Searching for the highest redshift Galaxies and AGN

- Did the intergalactic hydrogen reionize at z just beyond 6 ?

or was it earlier?

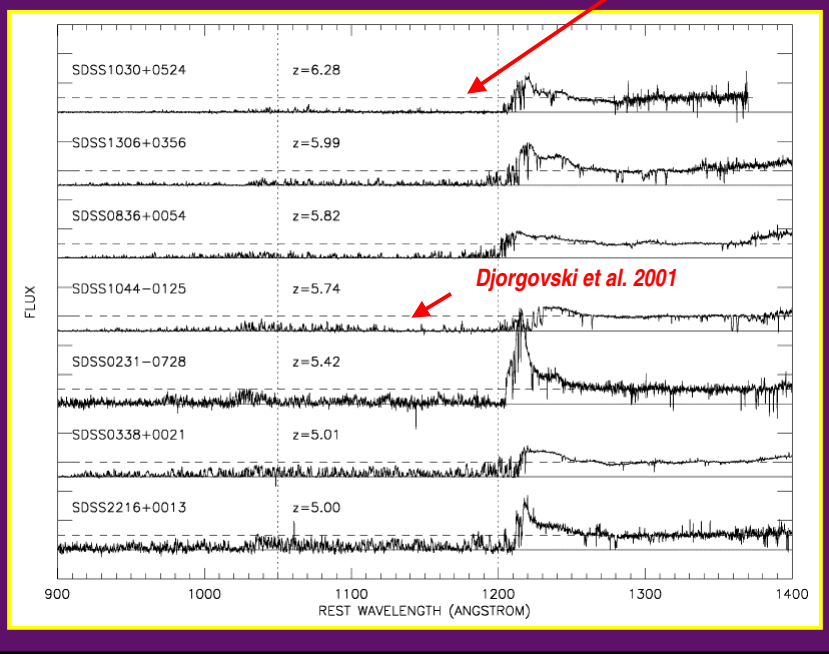
- Can we find the galaxies or faint AGN at these redshifts ?

Are there enough of them to ionize the gas?

What can we infer about the IGM evolution from the galaxy populations?

Is reionization at z=6 consistent with the galaxy observations?

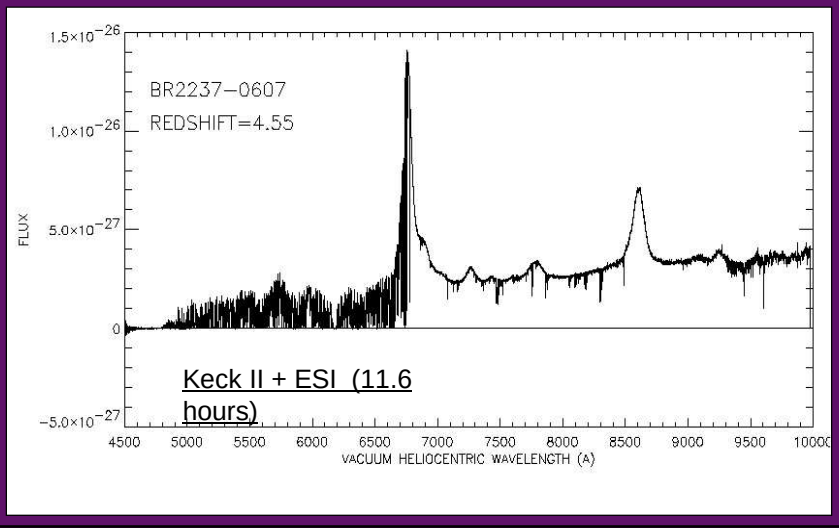
The high redshift IGM is very thick in the forest:



Even at z=4.5 we are failing to return to the continuum level.

i.e. even low density regions now have some significant opacity…

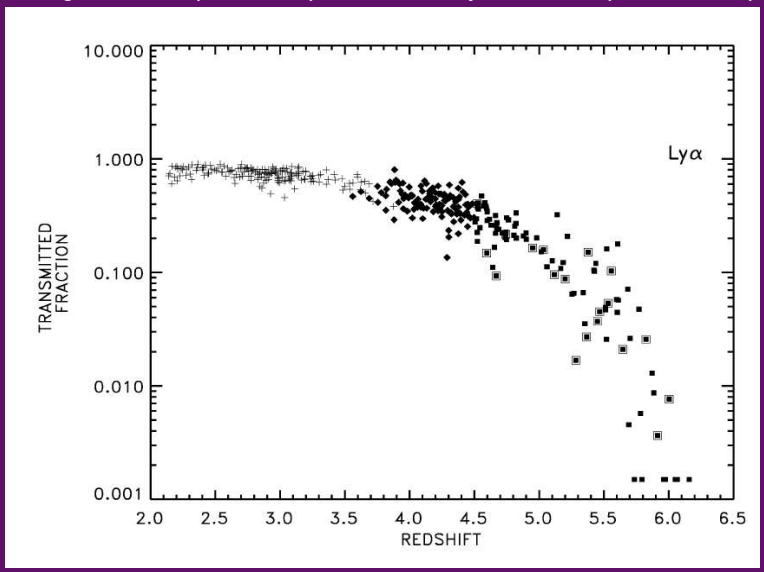
The average transmission has dropped to about a half.



Keck II + ESI (11.6 hours)

Mean transmission in Ly α forest (ESI and Hires sample)

25 Angstrom bins (rest-frame) blueward of Lyα emission (1050-1175 A)

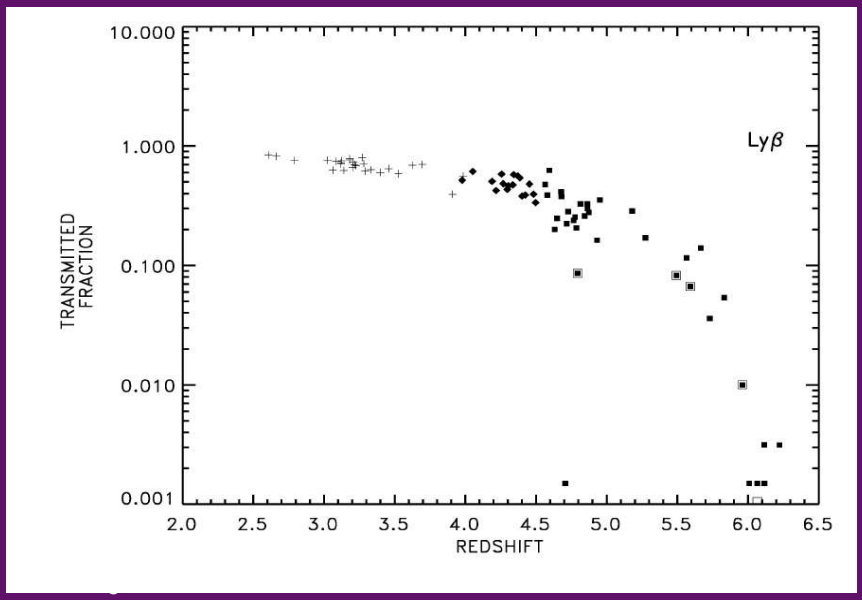


Songaila 2004 AJ 127

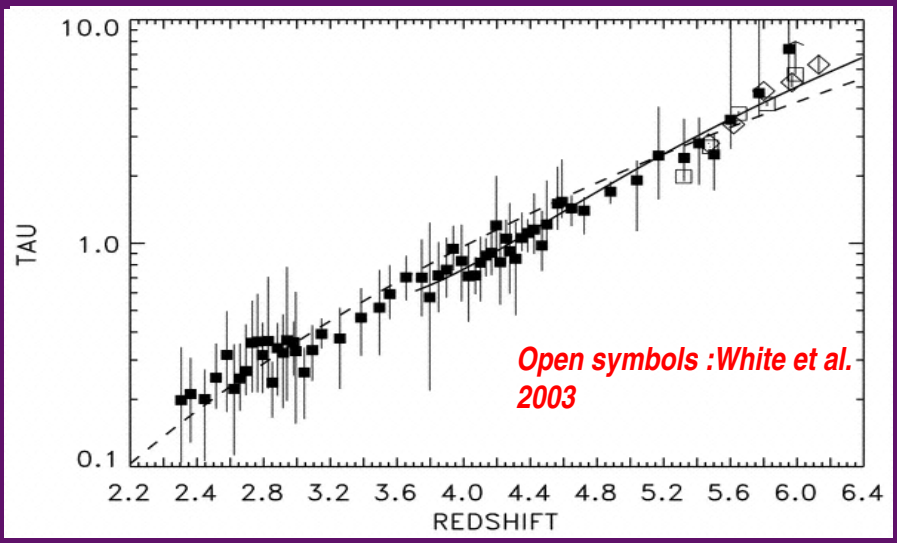
More galaxies at z>5

Mean transmission in Ly β forest (ESI + HIRES sample)

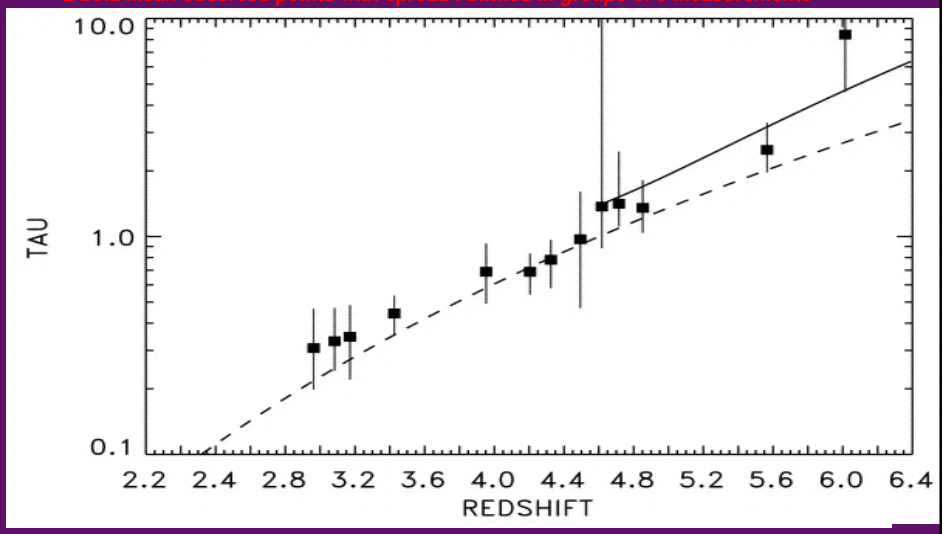
25 Angstrom bins (rest-frame) blueward of Lyβ emission



L alpha mean observed points with spread : binned in groups of 6 measurements



L beta mean observed points with spread : binned in groups of 6 measurements



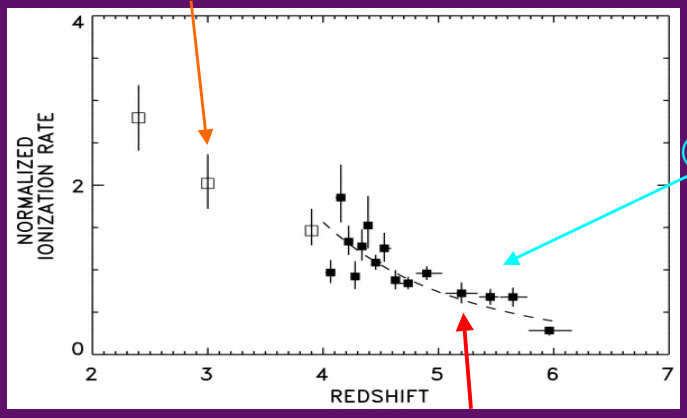
NOTE!!! L beta tau cannot be simply translated to L alpha tau. They are both complex functions of the opacity distribution. For uniform medium (dashed line) the ratio of beta/alpha is 0.16 but generally it is larger (0.4 for solid).

Ionization rate as a function of redshift

$$g \equiv \Gamma_{-12}\, T_4^{0.75} \left(\frac{\Omega_m}{0.35}\right)^{0.5} \left(\frac{\Omega_b h^2}{0.0325}\right)^{-2} \left(\frac{H_0}{65\ \mathrm{km\ s^{-1}\ Mpc^{-1}}}\right)$$

Γ_{-12} = ionization rate/baryon in units of 10^{-12}/s

(McDonald, 2000)



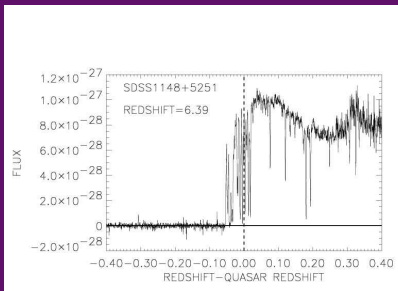
(ESI sample)

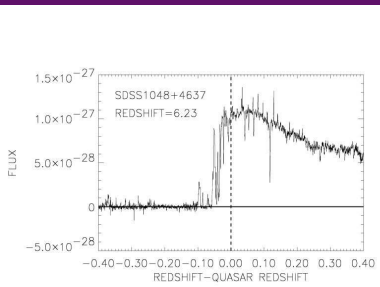
Drop of about 4 in the co-moving star formation rate from 3 to 6

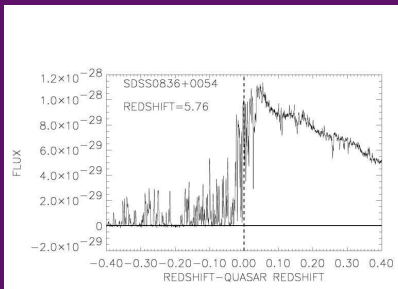
Songaila 2004 AJ 127 2598

g=0.74((1+z)/6)^(-4.1)

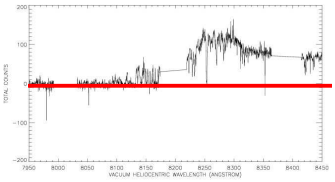
More galaxies at z>5







R=67000 spectrum SDSS0002



Big Question:

- H REIONIZATION at z~6.2 ???

•Or is it just the natural thickening of the forest as we move to high redshift?

VERY HARD to tell the difference between an optical depth of 10 and one of 10000!

ONE TEST: is there a change in the Lyman alpha line properties of galaxies across this redshift boundary? Either a change in the luminosity function or in the properties of the lines that might show they were now living in a neutral medium where the Lyman alpha line is cut away by the damping wings of the IGM?

High redshift galaxies and AGN

- Can we develop large well selected samples in the z=5-7 redshift range to answer this question?

And also:

- How does initial structure formation and reionization take place?
- Is ionization at this redshift produced by high redshift AGN? star-forming galaxies?
- What is the history of star formation in the Universe in the z=5-7 range?

How can we find galaxies and AGN at these redshifts?

Red color break searches.

(SDSS Fan et al. 2003 z=6.4)

Lyman alpha with narrow band filters or direct spectroscopic techniques.

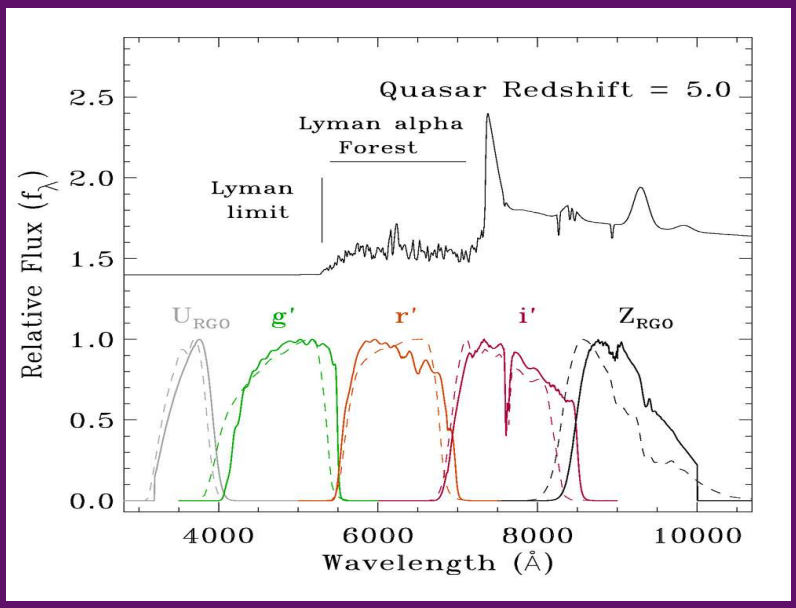
(Hu et al 2002, Taniguchi et al. 2004 , Ellis et al 2004, z=6.7,7)

(z=10?)

Targeted searches of X-ray or radio selected objects.

(Cowie et al. 2004 z=5.4)

McMahon



High z galaxies

Need many very large fields

Objects are sparse at brighter magnitudes

(few hundred per square degree

for AB <25.5)

Fields are highly correlated on subdegree scales

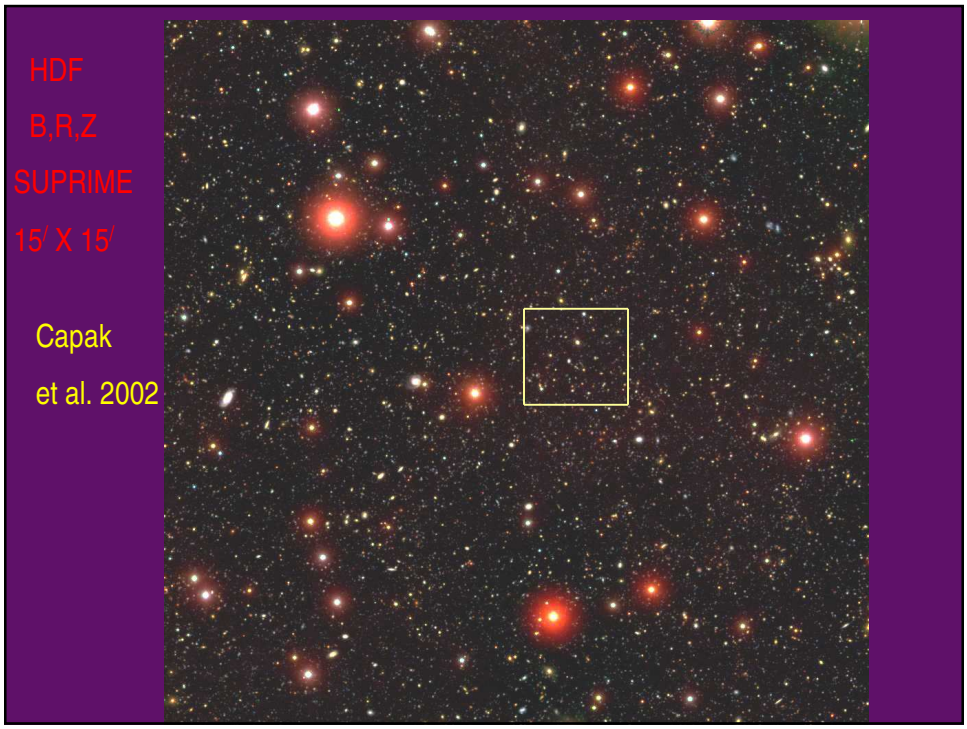
(Capak et al. 2004, Brodwin et al.2003 (astro-ph/0310038))

Hawaii survey: Widefield color and narrow band mapping of the z=5-7 range

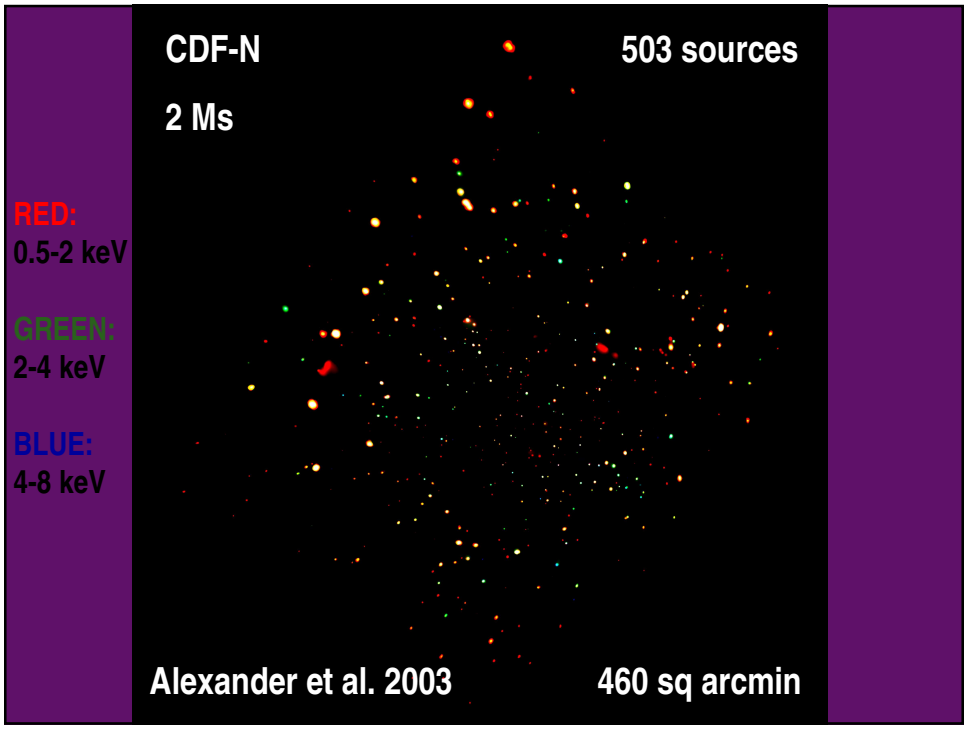
Peter Capak, Esther Hu, Len Cowie, Amy Barger, Richard McMahon, Yuko Kakazu, Wei-Hao Wang, Tomoki Hayashino, Yutaka Komiyama, Ed Fomalont, Niel Brandt,Dave Alexander, Franz Bauer, Gordon Garmire, Mark Bautz, Aaron Steffen, Yuxuan Yang, Richard Mushotzky, Mauro Giavilisco, Mark Dickinson, Dan Stern, S. Okamura,, C. Kretchmer, S. Miyazaki

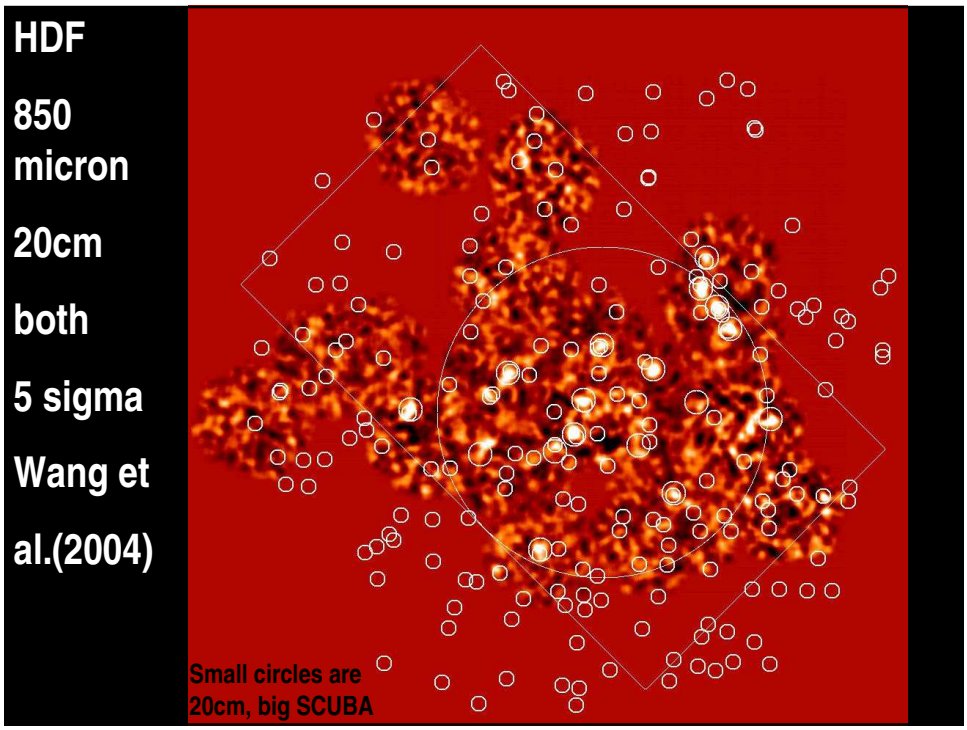
6 Well studied fields: HDF, SSA22, Lockman Hole NW, SSA13, SSA17, A370
Deep X-ray ,radio and submillimeter data for most of these.

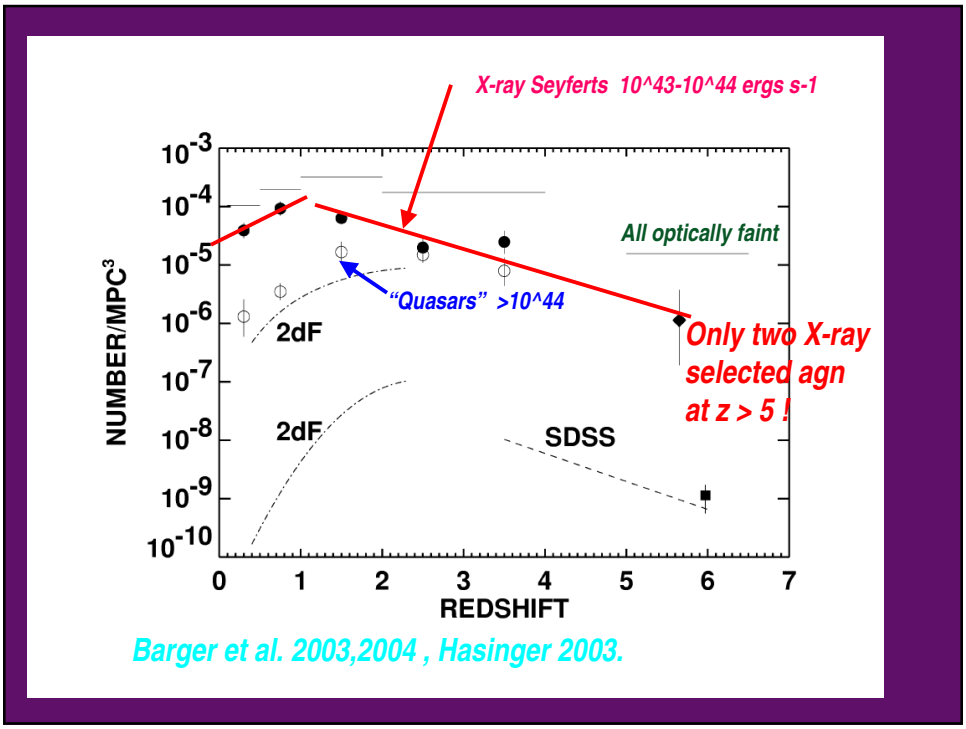
	(Z=6.6) (Z=5.7)
Muliticolor imaging With Suprime on Subaru Megaprime on CFHT, ULBCAM on 2.2m	*HK', J, Z', 9120/120, I, 8150/120, R, V, B, U Total area just over a square degree.*
Spectroscopy with Deimos on Keck II	*Spectroscopy of all X-ray and radio sources , all z=5.7 and 6.6 emission line candidates and all red color selected objects together with large magnitude selected field samples.*



More galaxies at z>5







HIGH z AGN SUMMARY:

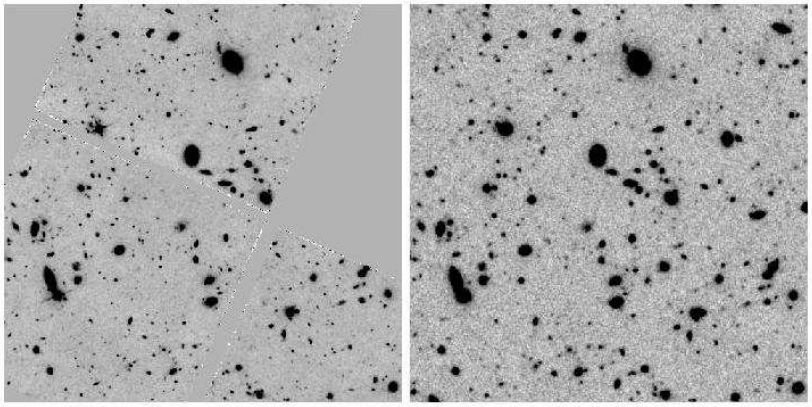
Faint AGN luminosity function is declining at high redshift (even including every possible!!!)

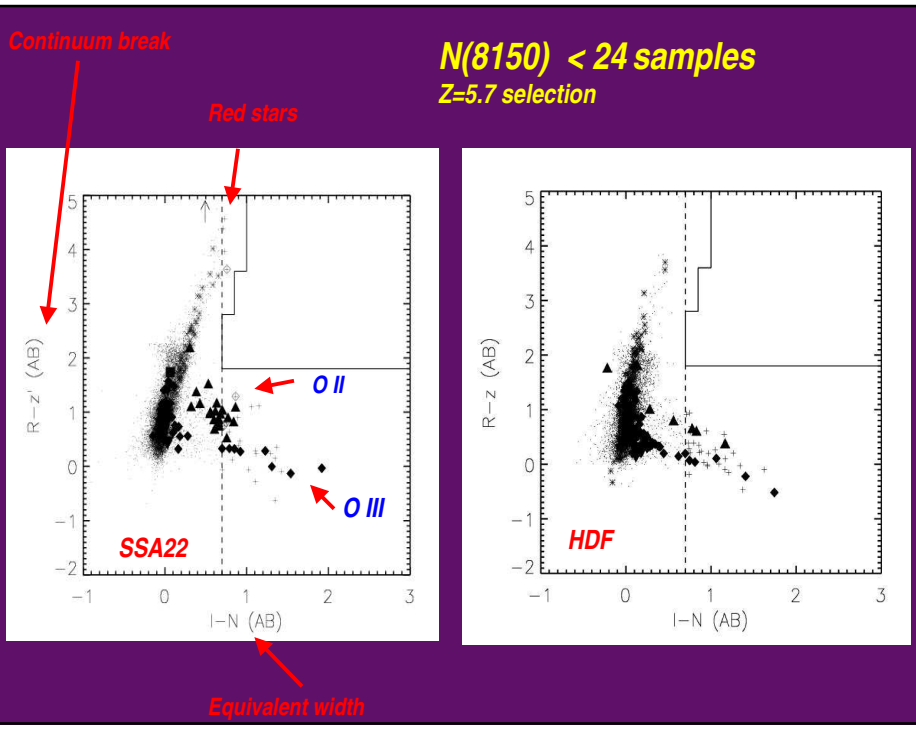
Potential sources are optically faint

Two orders of magniitude too little rest frame UV light for ionization

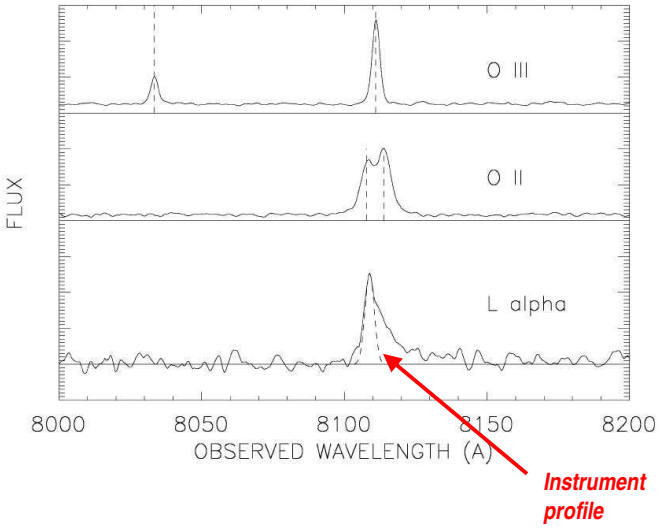
AGN do not appear to be the ionization source

HST F814W vs Suprime 8160 narrow band

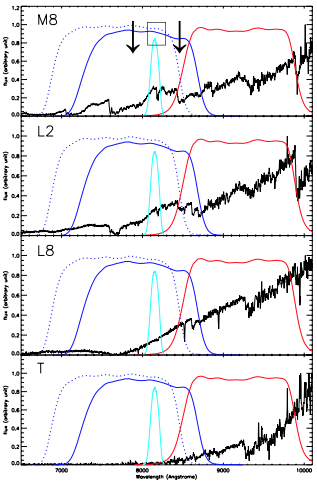




Composite of Deimos Spectra Hu et al. (2003)
R=2700 spectra allow us to easily distinguish OII and OIII emitters.



New Color Selection Technique (Yuko Kakazu)

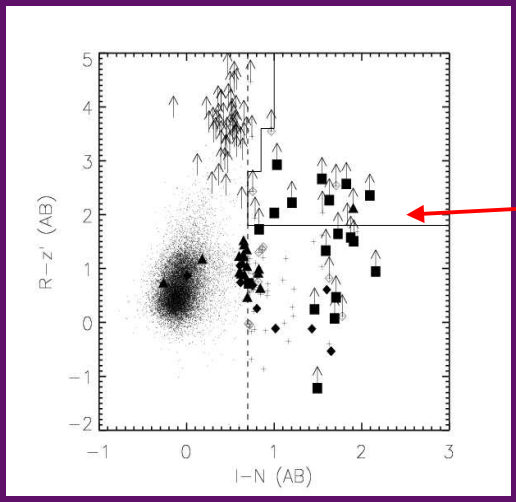


- Narrowband filter NB816
  (FWHM ~ 120Å, **λ** ~ 8150Å)
  - originally invented to detect Ly**α**emission from galaxies at z ~ 5.7

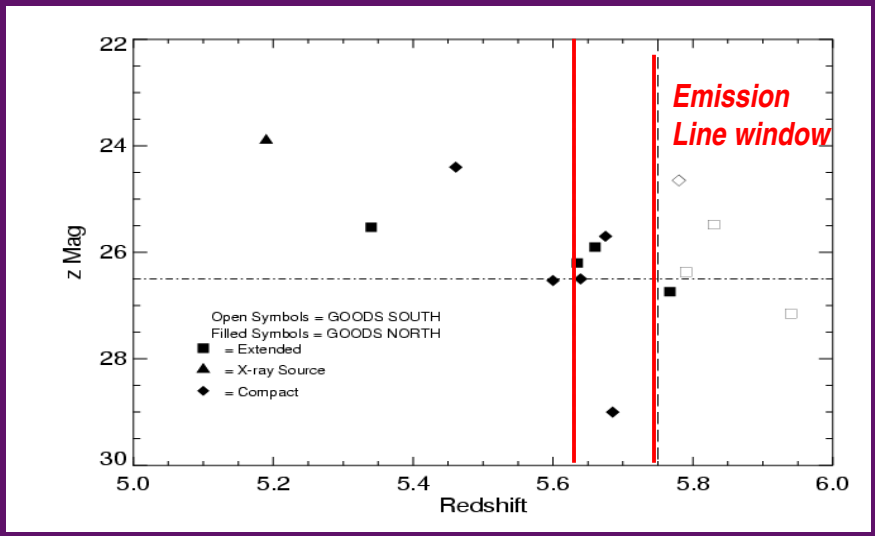
- Coincidently, molecular absorption lines (mainly VO, TiO) of early L-type dwarfs fall at the sides of a narrowband filter, NB816
  - “pseudo” emission feature in NB816 for early L-type. Slightly red (I-NB)color
  - relatively flat (I – NB) for late L- & T- type dwarfs

We can use (I – NB) color to separate dwarfs from high-z objects

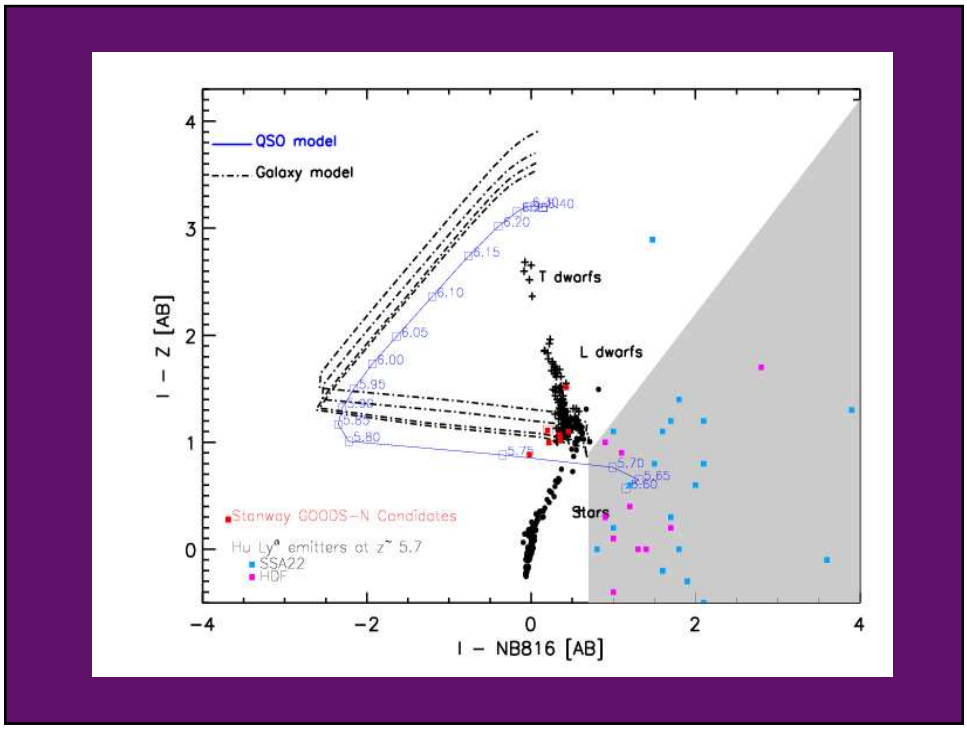
SSA22 field to N(AB)=25.1
19 spectroscopic L alpha emitters

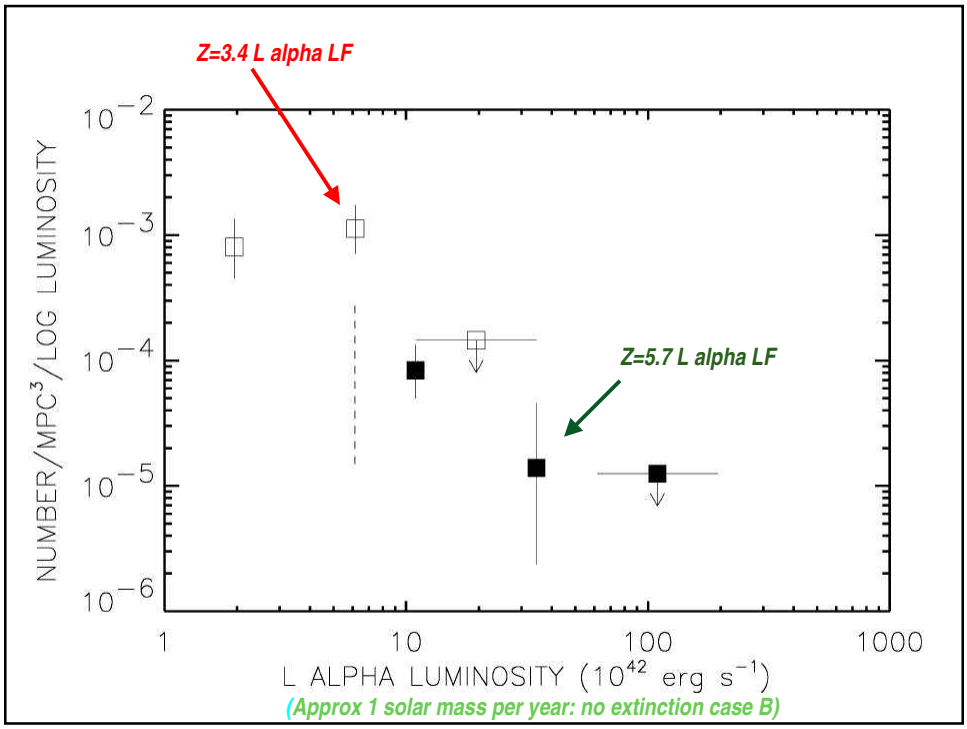


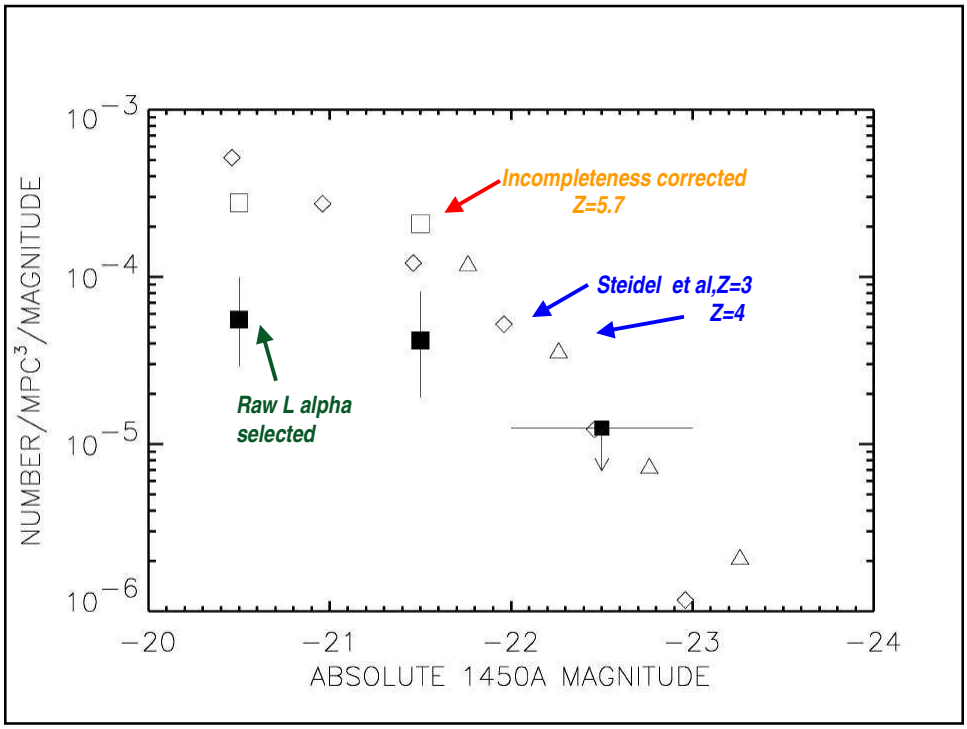
GOODS-S Continuum objects from Stanway, Bunker et al
GOODS-N from Spinrad et al, Weyman et al. Barger et al,



More galaxies at z>5







High z Galaxies

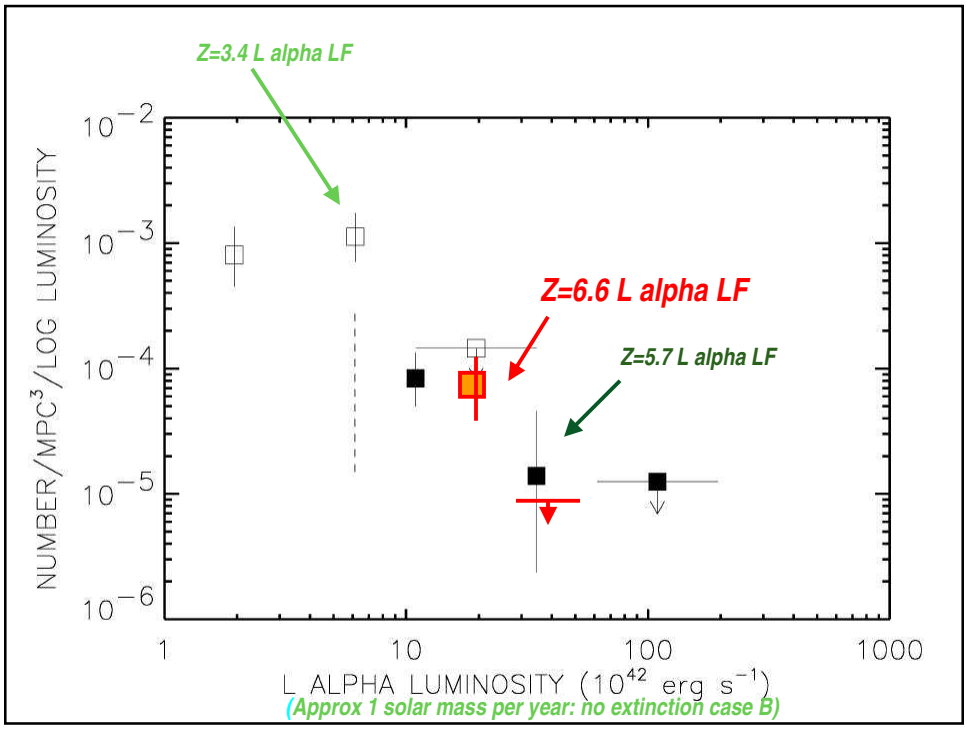
Lyman alpha emission line galaxies:
(Hu et al. 2003,2004)

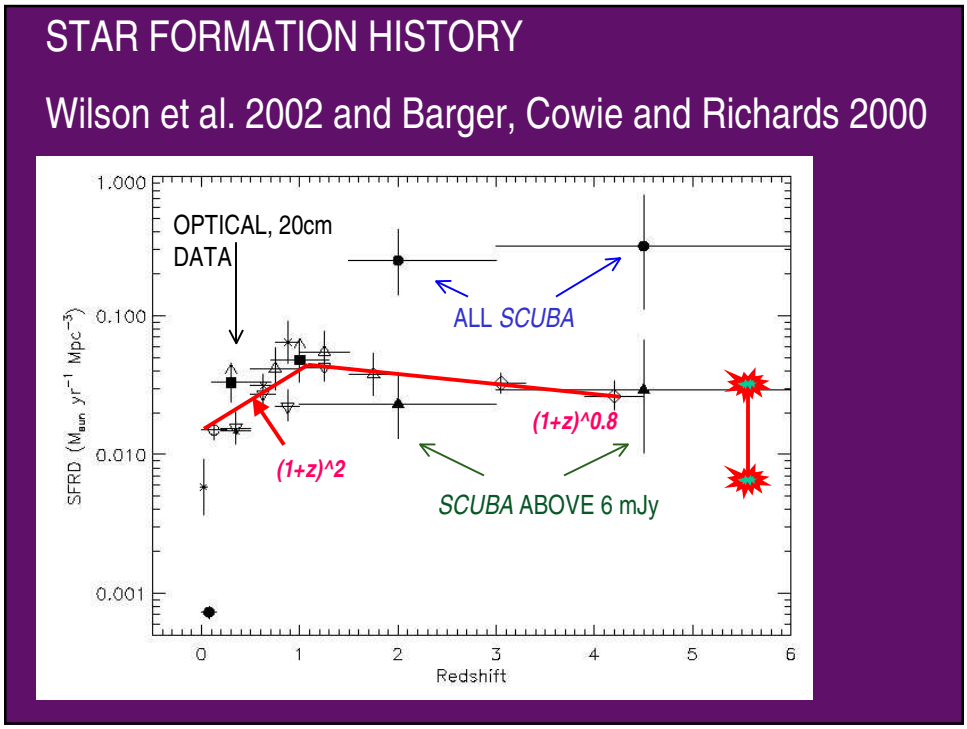
z=5.7: 33 galaxies in the HDF and SSA22
(19 in SSA22, 14 in HDF)

z=6.6: 9 galaxies in A370 and HDF fields
(9 in A370, 0 in HDF)

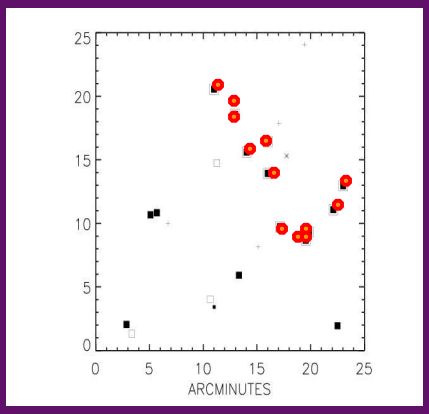
(Taniguchi 2004 describes similar z=6.6 sample in the Subaru Deep field.)

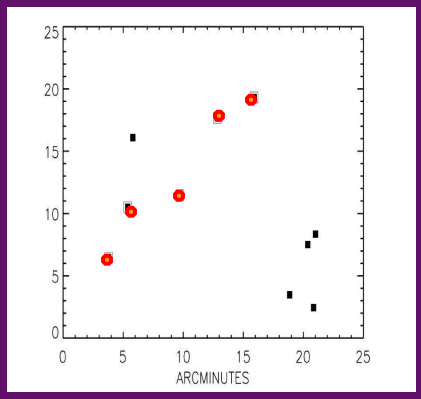
More galaxies at z>5





Z=5.7 L alpha emitters in SSA22 and the HDF





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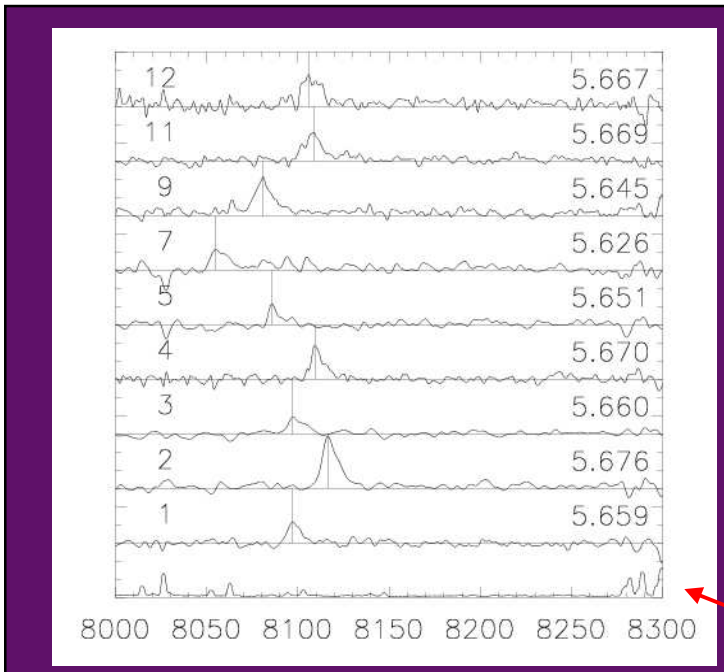
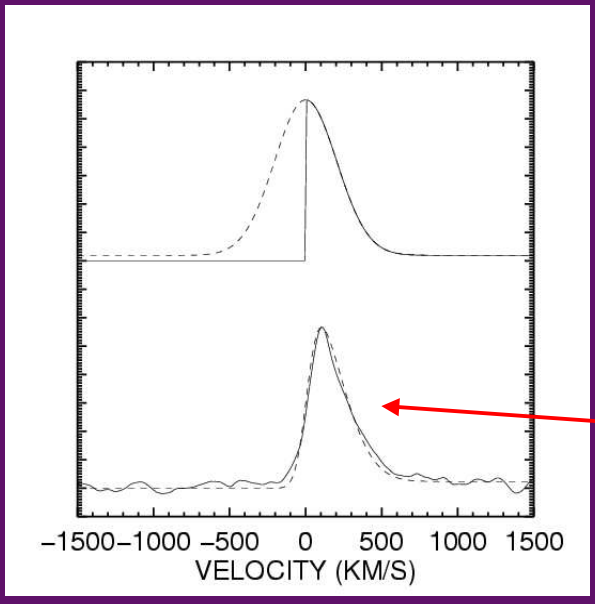
More galaxies at z>5



SSA22

9 0f 19 L alpha emitters in field

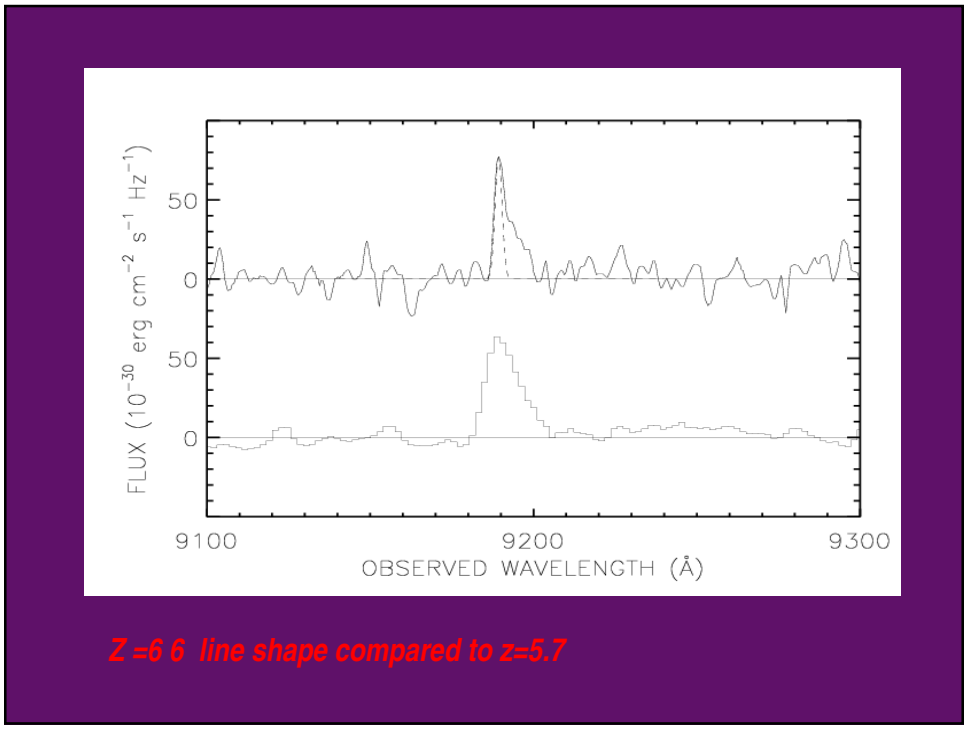
SKY spectrum



Input profile Gaussian (200 Km/s) Truncated By IGM scattering

Stacked profile Of 19 L alpha Emitters in SSA22

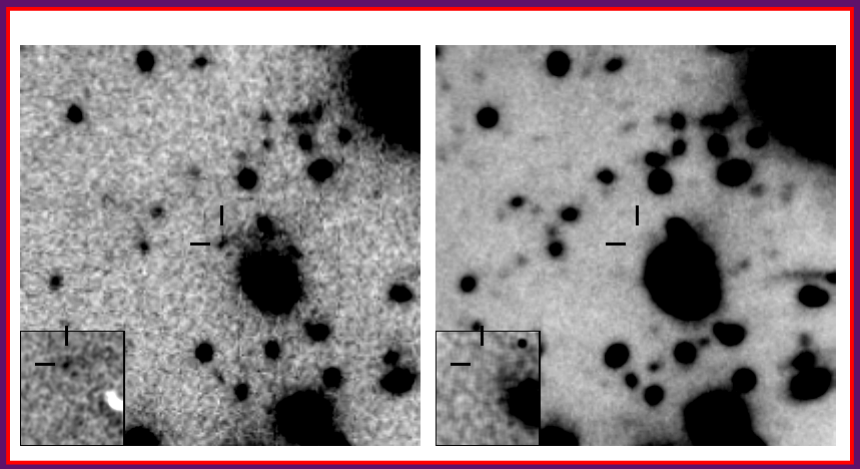
More galaxies at z>5



Z =6 6 line shape compared to z=5.7

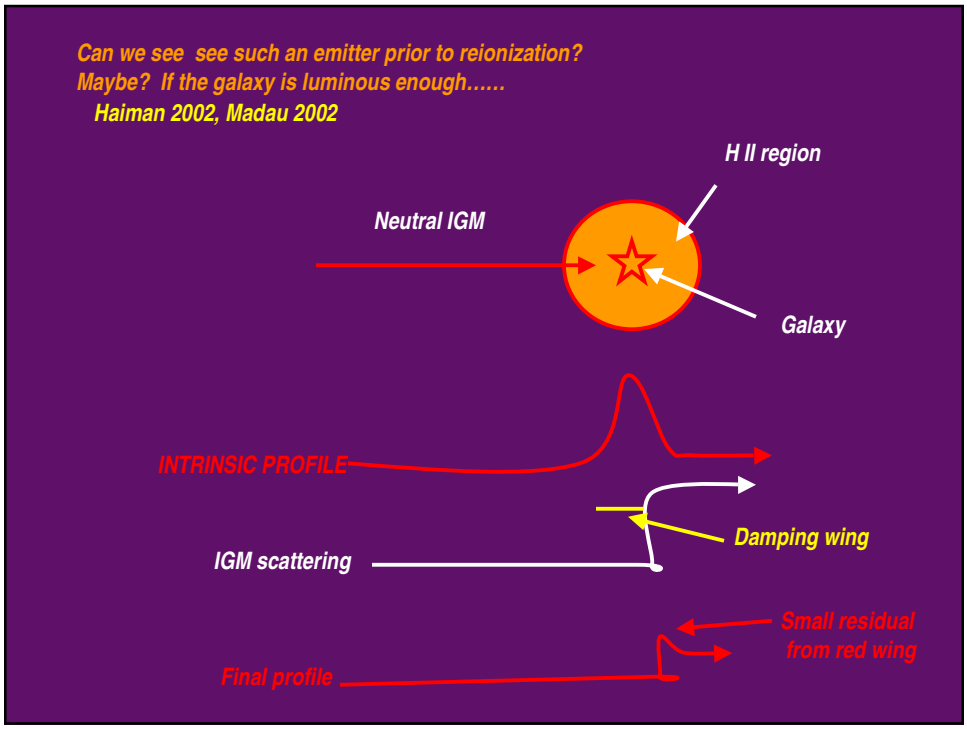
Z=6.56 Galaxy comp'd in narrowband vs. R

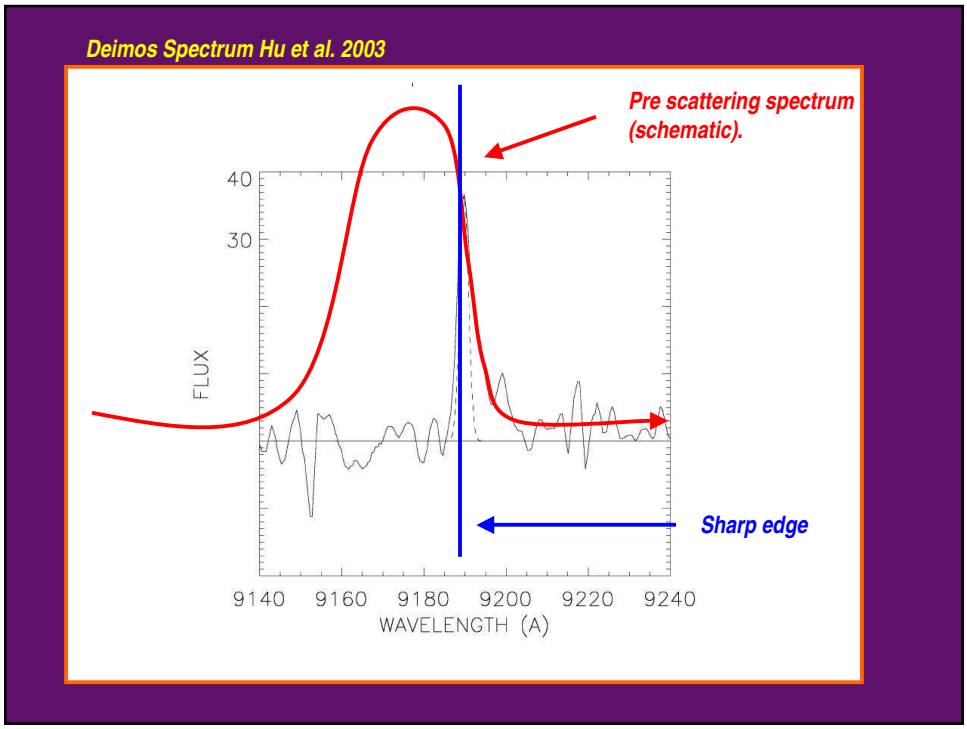
z=6.56 Galaxy Behind A370

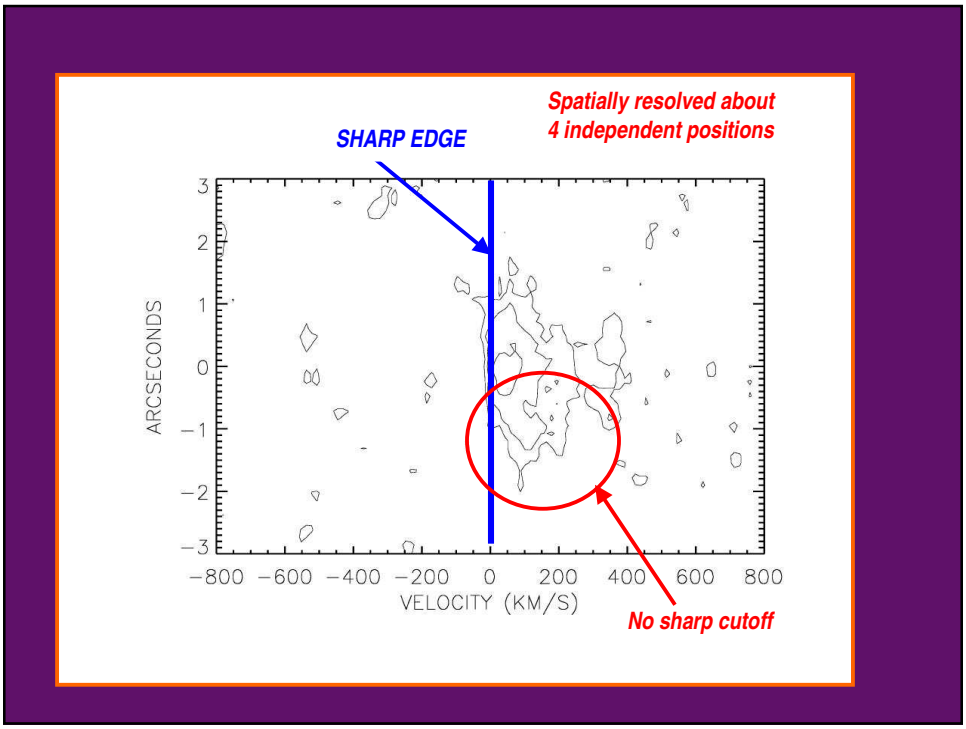


NARROW BAND (strong Ly α emission)

R BAND (no galaxy detected)


Can we see see such an emitter prior to reionization?
Maybe? If the galaxy is luminous enough.....
Haiman 2002, Madau 2002
H II region
Neutral IGM
Galaxy
INTRINSIC PROFILE
Damping wing
IGM scattering
Small residual
from red wing
Final profile


Deimos Spectrum Hu et al. 2003
Pre scattering spectrum
(schematic).
40
30
FLUX
Sharp edge
9140
9160
9180
9200
9220
9240
WAVELENGTH (A)



Summary

Large samples of z=5.7 and 6.6 objects can now be obtained.

L alpha and continuum luminosity functions at 5.7 seem similar to those at lower redshifts. (Galaxies are the dominant ionizers rather than AGN.)

L alpha luminosity function and L alpha line shapes are similar at z=6.6 and z =5.7

We may be able to make 3 dimensional maps of the cosmic web at these redshifts!