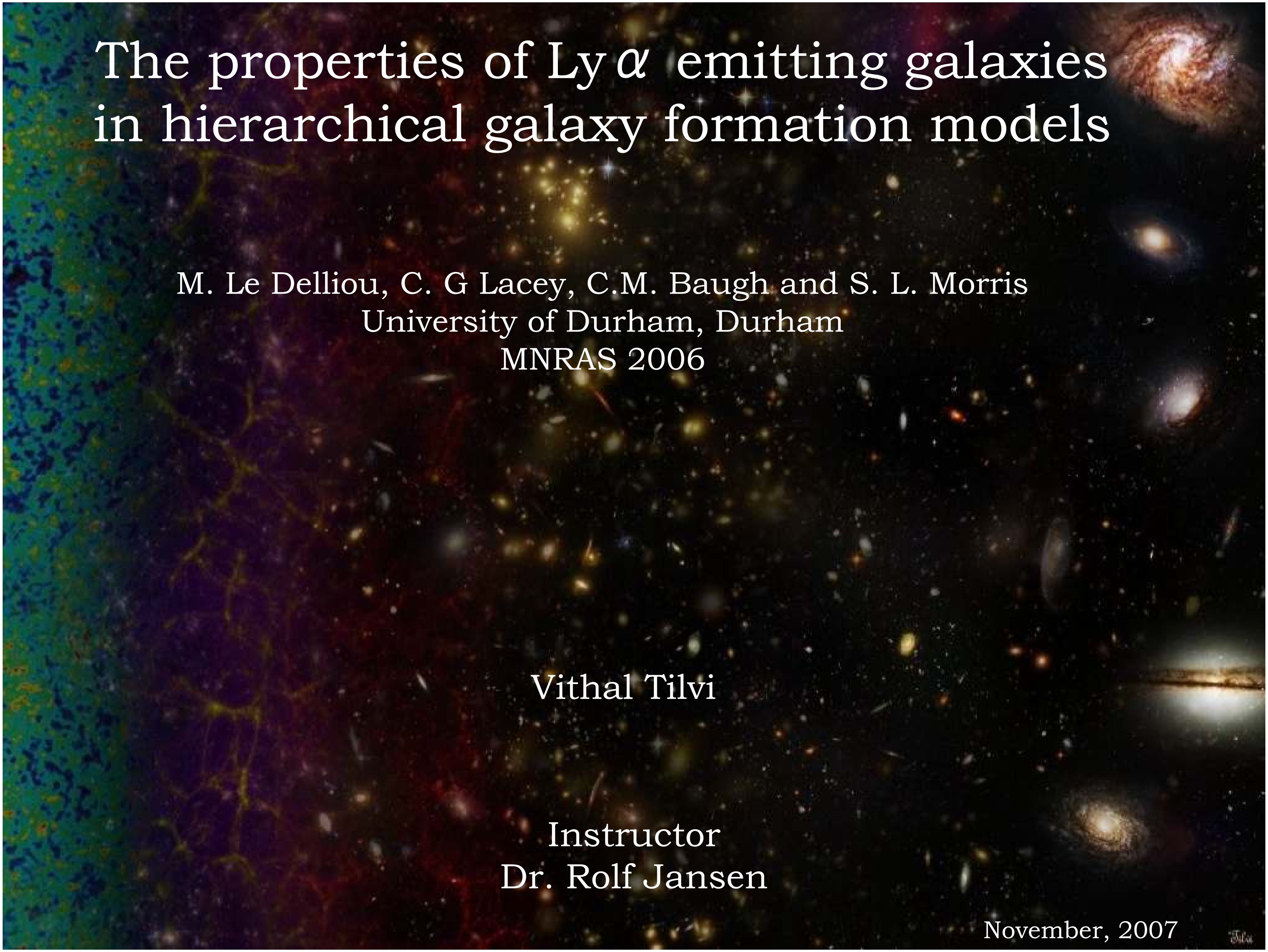


# The properties of Ly$\alpha$ emitting galaxies in hierarchical galaxy formation models

M. Le Delliou, C. G Lacey, C.M. Baugh and S. L. Morris
University of Durham, Durham

MNRAS 2006

Vithal Tilvi

Instructor
Dr. Rolf Jansen

November, 2007

Goals:

Using semi-analytical model

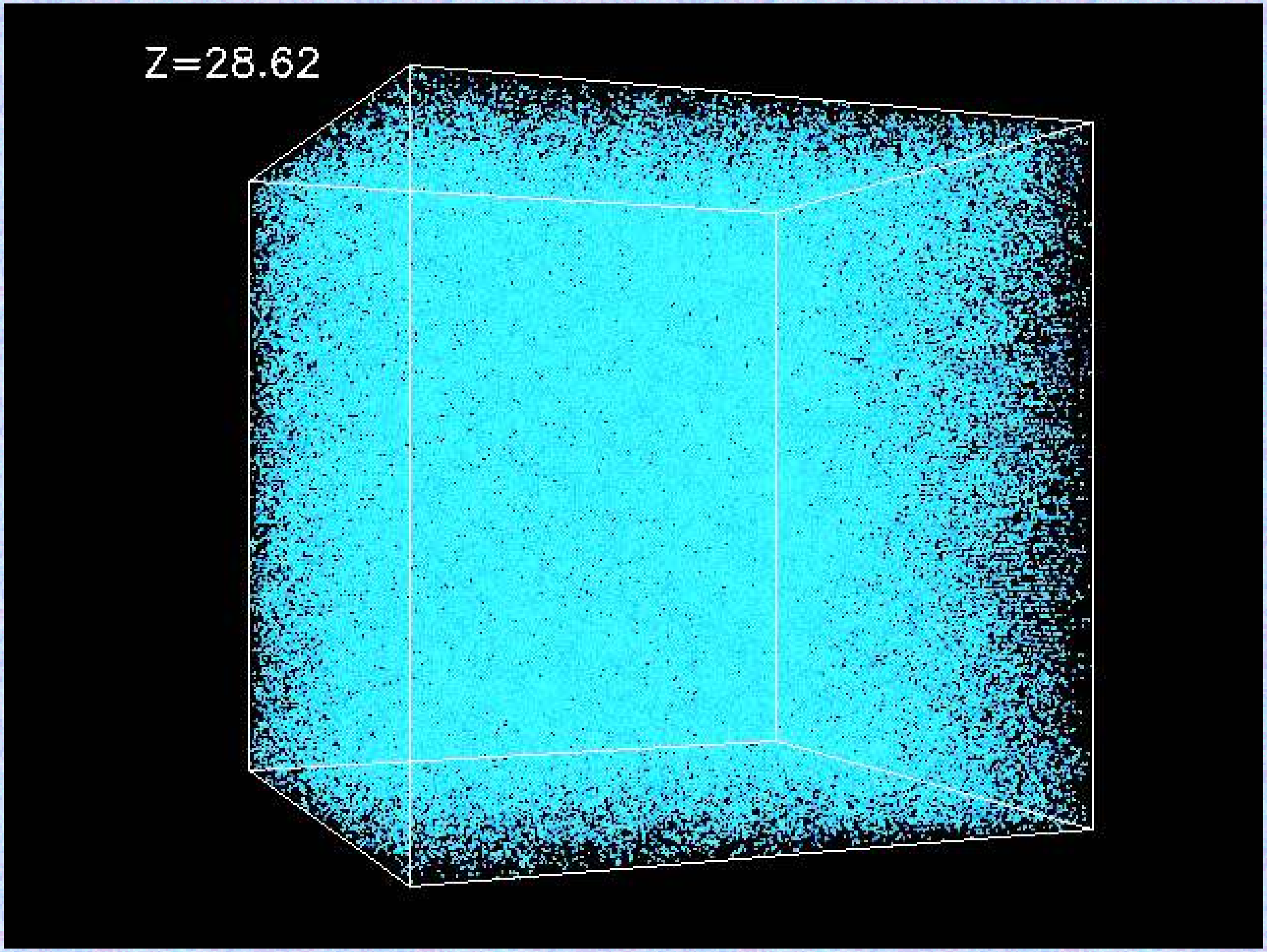
- Prediction of properties of Lyα emitting galaxies

- Reproduce the observed luminosity functions for LBG over $3<z<6$

- Clustering of LAEs at high redshift

- Prediction of LA luminosity function at $z>7$

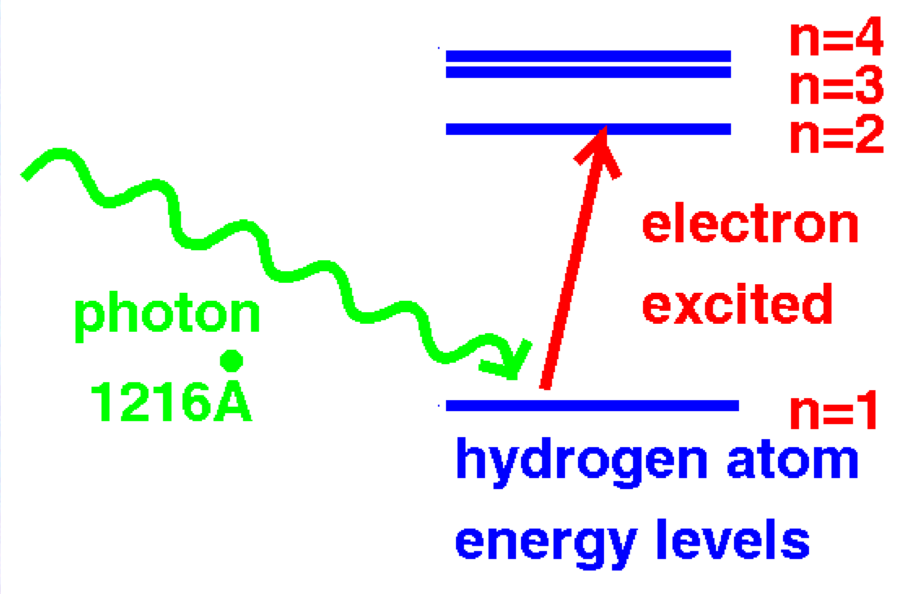
# Galaxy and large scale structure formation




Credits: NCSA, University of Chicago

# Lyman alpha transition

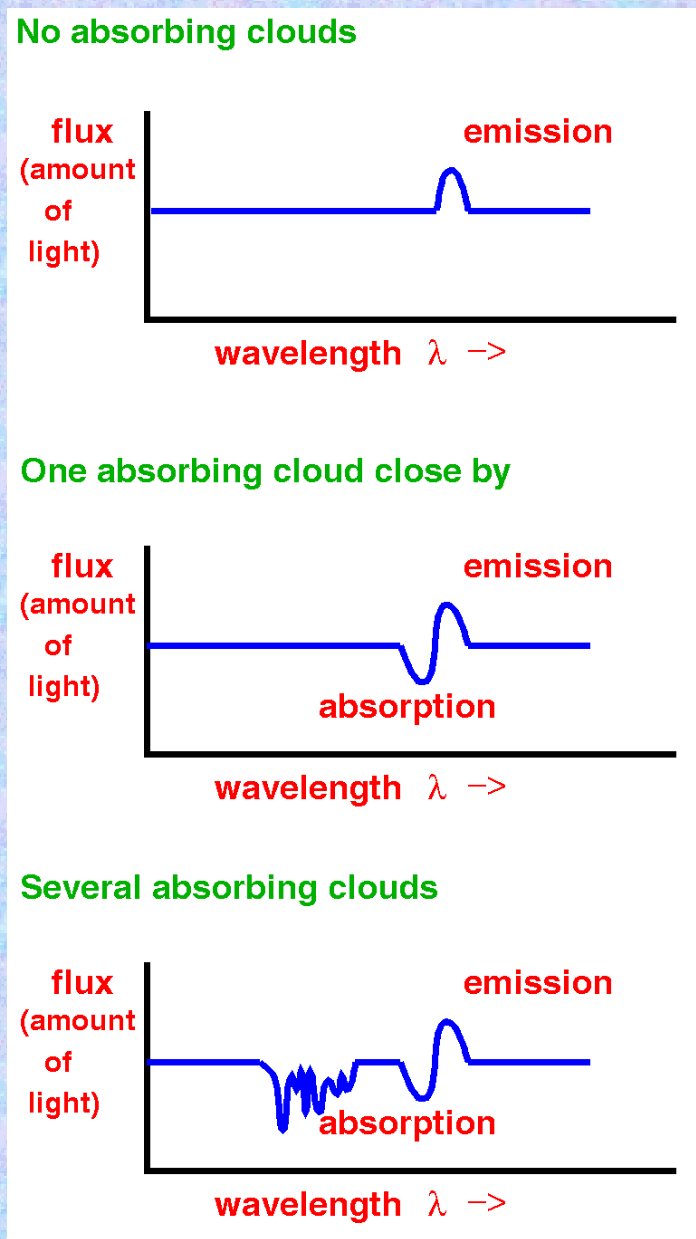
Energetic photons incident on $H_I$, ejects an electron




Ionizing energy for H =13.6 eV (UV radiations)



Source: http://astro.berkeley.edu/~jcohn/lya.html

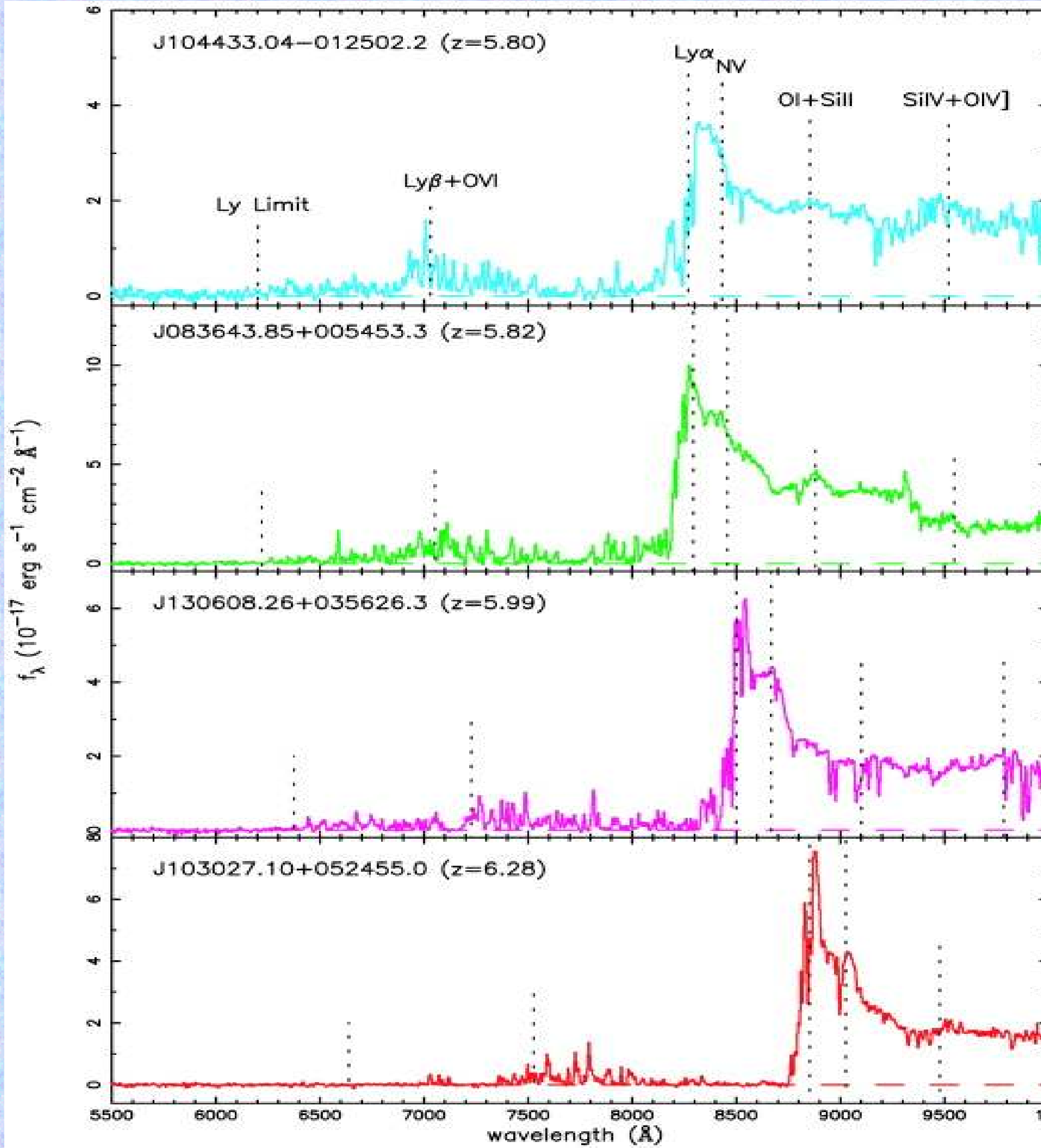





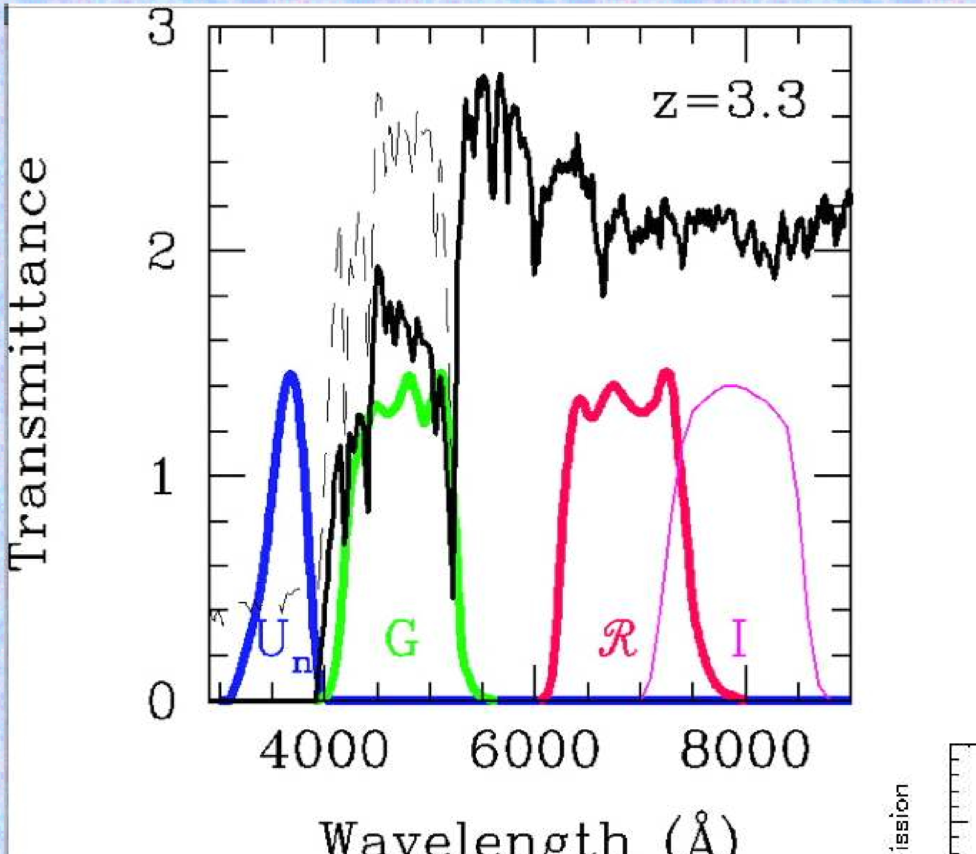

Source: http://astro.berkeley.edu/~jcohn/lya.html

# Quasars spectra

One of the methods to find $z$

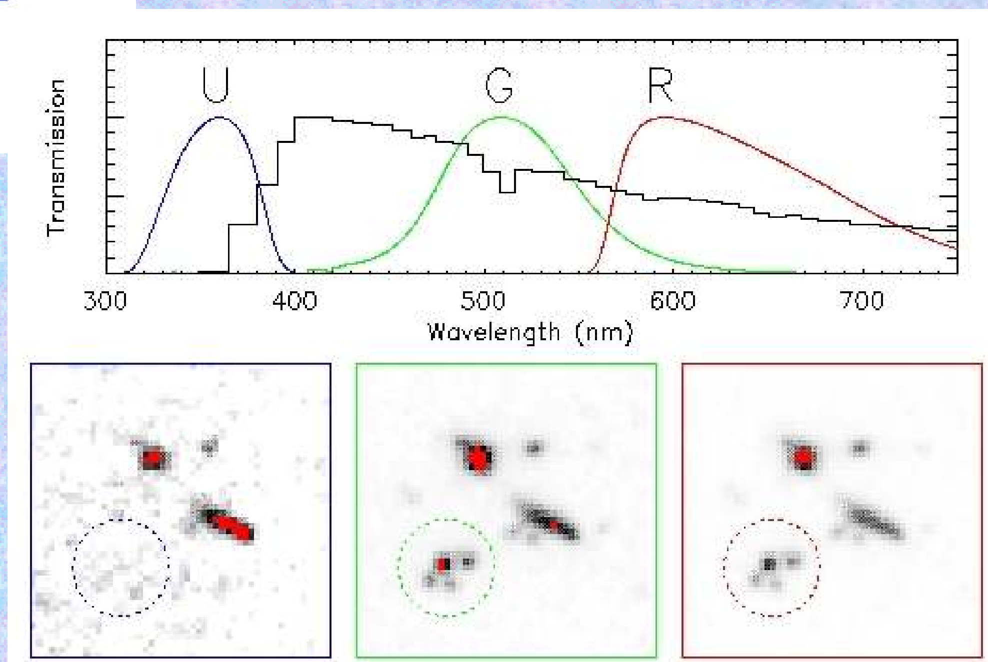



Fan et al 2001, Becker at al. 2002



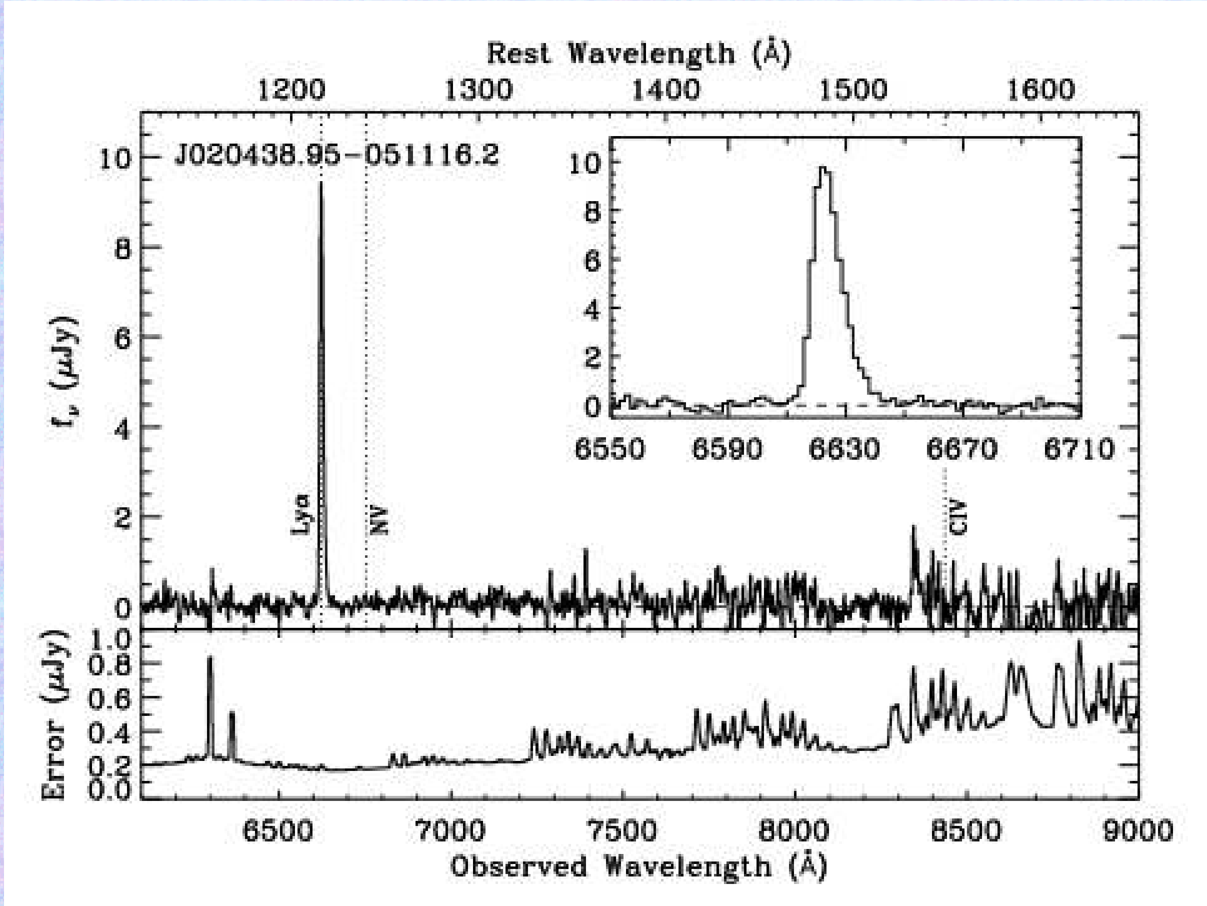

## Lyman break selection

Giavalisco 2002




Source: http://www.astro.ku.dk/~jfynbo

# LAE spectrum




Z=4.5 LAE; Wang et al 2004

## Sources of UV radiations

- Young, hot and massive stars
- AGN
- Intergalactic UV radiations
- Collissional excitation of gas during gravitational collapse of dark matter haloes
- Shock heating by galactic winds

## GALFORM model

Semi-analytical model (galform.org)

- Collapse & merging of dark matter (DM) haloes

- Galaxy discs formation: Shock heating and radiative cooling of gas inside DM haloes

- Quiescent star formation in galaxy discs

- Chemical enrichment of the stars and gas

- Galaxy mergers by dynamical friction $\Rightarrow$ star bursts

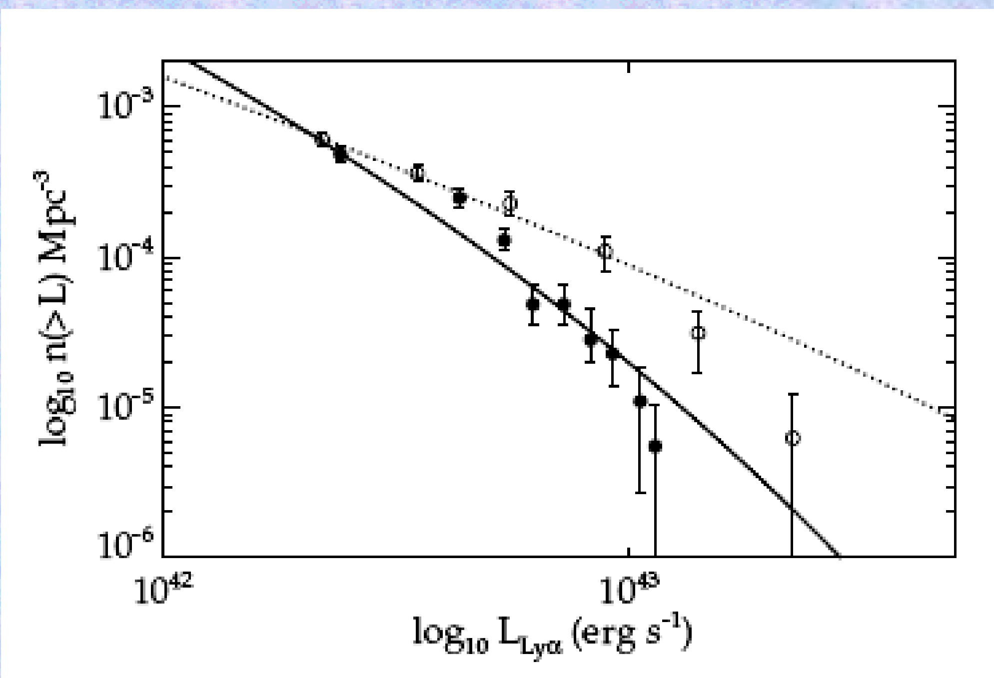
- Supernova feedback

Output from this model

- Stellar masses
- Halo sizes
- Star formation history
- Merger history
- Metallicities

## Supernova feedback

- Heats the gas and returns it to halo
- Ejects some gas from haloes as superwinds, which prevents formation of massive haloes (required to produce sharp cut-off at brighter end of the luminosity function).




Stark et al 2007

**Assumptions :**

$Z_{reion} = 10$

Two different IMFs :

- Quiescent star formation in galaxy disks (Solar neighbourhood IMF)

- Bursts of star formation from galaxy mergers assumes top-heavy (***which is controversial***)
  *(to match with the observed counts of galaxies at sub-mm wavelengths)*

No attenuation by IGM

**Constant escape fraction $f_{esc}$ =2 %**

## Computing galaxy properties

Conservation of momentum during collapse

⟹ Rotationally supported galaxy disc

Radius is calculated from the angular momentum

Star formation and metal enrichment history

## Integrated stellar spectrum

Uses star formation & metal enrichment history combined with *Padova* stellar evolution tracks

Redshifting the galaxy spectrum

Convolving the redshifted spectrum with filter response functions

Corrects for extinction due to dust in the galaxy

Includes IGM attenuation

# Calculating Ly$\alpha$ luminosity

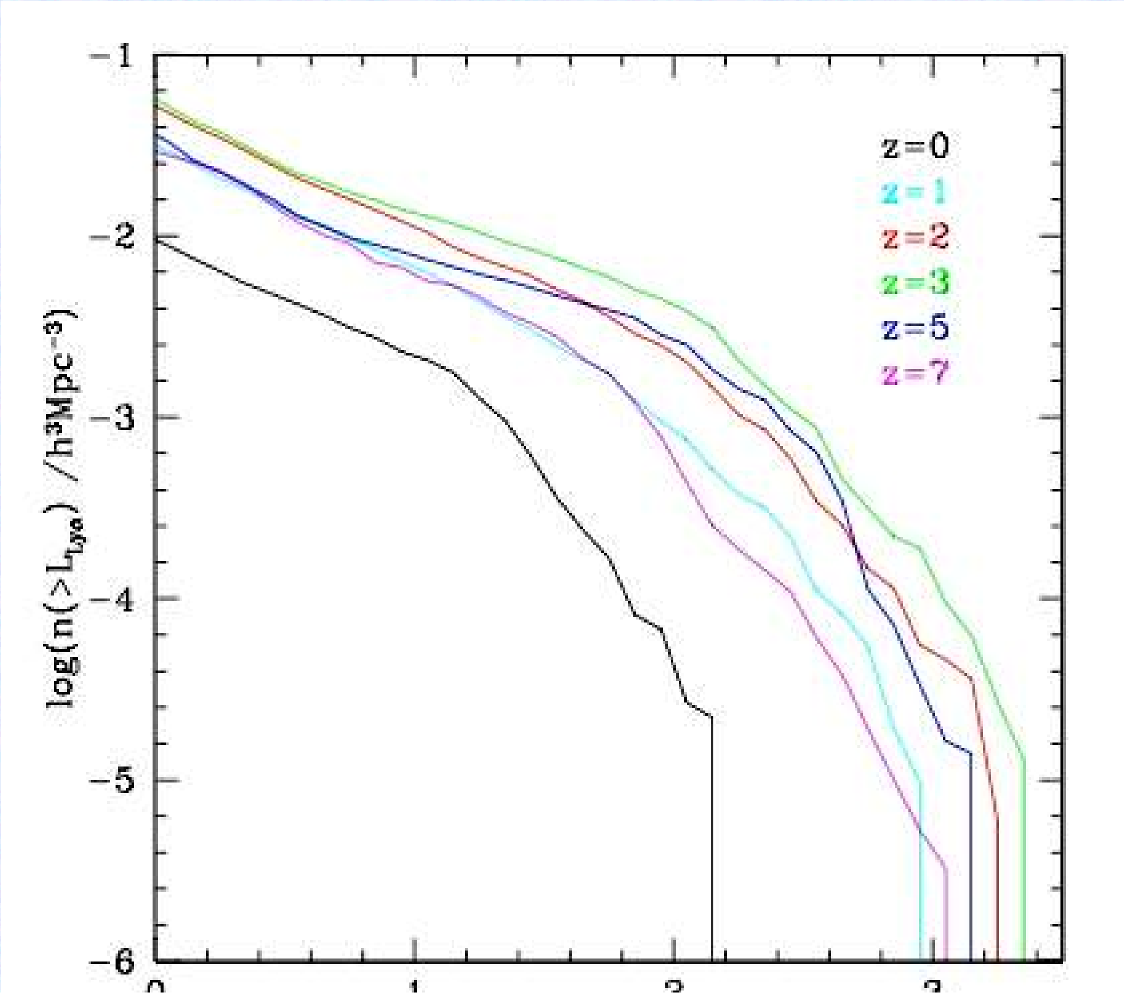
Integrate the stellar spectrum to compute the rate of production of Lyman continuum

Assume all the ionizing photons are absorbed by $H_I$ within the galaxy

Assume 2% escape fraction of Ly$\alpha$ photons (gives good match to the observed LF at different $z$)

No attenuation of Ly$\alpha$ flux by IGM

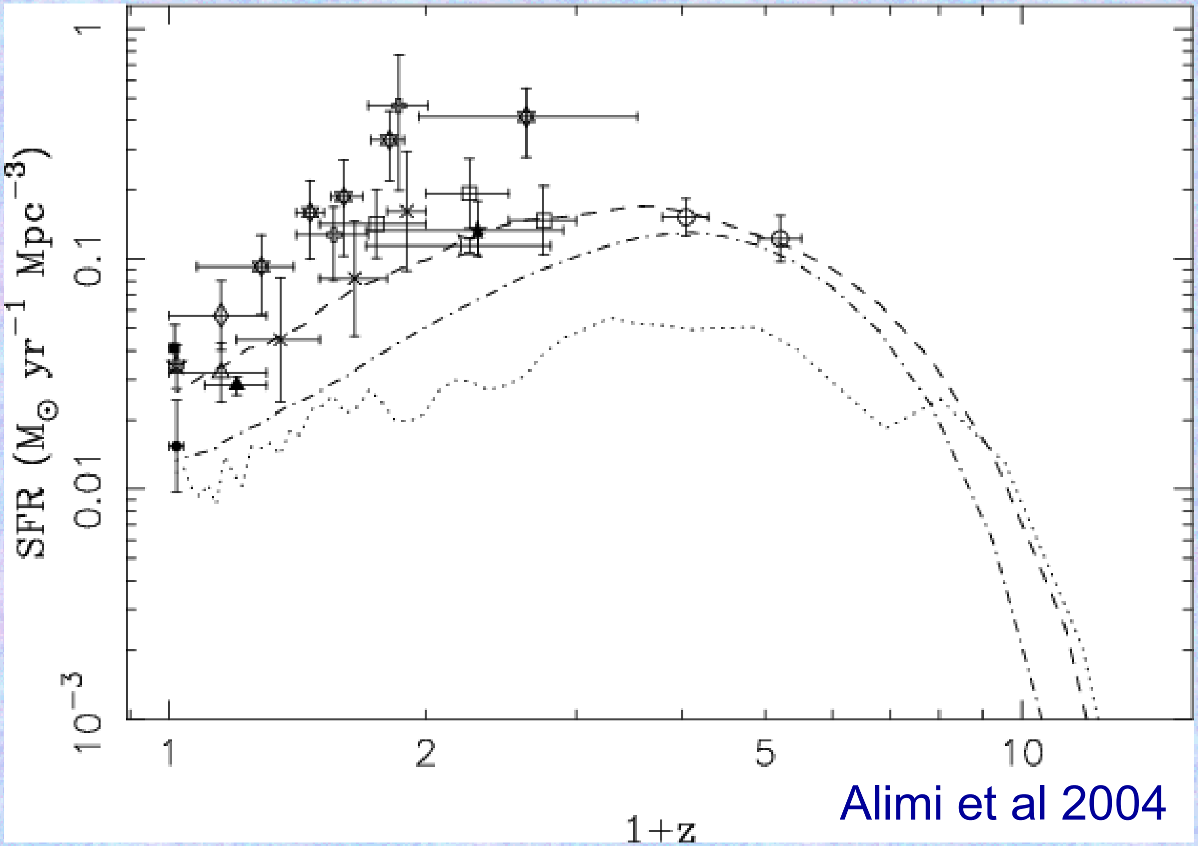
# Evolution of the predicted Ly$\alpha$ luminosity function




basically follows the SFR density

$\Rightarrow$ from $z$=3-7, the intrinsic #density of LAEs decreases, based on the assumption that IGM doesn't attenuate Lyman alpha photons

# Star formation rate density



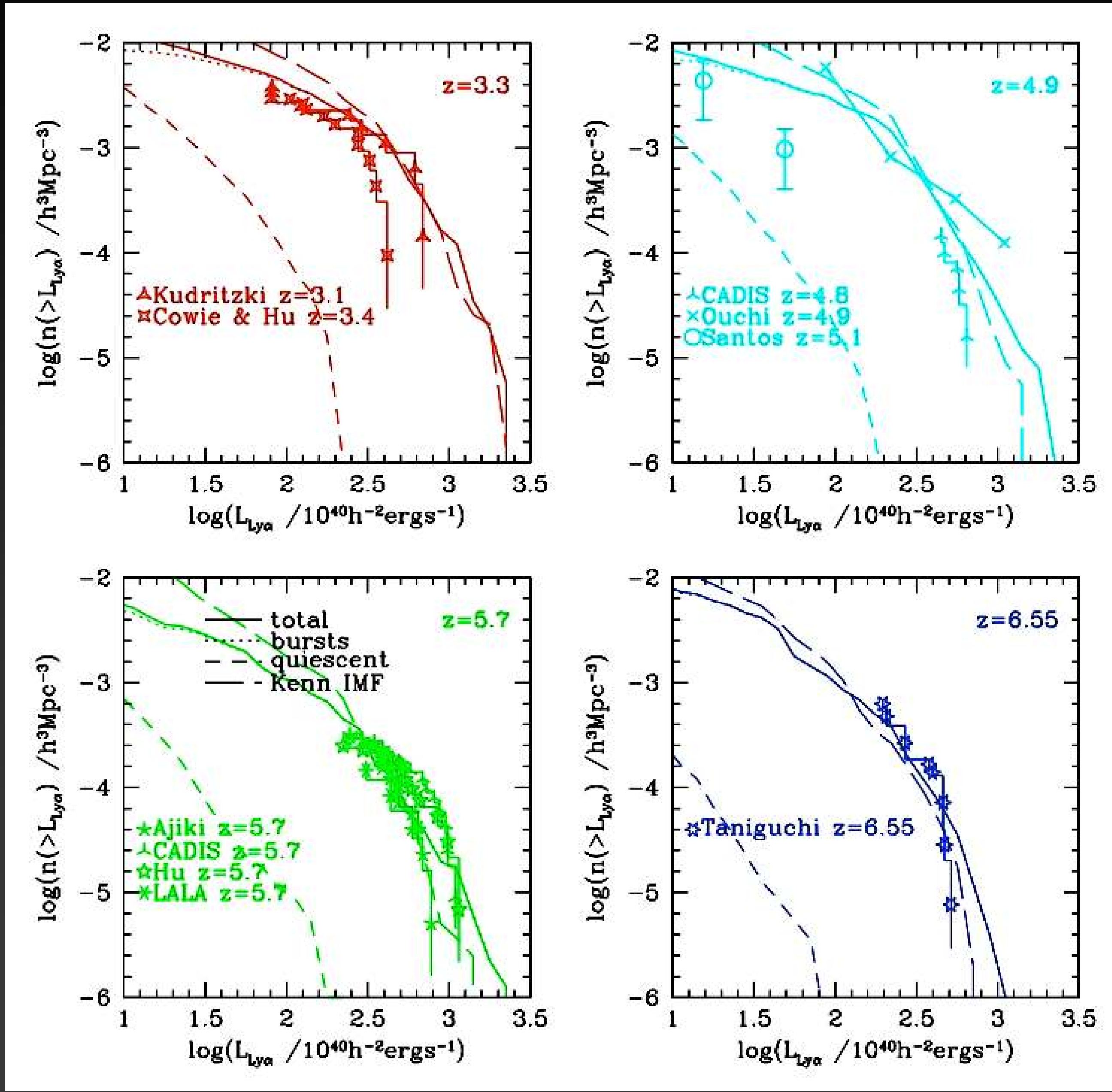

From model, the fraction of star formation in bursts increases from

5% at $z$=0

50% at $z$=3.5

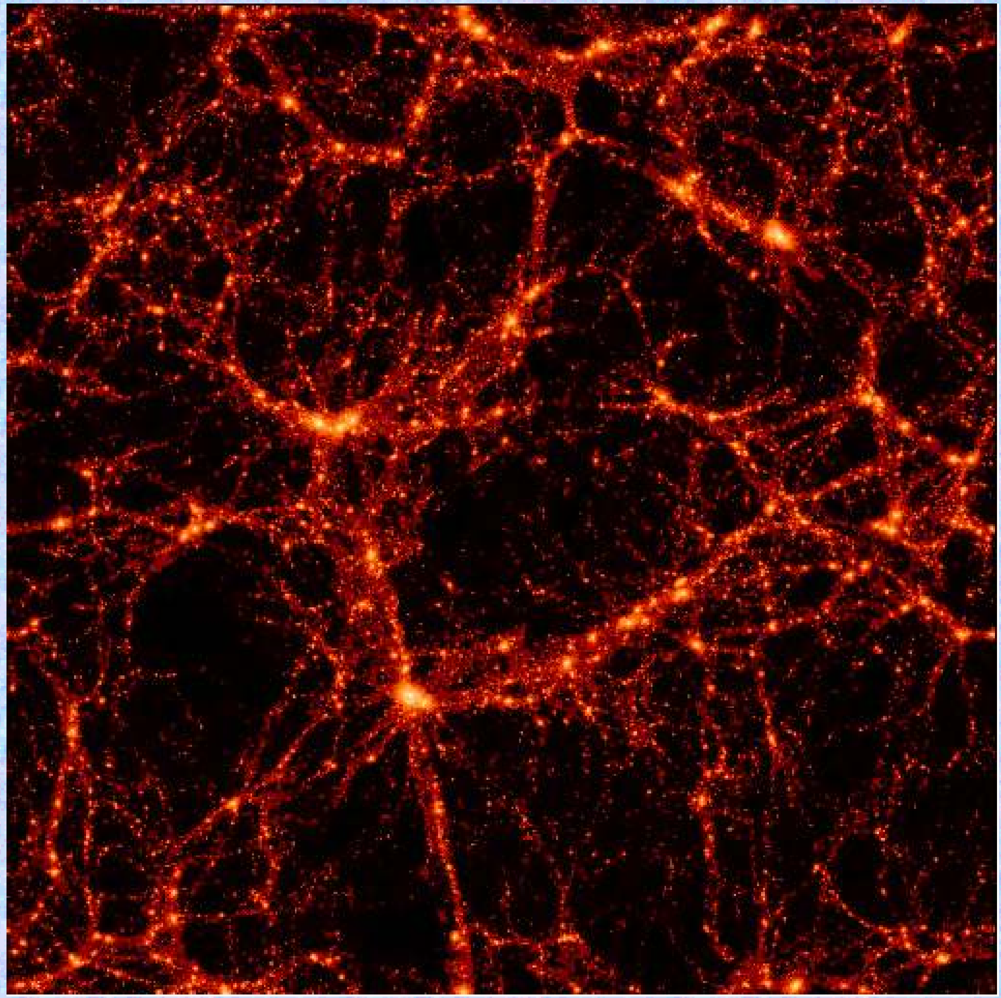
80% at $z$ >6

# Cumulative LALF with star burst & quiescent star formation



# Differences in observed and model LALF

1. Contamination due to other objects
   - < 5 % of LAEs could possibly be AGNs (Wang et al 2004)
2. Sample selection method ( EW and Flux limit)
   - Later it is shown that EW doesn't significantly change the LALF
3. Cosmic variance
4. Sample size



Credits: Virgo consortium

# Changing $z_{reion}$ from $z$=6.5 - 20

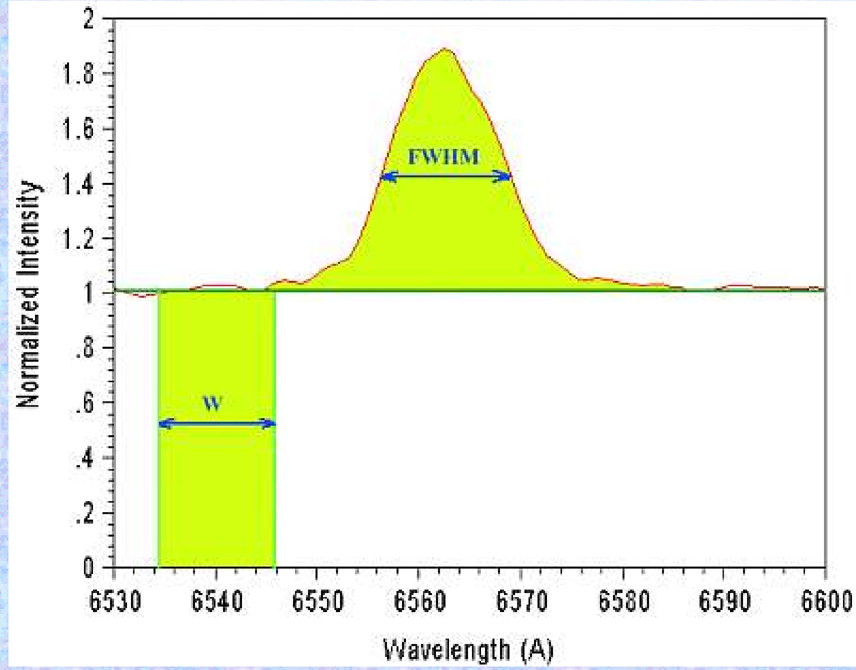
- Changes LALF by less than the scatter between different observational data sets

$f_{esc}$ =2% is very small.

This is because of top-heavy IMF ➔ SFR 10 times larger than standard IMF

# Predictions of observable properties of LAEs

## Equivalent width (EW)




Source: http://astrosurf.com/buil/us/spe2/hresol7.htm

## Computing EW of Ly alpha emission line each galaxy

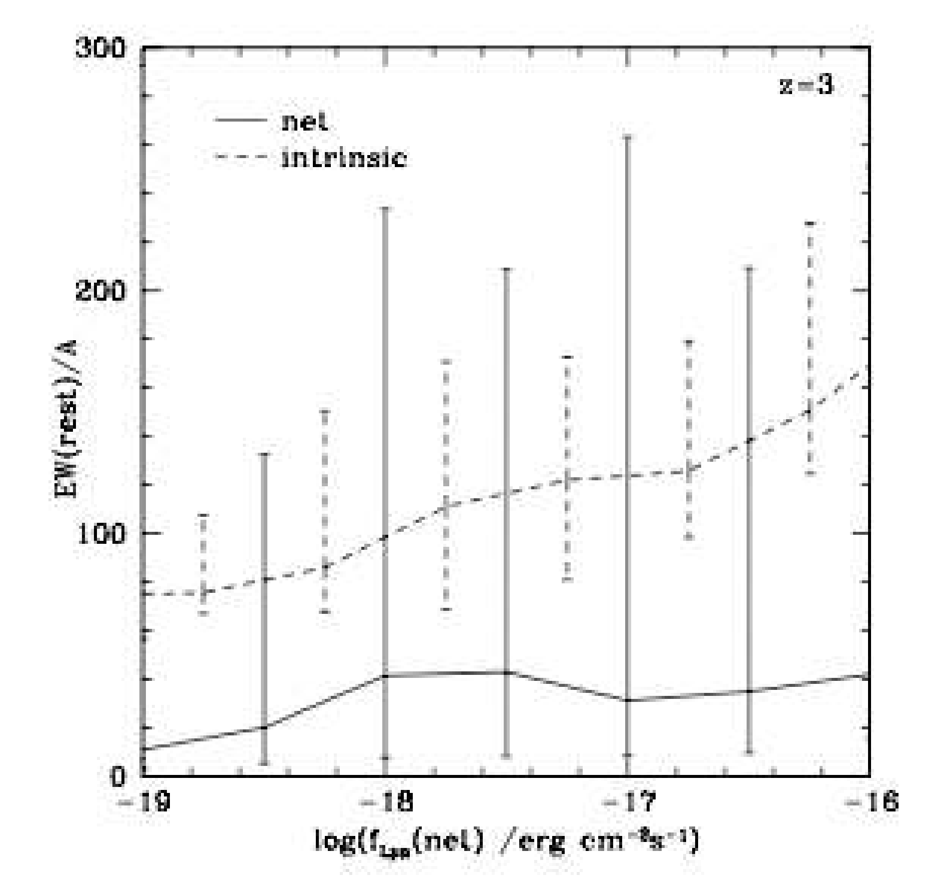
- Divide the luminosity in emission line by mean luminosity per unit wavelength of the stellar continuum on either side of the line

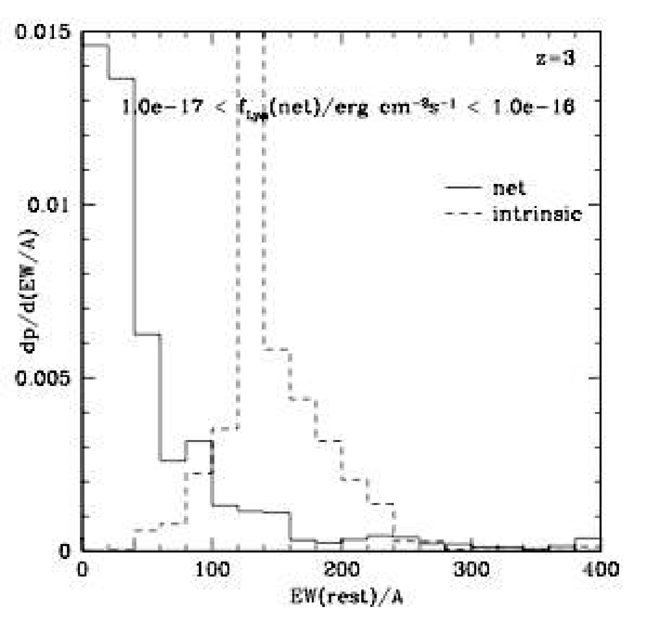
- Attenuate the stellar luminosity by dust extinction

- Multiply LAL by escape fraction

  $\Longrightarrow$ Net values

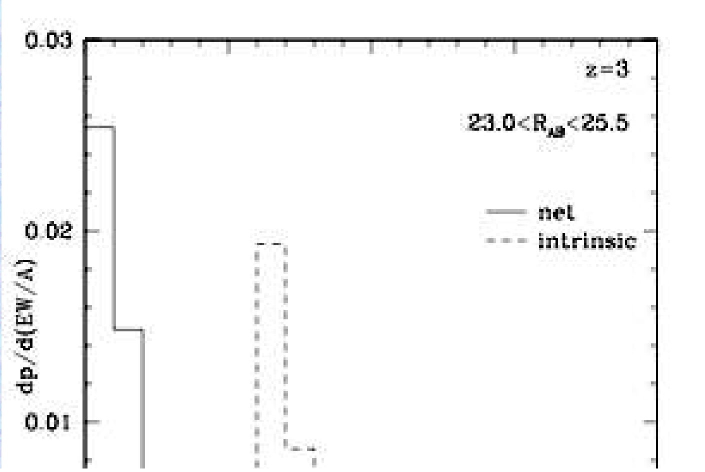
  $\Longrightarrow$ Before attenuation (Intrinsic)




LA flux $10^{-17}$ - $10^{-16}$ erg cm$^{-2}$ s$^{-1}$

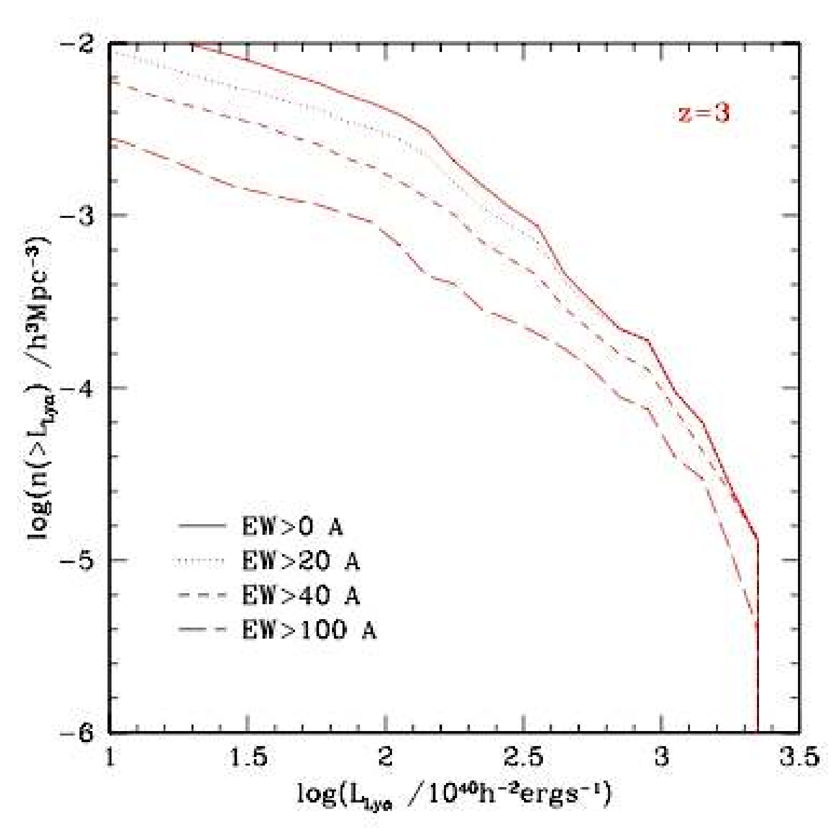
Median EW vs LA flux

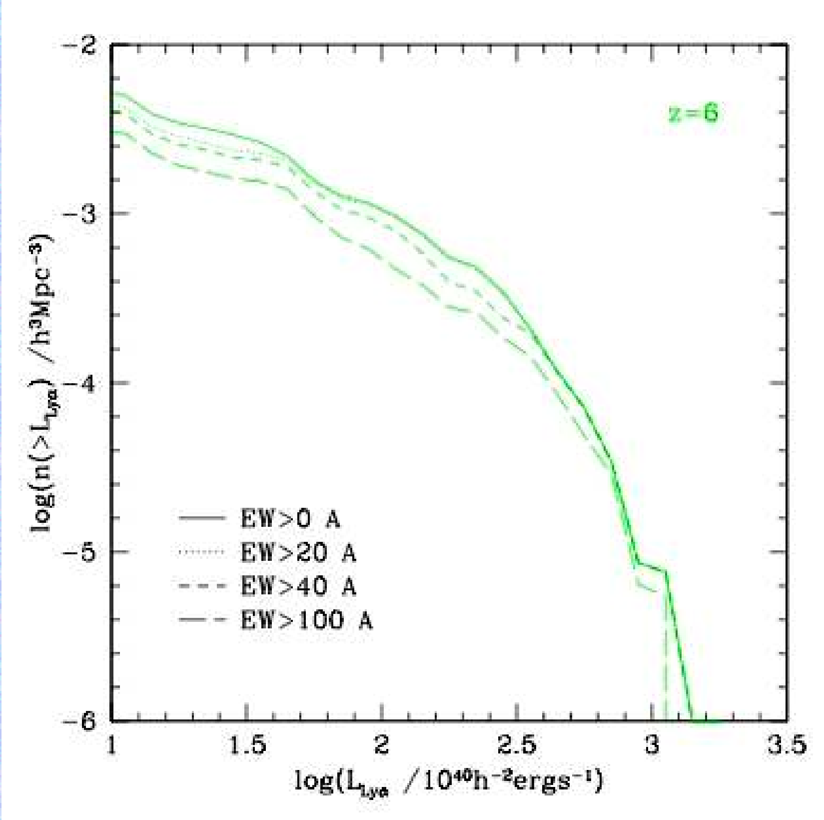



Wide spread between net & intrinsic EW

$F_{esc}$ of Ly$\alpha$ decreases EW , while dust decreases continuum ➔ increases EW

# Effect of different EW threshold on LALF



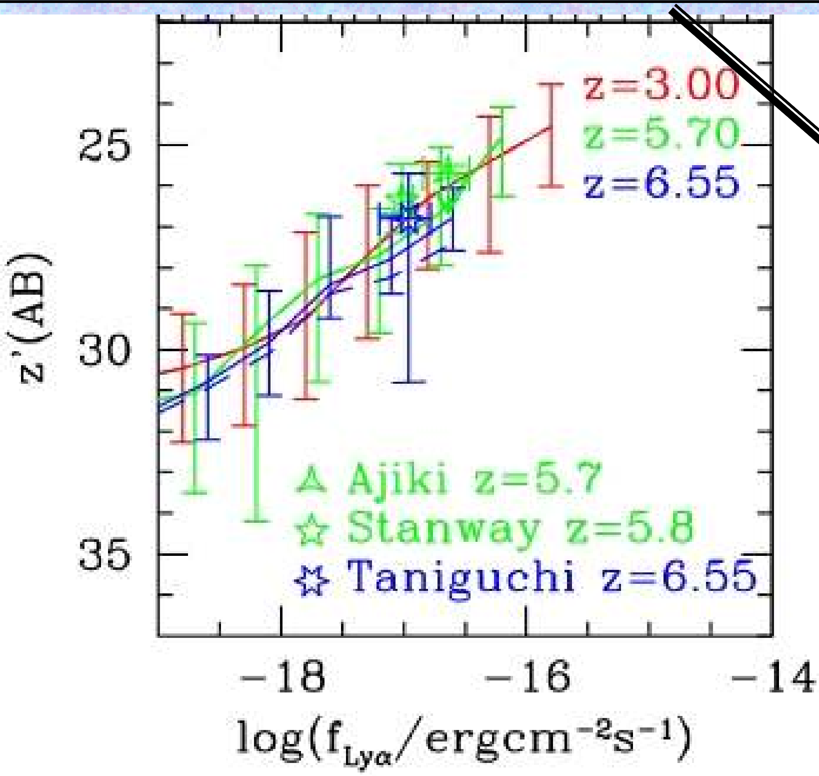

Most of the observation data have $EW_{min}$ ~ 20A

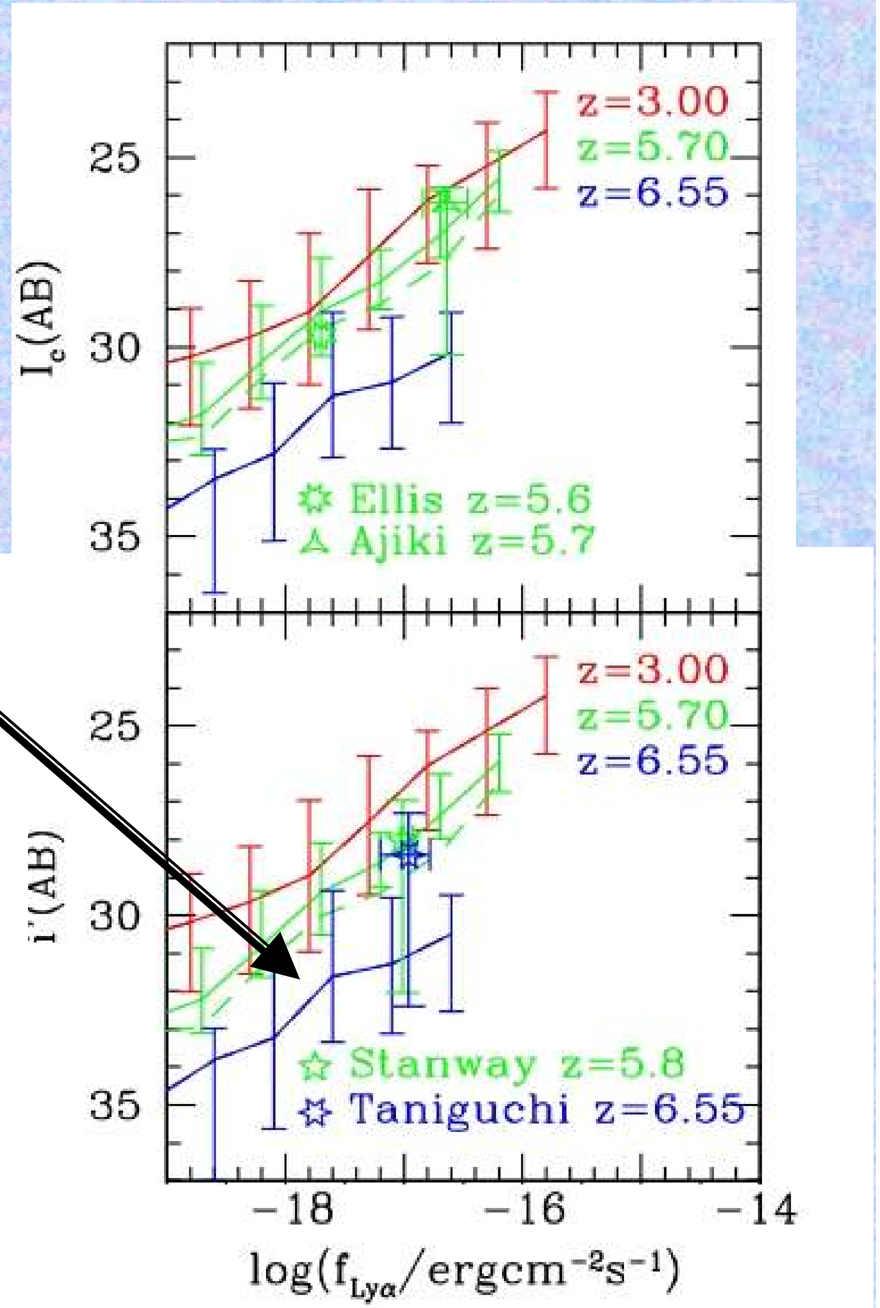
➔ Does not affect the LALF significantly

# Stellar continuum measured in broad-band filters

- Corrected for dust extinction
- Dust attenuation by IGM

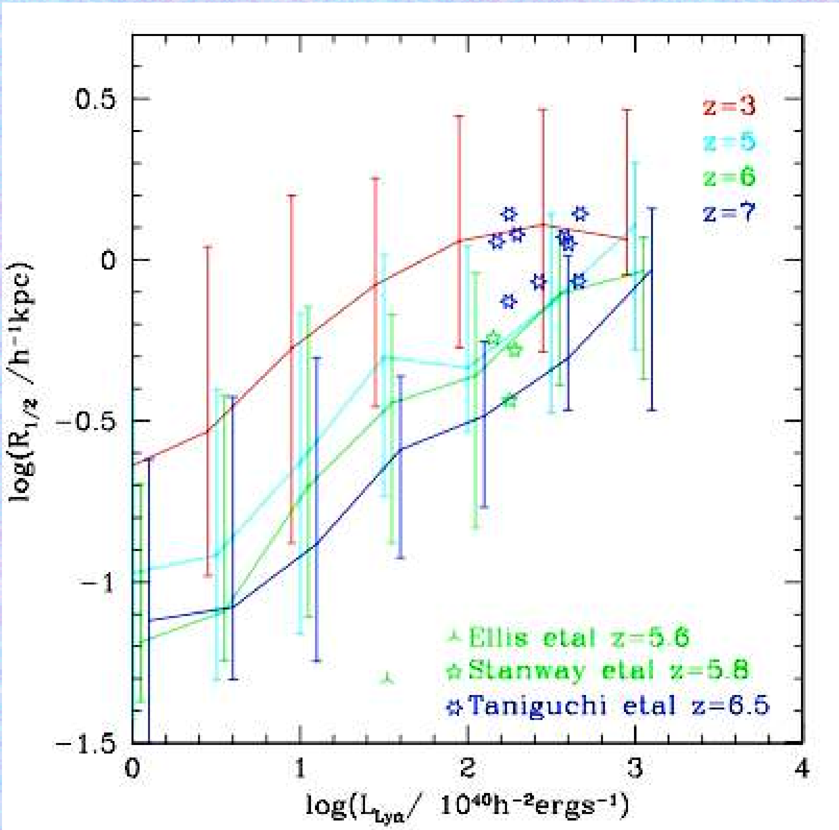
3 mag off



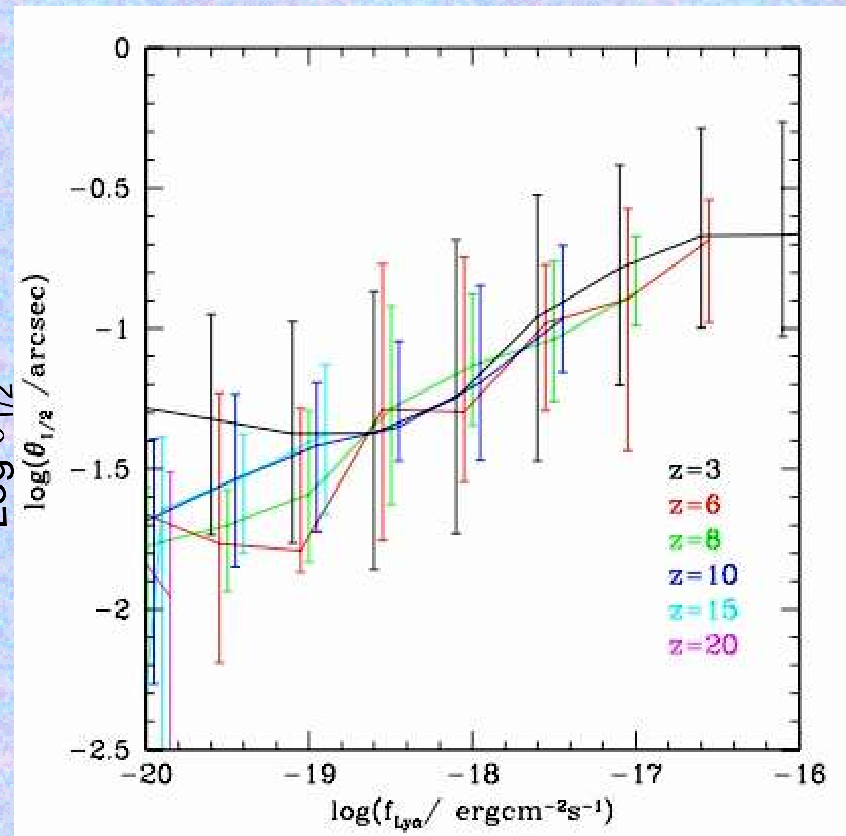
# LAE sizes

Log $R_{1/2}$




Log(Lyα )

Log $\theta_{1/2}$




Log($f_{Ly\alpha}$ )

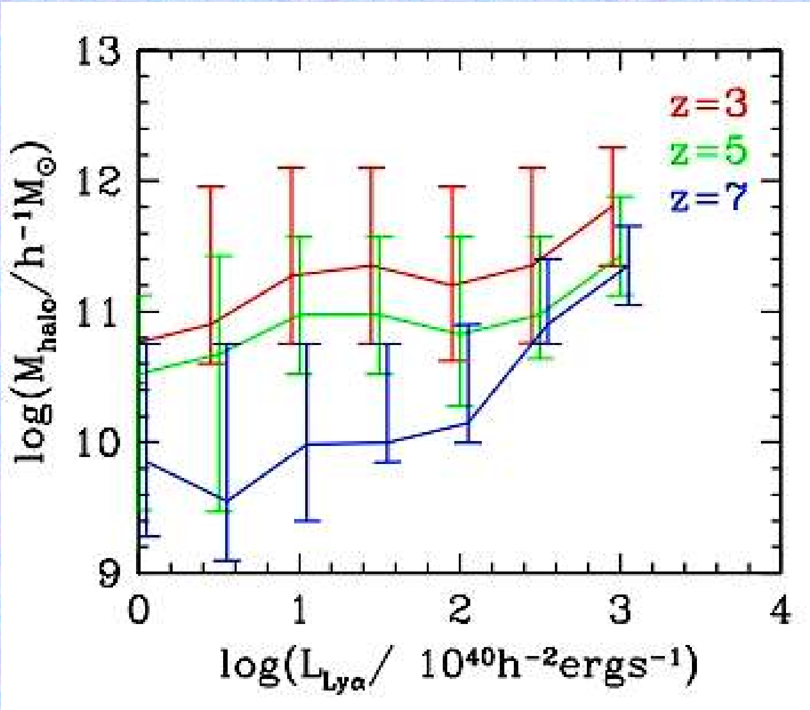
Half mass radii decreases from 1.4 Kpc at $z$=3 to 0.7 Kpc at $z$=7

$$R_{1/2} \propto L^{1/3}$$

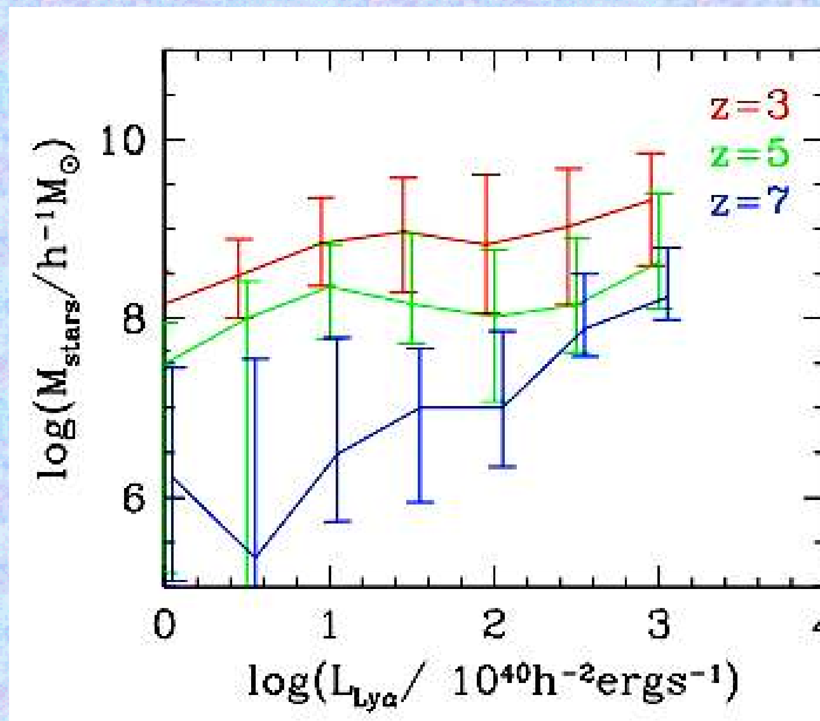
Taniguchi et al finds sizes 2 times larger

This might be due to extended Ly$\alpha$ emission

**Dark matter halo masses**

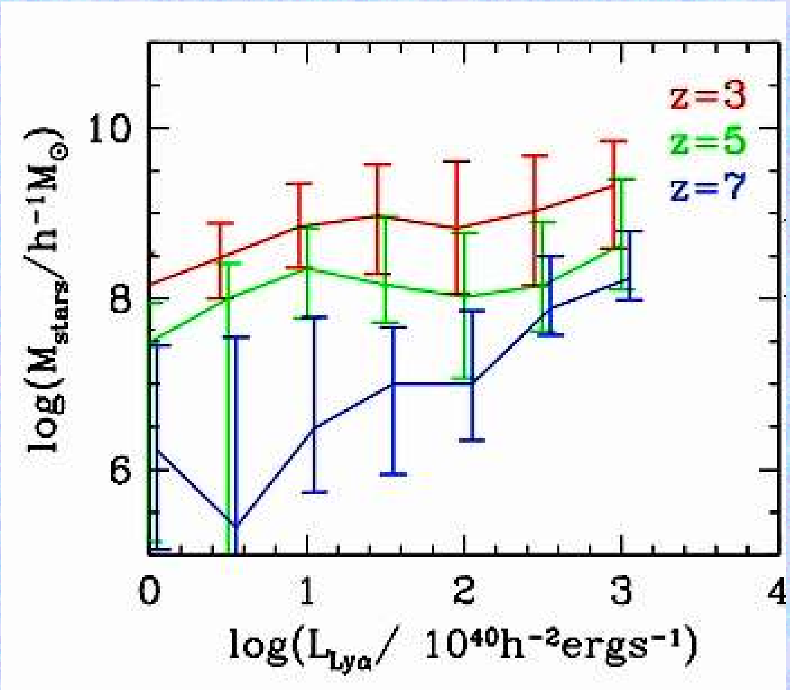



**Stellar mass**




- At a given luminosity, halo mass decreases with redshift
- At lower luminosity, the trend is stronger
- Stellar mass follows the DM halo masses

**Stellar mass**

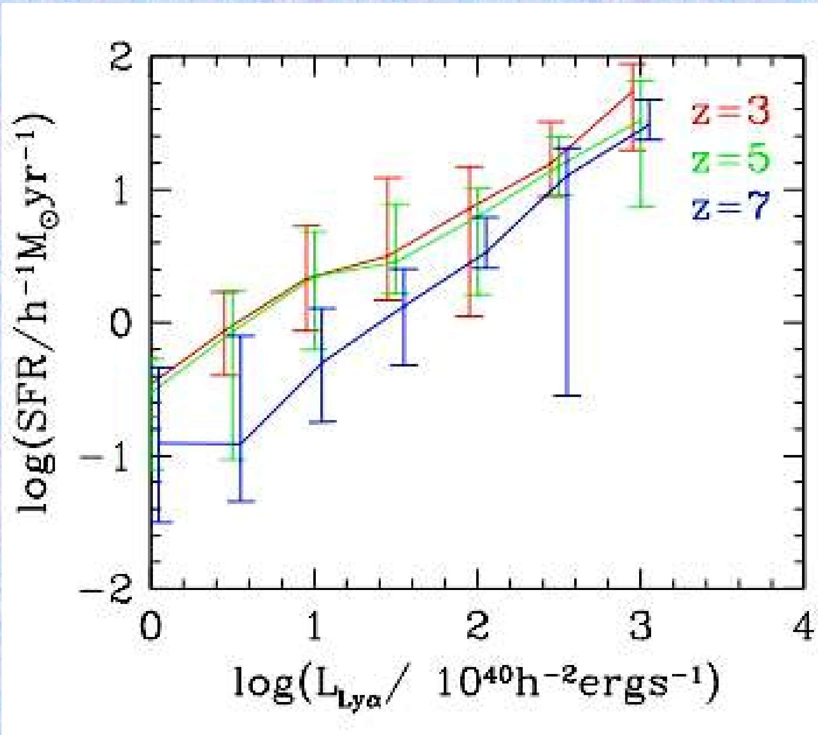


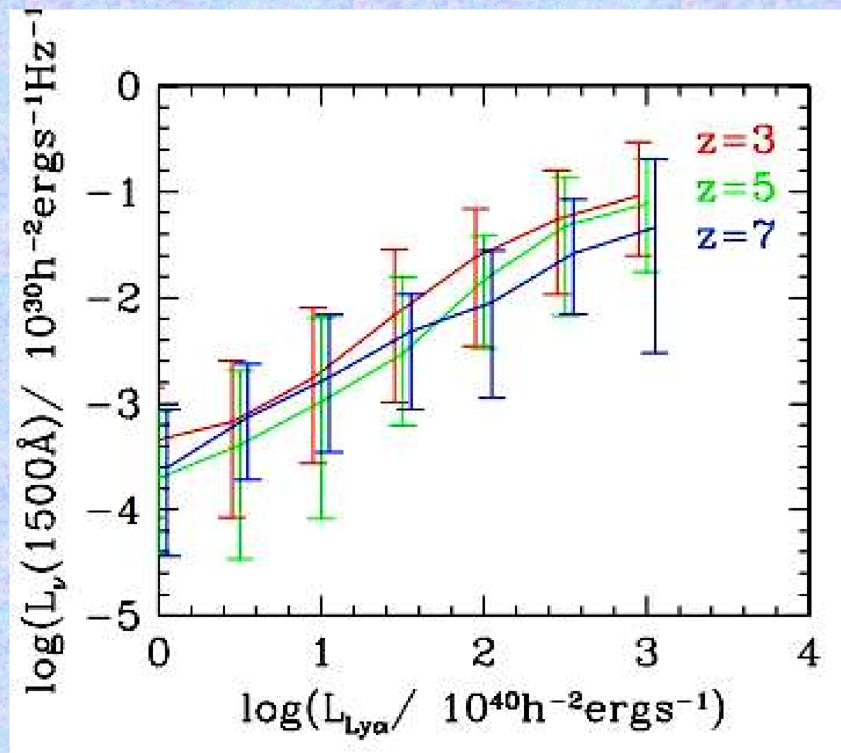

- At higher $L_{Ly\alpha}$, LAEs are dominated by bursts
- At lower $L_{Ly\alpha}$, LAEs are dominated by quiescent star formation

Weak dependence of mass on $L_{Ly\alpha}$ at low *z*

- Bursts introduces large scatter in the relation between instantaneous SFR and mass

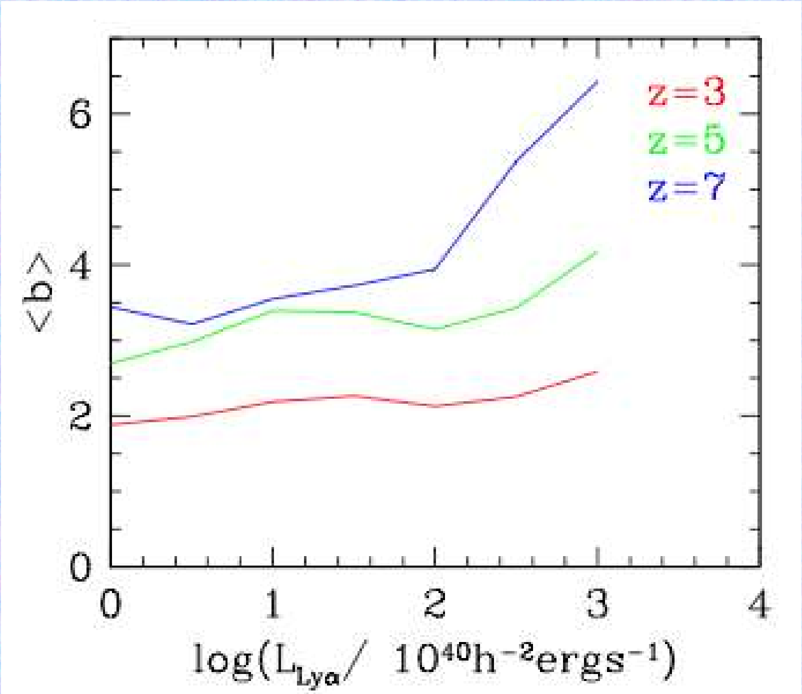
**Star formation rate** **UV continuum**



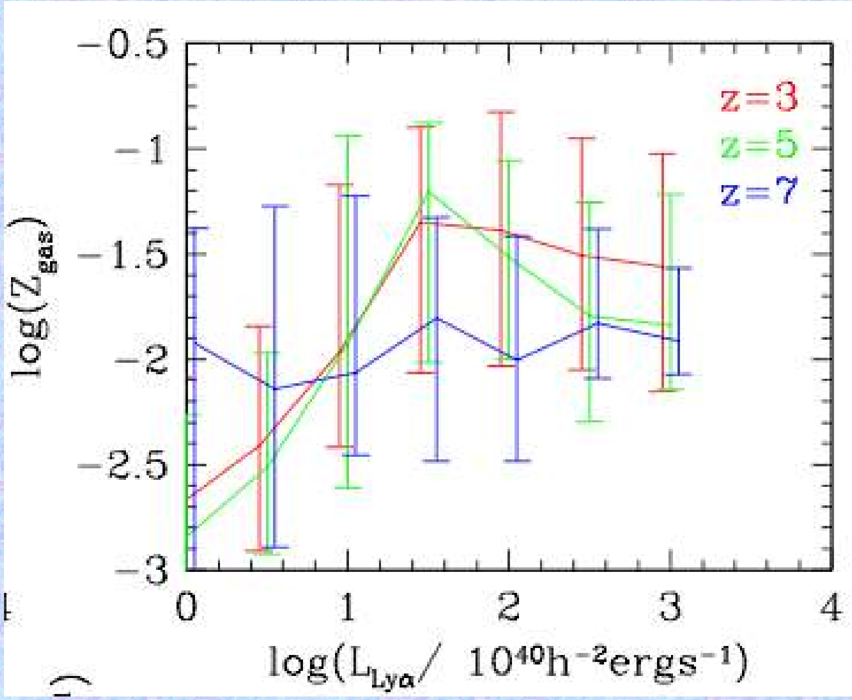




- $L_{Ly\alpha}$ follows the SFR
- The trend increases with *z* due to the increases in IMF (starburst galaxies)
- UV continuum follows $L_{Ly\alpha}$

**Clustering bias**




**Metallicities of cold gas**

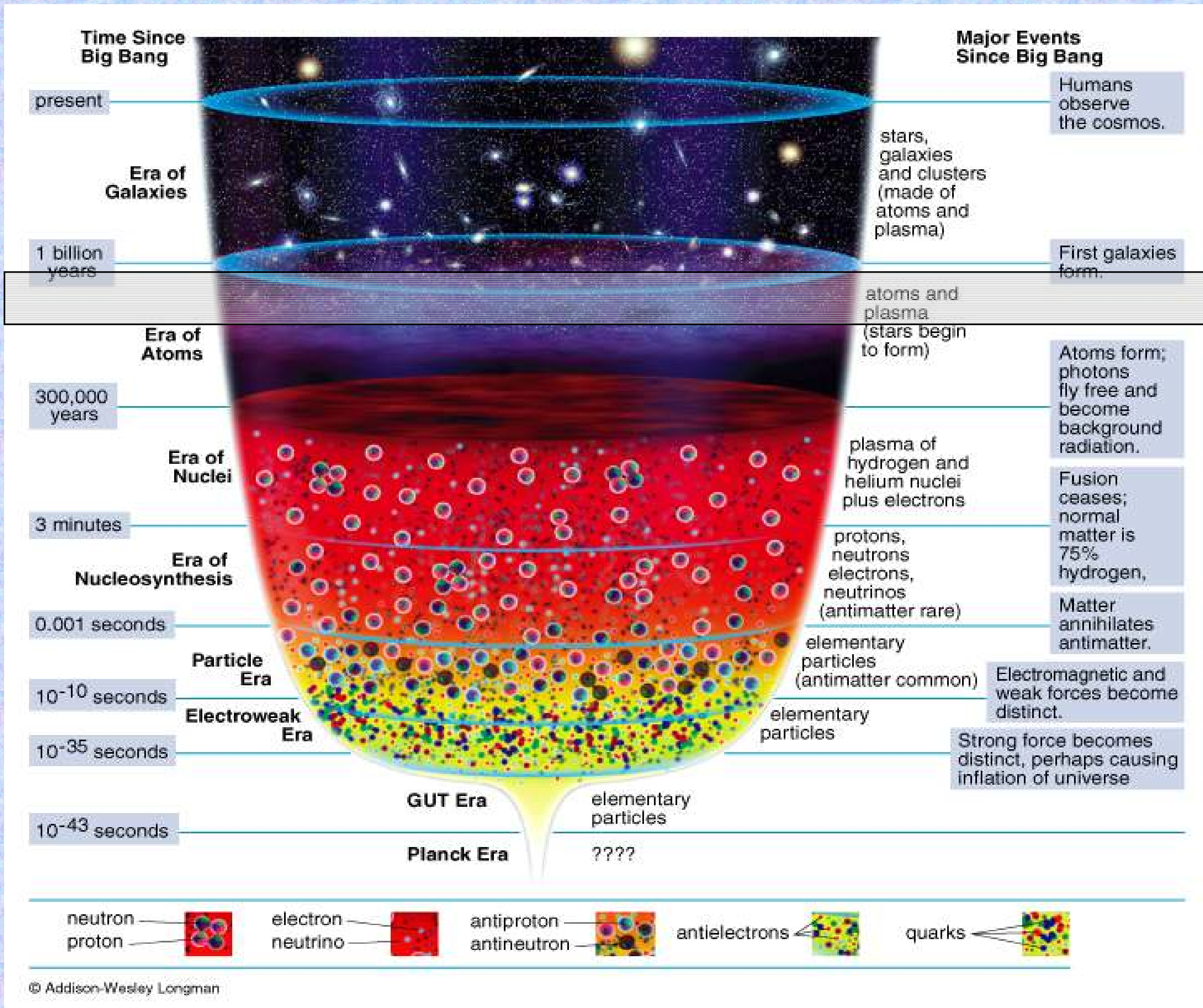



- At a given luminosity, clustering bias increases with *z*
- Metallicities are comparable to Solar even at high *z*

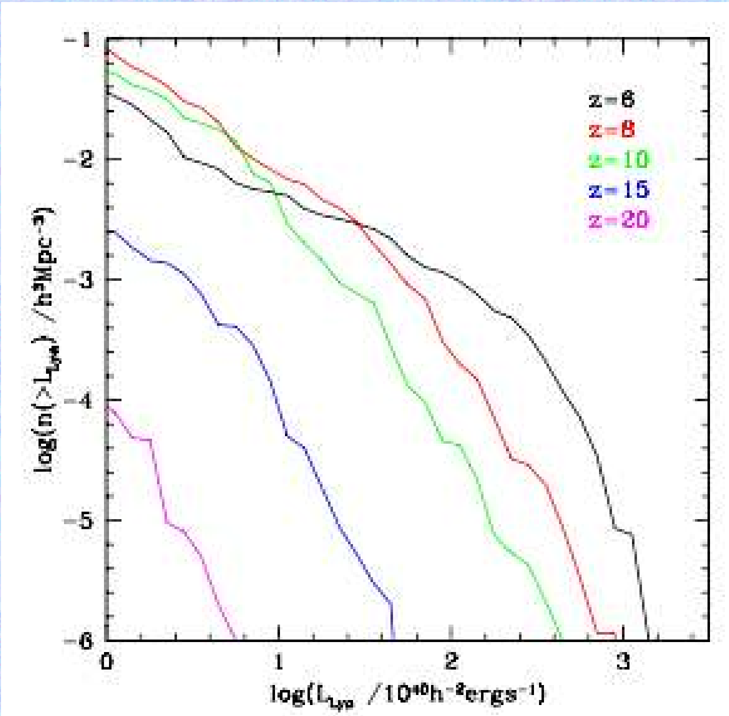
  ⟶ *self enrichment by galaxies*

*Because mean metals in baryons is lower at high z*

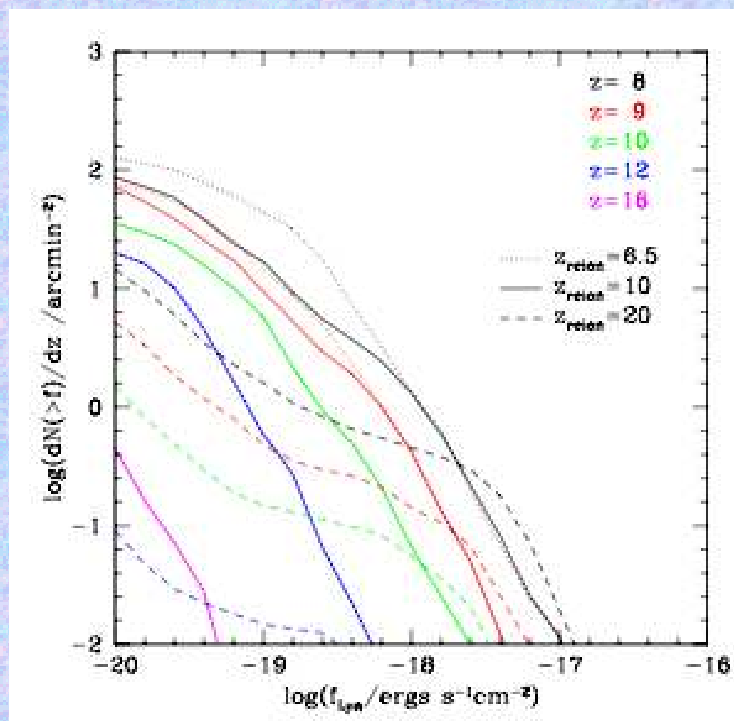
# abundances of LALF at z >7



# abundances of LALF at z >7




Cumulative LALF
assuming $z_{reion}$=10




LALF with different $z_{reion}$

# Conclusions

Assuming constant $f_{esc}$

**Everything matches with everything**