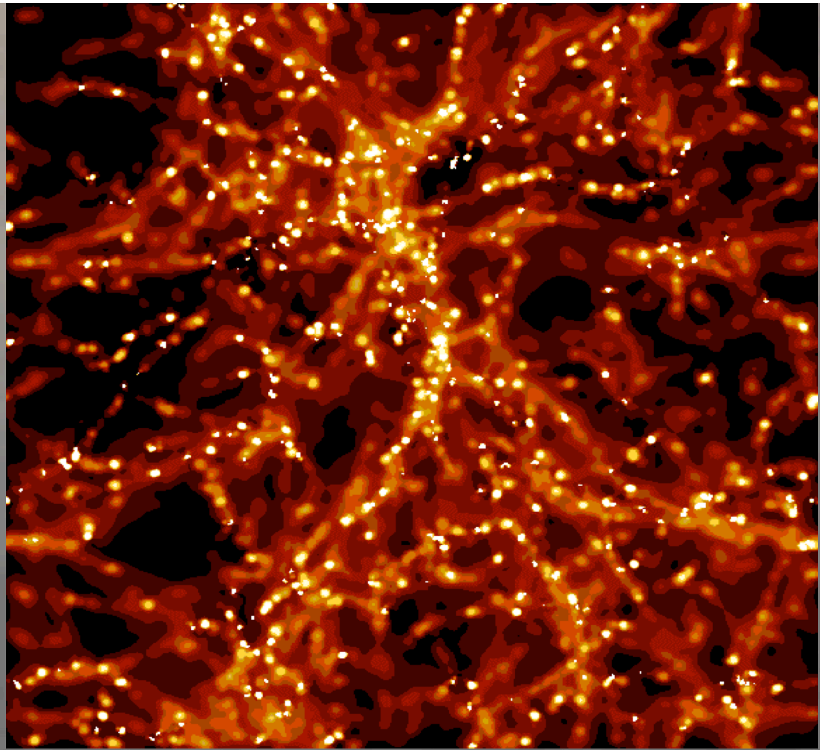
Large Scale Structure at high redshift



Where do stars form?

- Cosmological simulations can pinpoint regions of overdensity.
- How does that relate to early star-formation?

The deepest view of the universe

- 400 orbits with the Advanced Camera for Surveys (PI Beckwith)
- In B, V, i', z'
- One field 210"x210"
- Two epochs about 75 days apart: variability, proper motion studies.
- 10,000 objects at s/n > 10.
- Parallel fields in the IR with NICMOS.
- NICMOS coverage of about half the field in J and H bands (PI: Thompson)
- Low resolution spectra with ACS Grism (PI: Malhotra)

GRism ACS Program for Extragalactic Science (GRAPES)

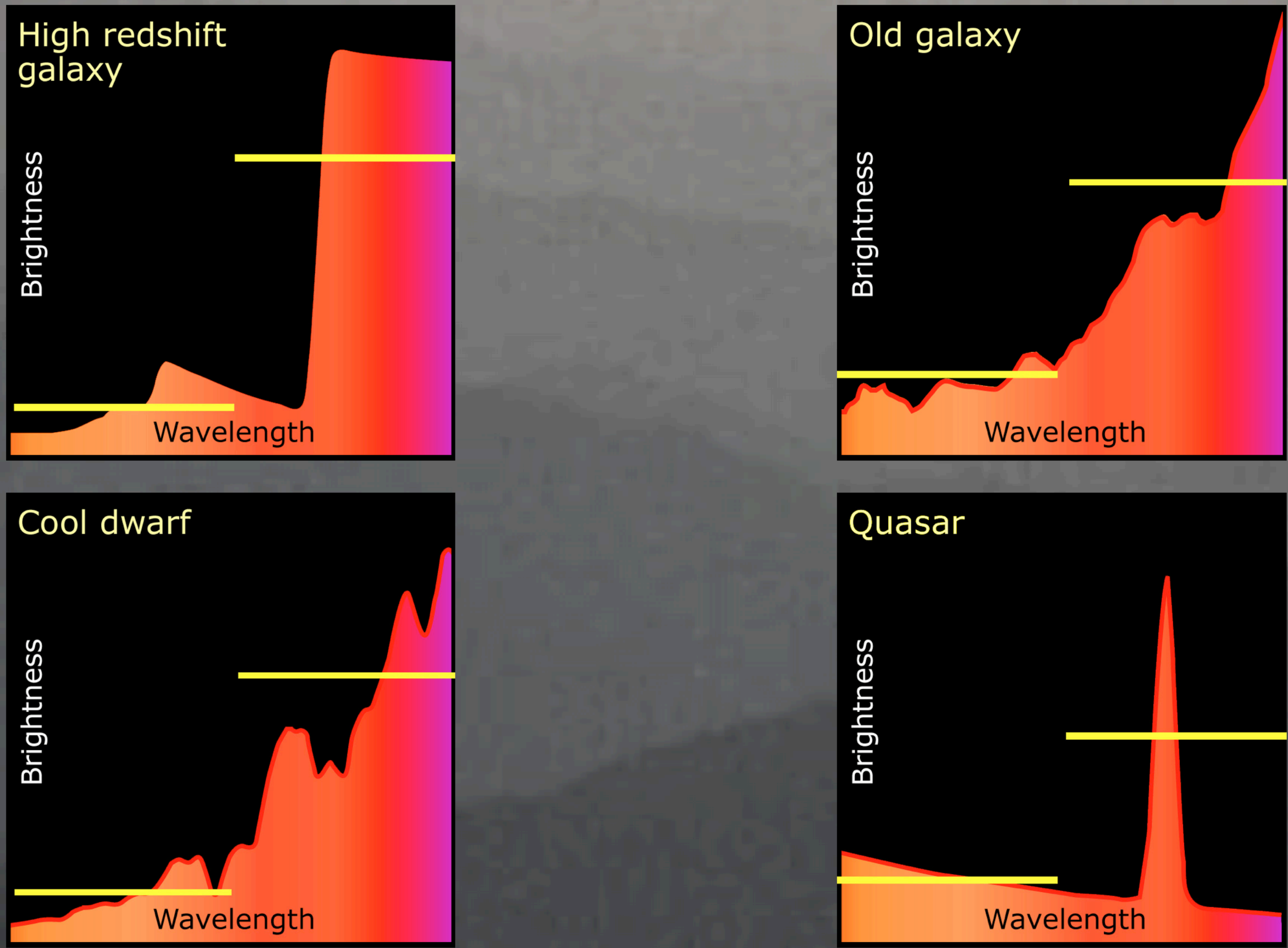
Deepest Unbiased Spectroscopy yet. I(AB) < 27.5

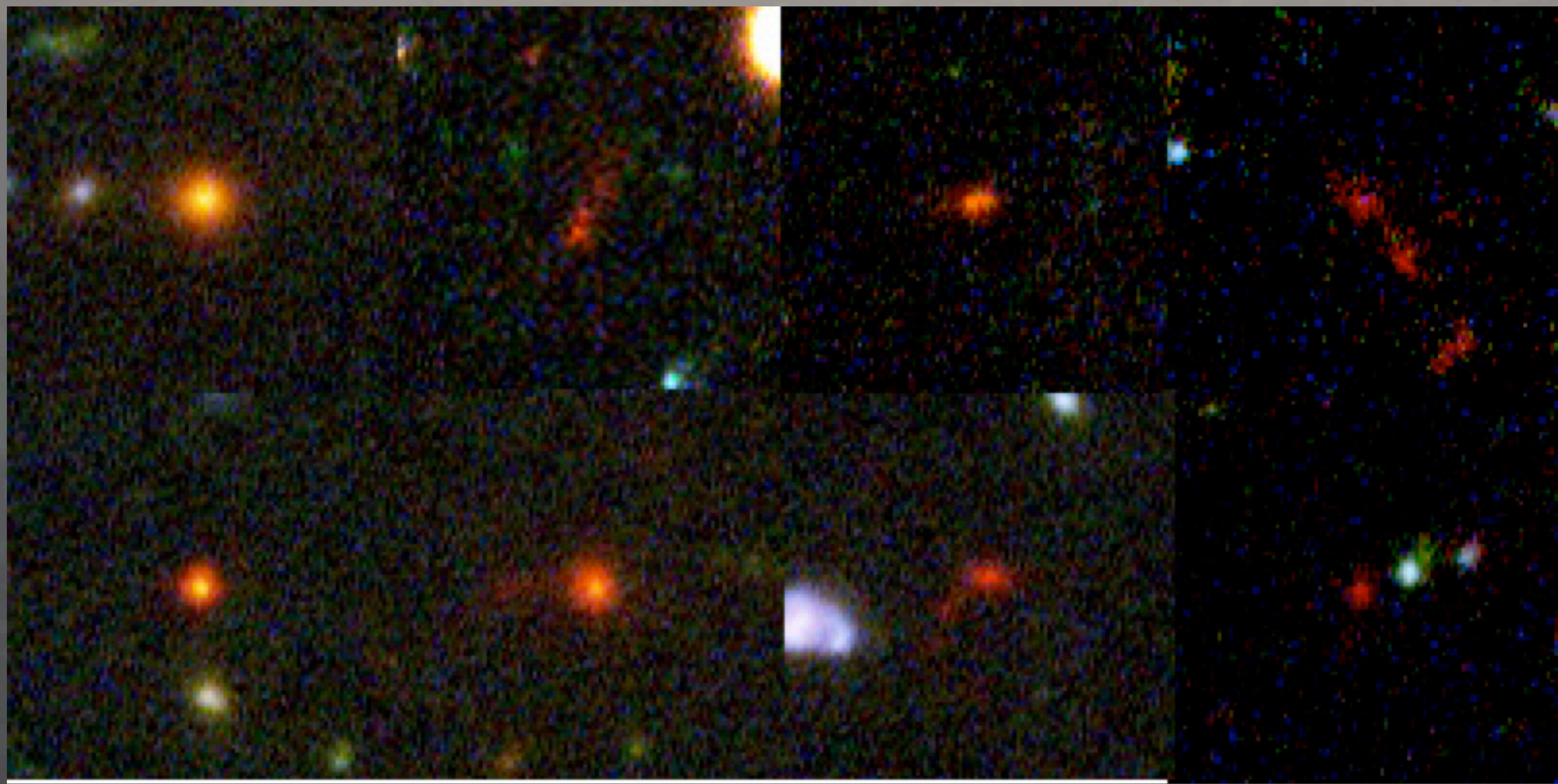
To match the deepest imaging (Hubble Ultra Deep Field)

Team: S. Malhotra, James Rhoads, Nor Pirzkal, Chun Xu

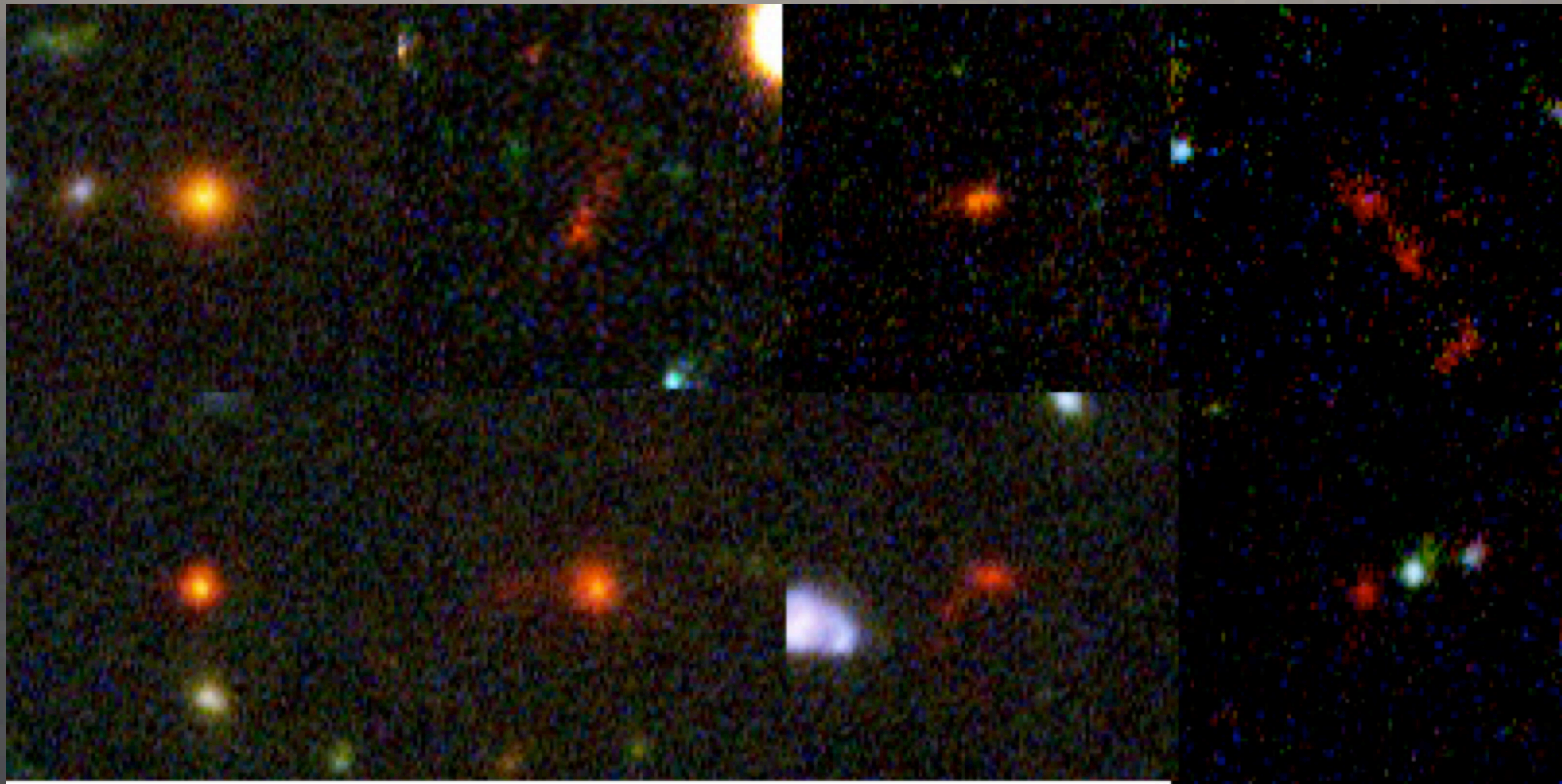
A. Cimatti, E. Daddi, H. Ferguson, J. Gardner, C. Gronwall, Z. Haiman, A. Koekemoer, L. Moustakas, A. Pasquali, N. Panagia, L. Petro, M. Stiavelli, S. di Serego Aligheri, Z. Tsvetanov, J. Vernet, J. Walsh, R. Windhorst, H.J. Yan

Spectra Vs. Color selection





Which of these are not like the others?



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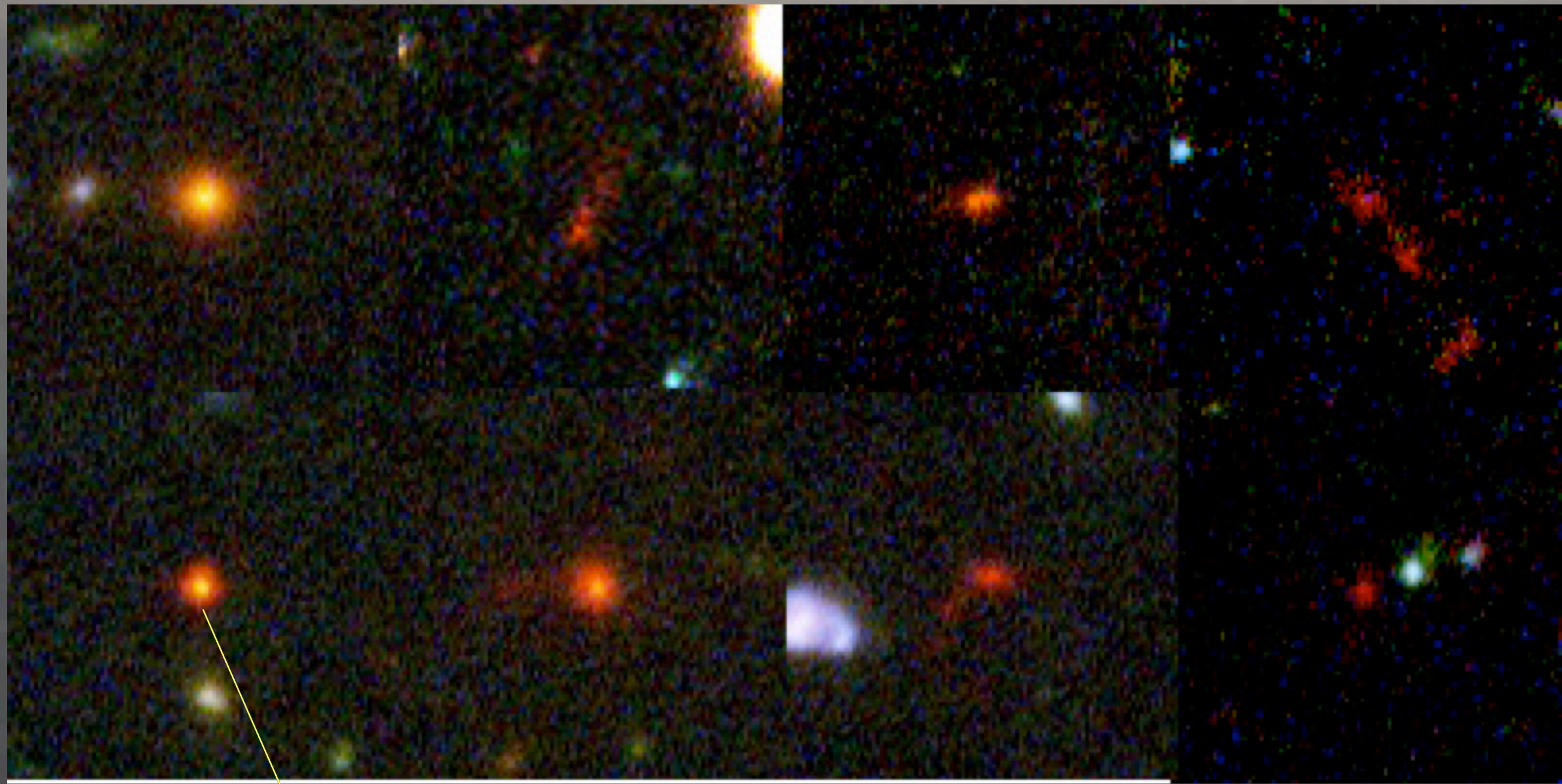

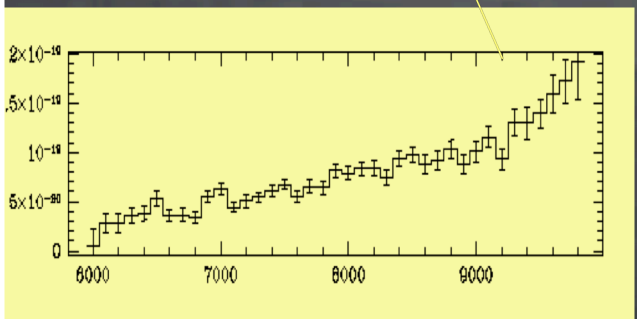

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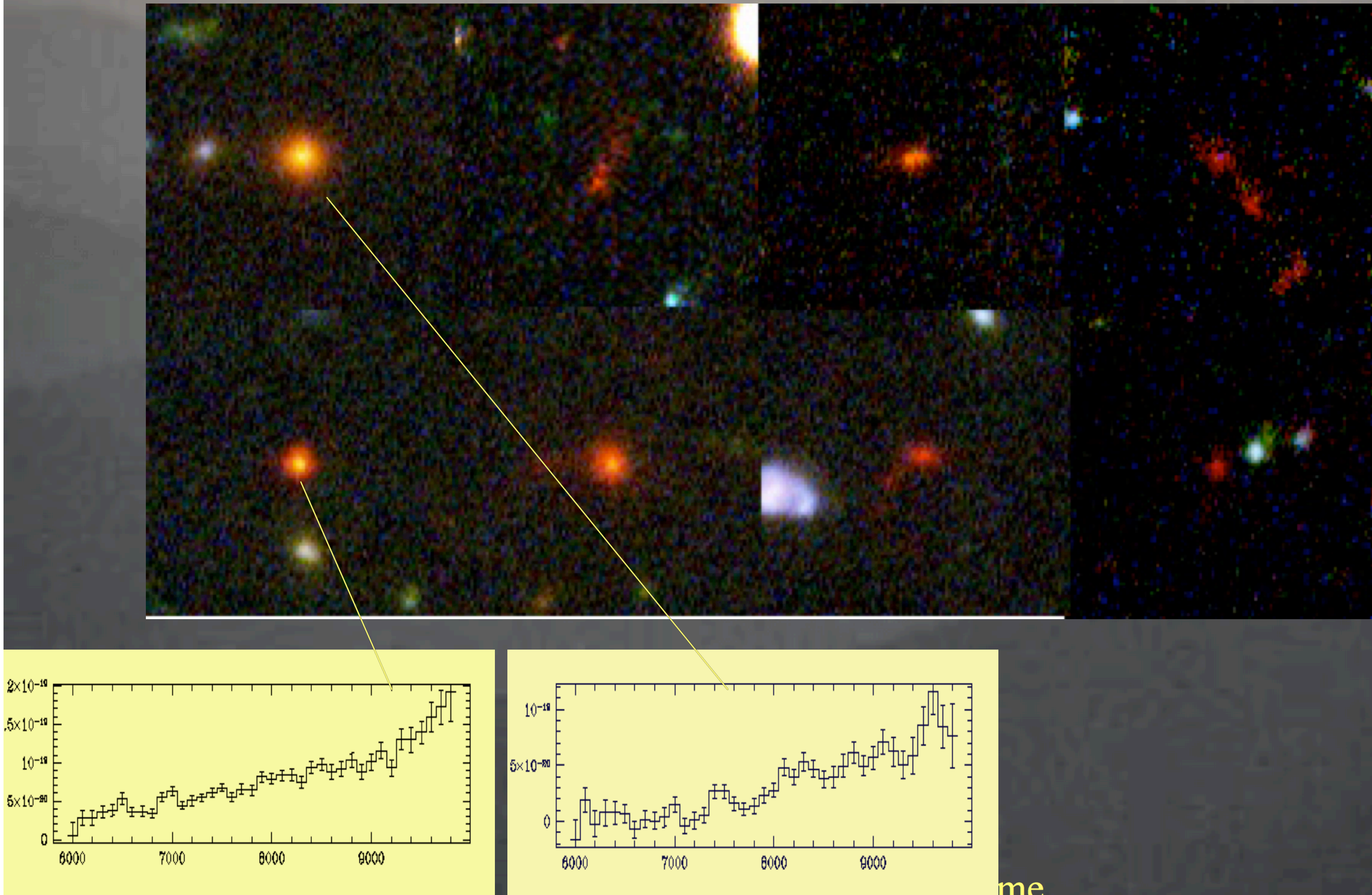

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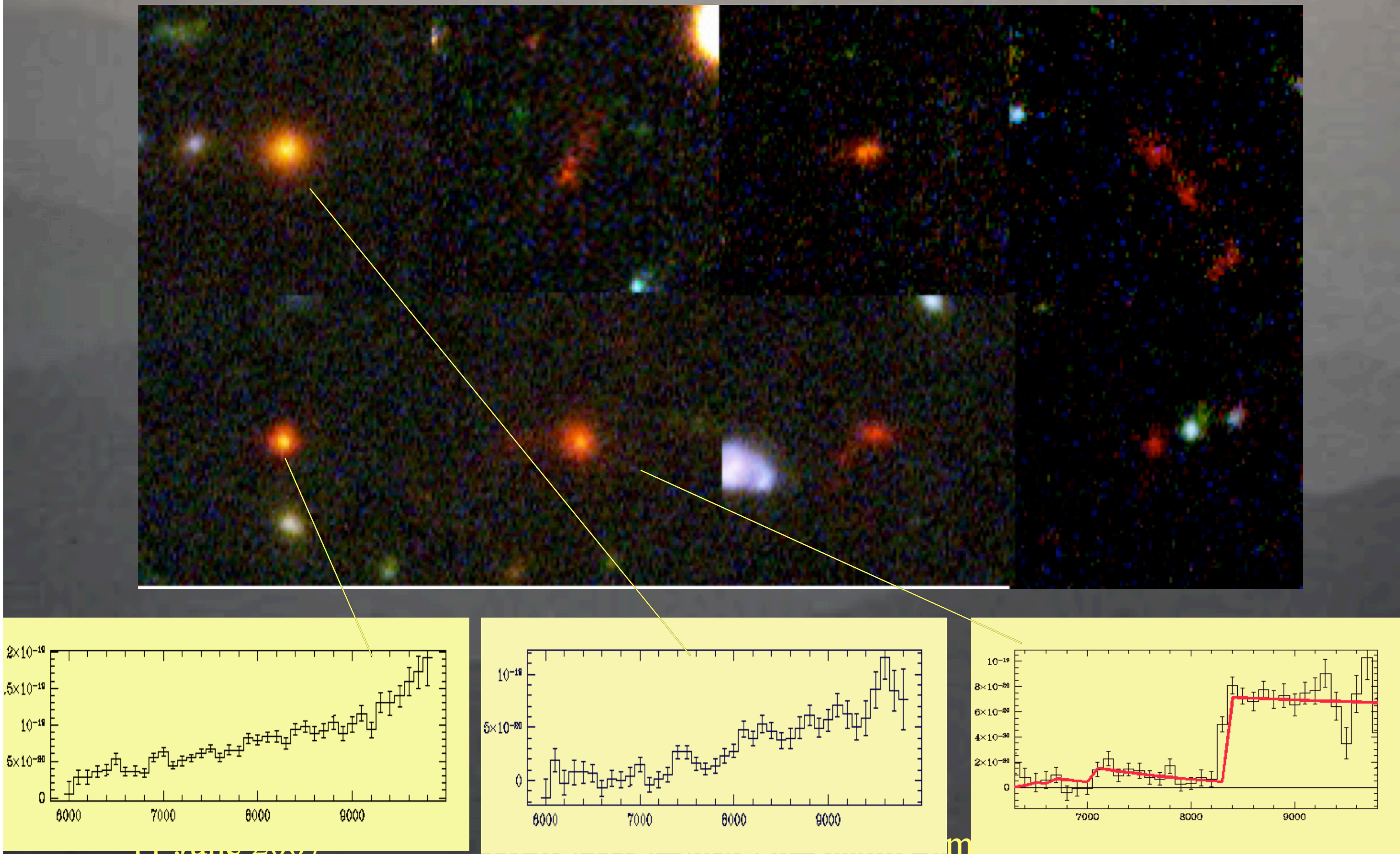

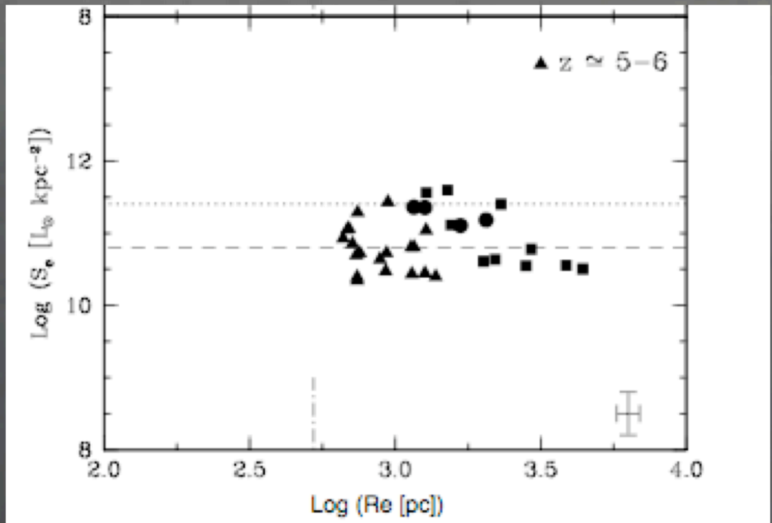

▲ z ≃ 5−6
Log (S_e [L_⊙ kpc^-2])
Log (Re [pc])
2.0
2.5
3.0
3.5
4.0
8
10
12


11 June 2007
HI Survival through cosmic time