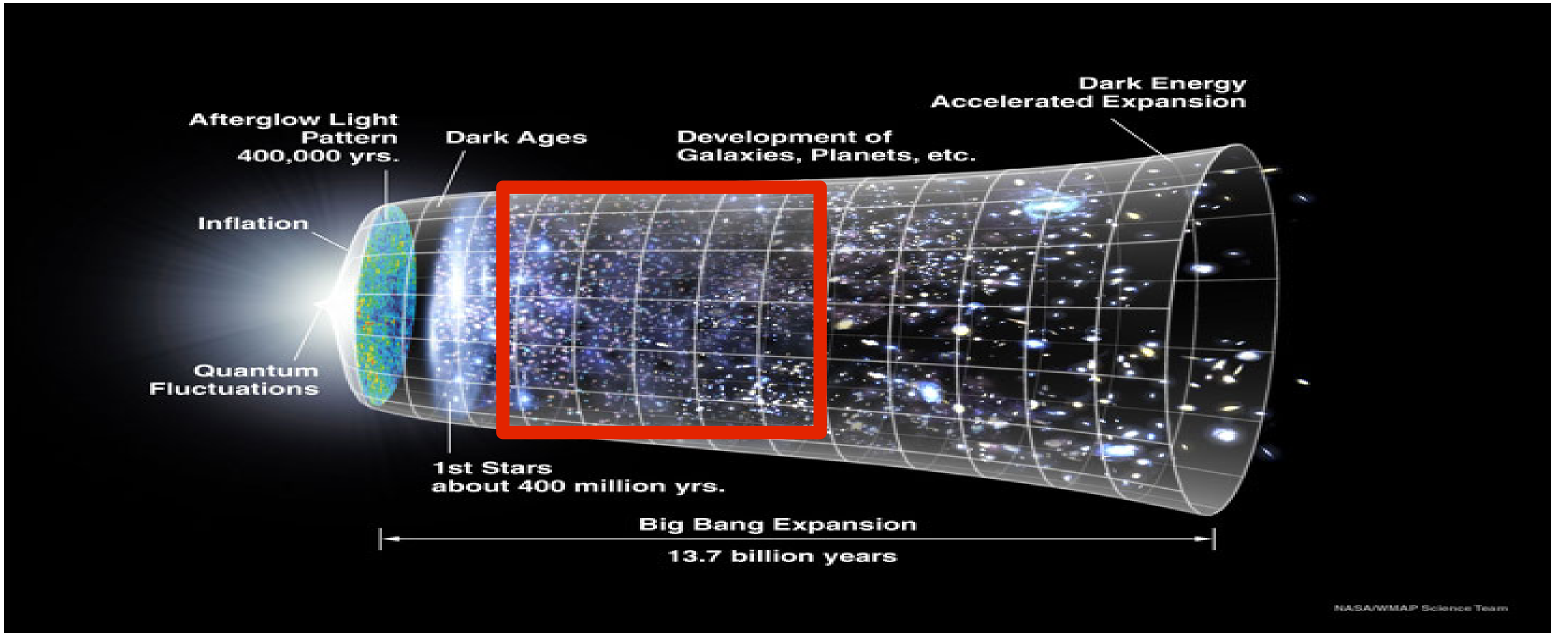
The earliest galaxies: probing cosmic dawn

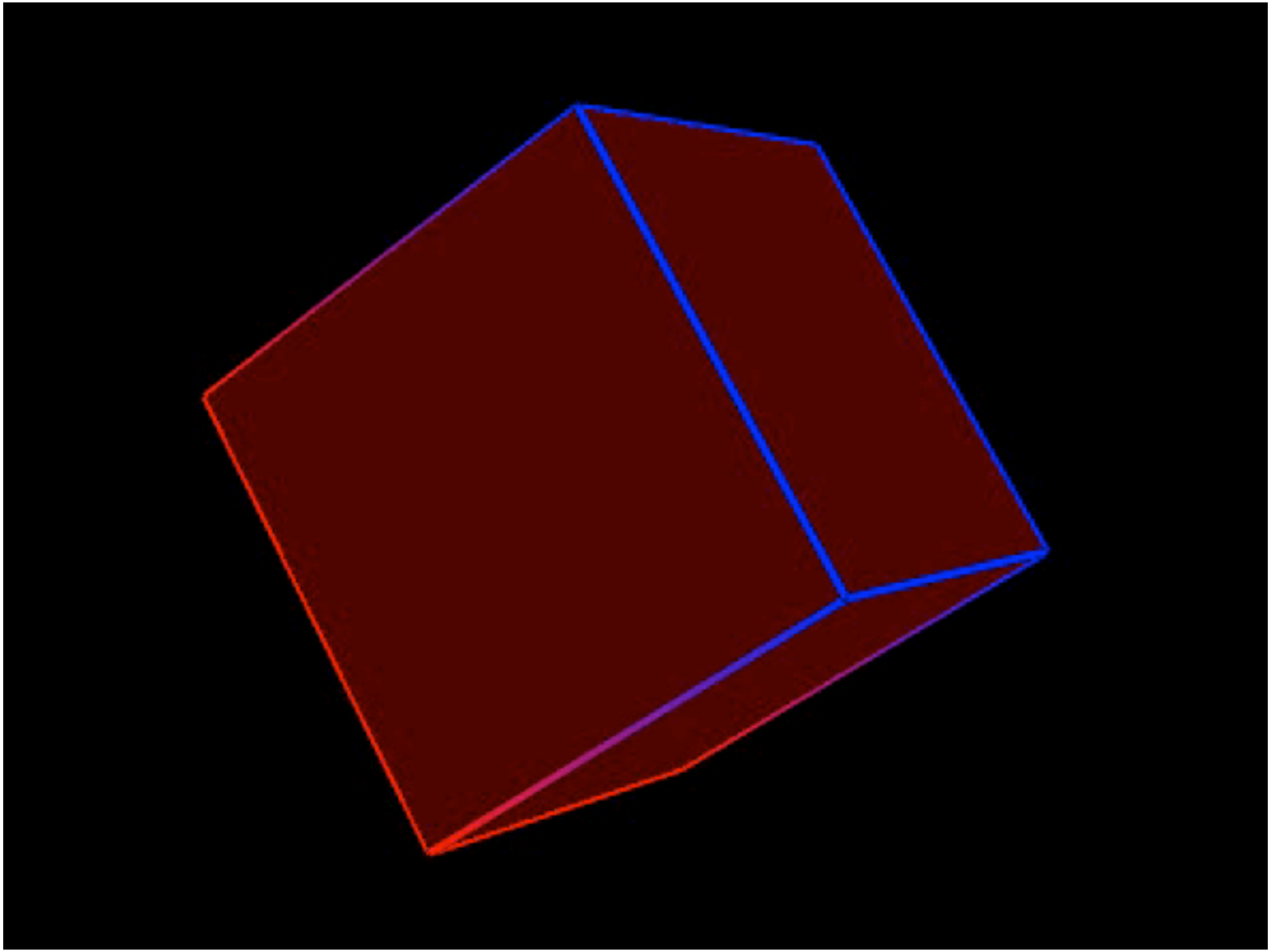
Pratika Dayal



Collaborators: Stefano Borgani, Benedetta Ciardi, James Dunlop, Andrea Ferrara, Umberto Maio, Antonella Maselli, Alex Saro, Luca Tornatore

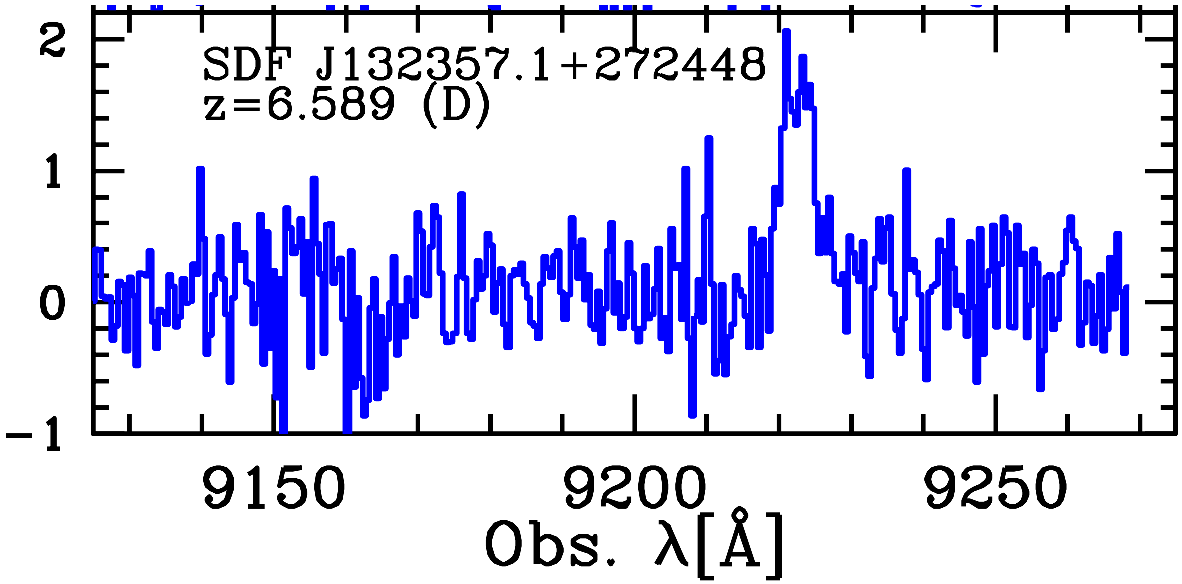
AlbaNova and Oskar Klein Centre, 4th December 2012

Reionization in one slide



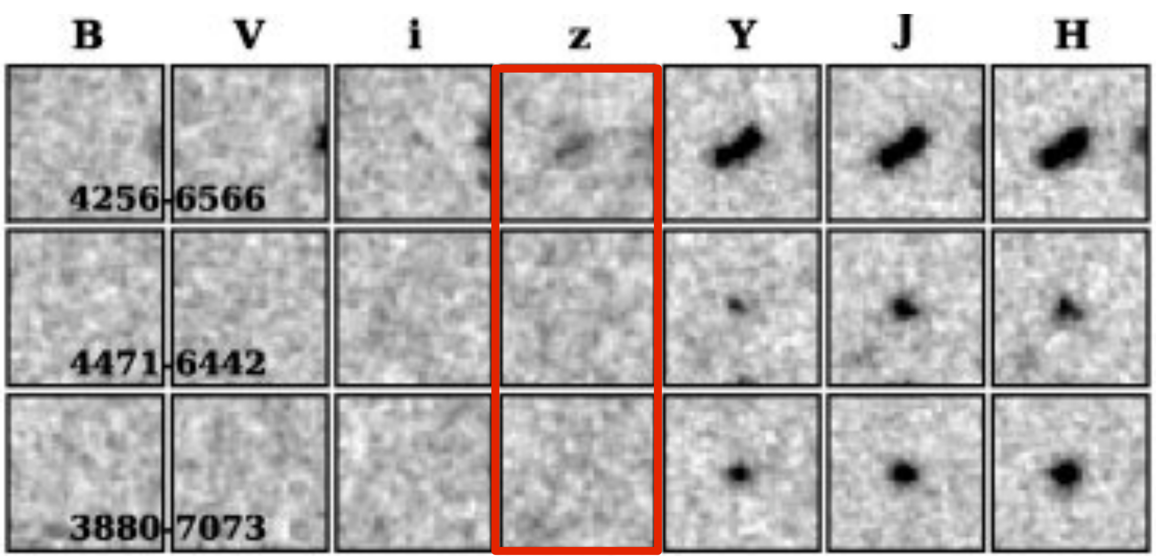
Courtsey: Nick Gnedin, http://home.fnal.gov/~gnedin/MOVIES/ifrit_REI5.mpg

Observing LAEs and LBGs



LAEs - Narrow Band Spectroscopy to observe very strong and narrow Lya emission line to get exact source redshift.

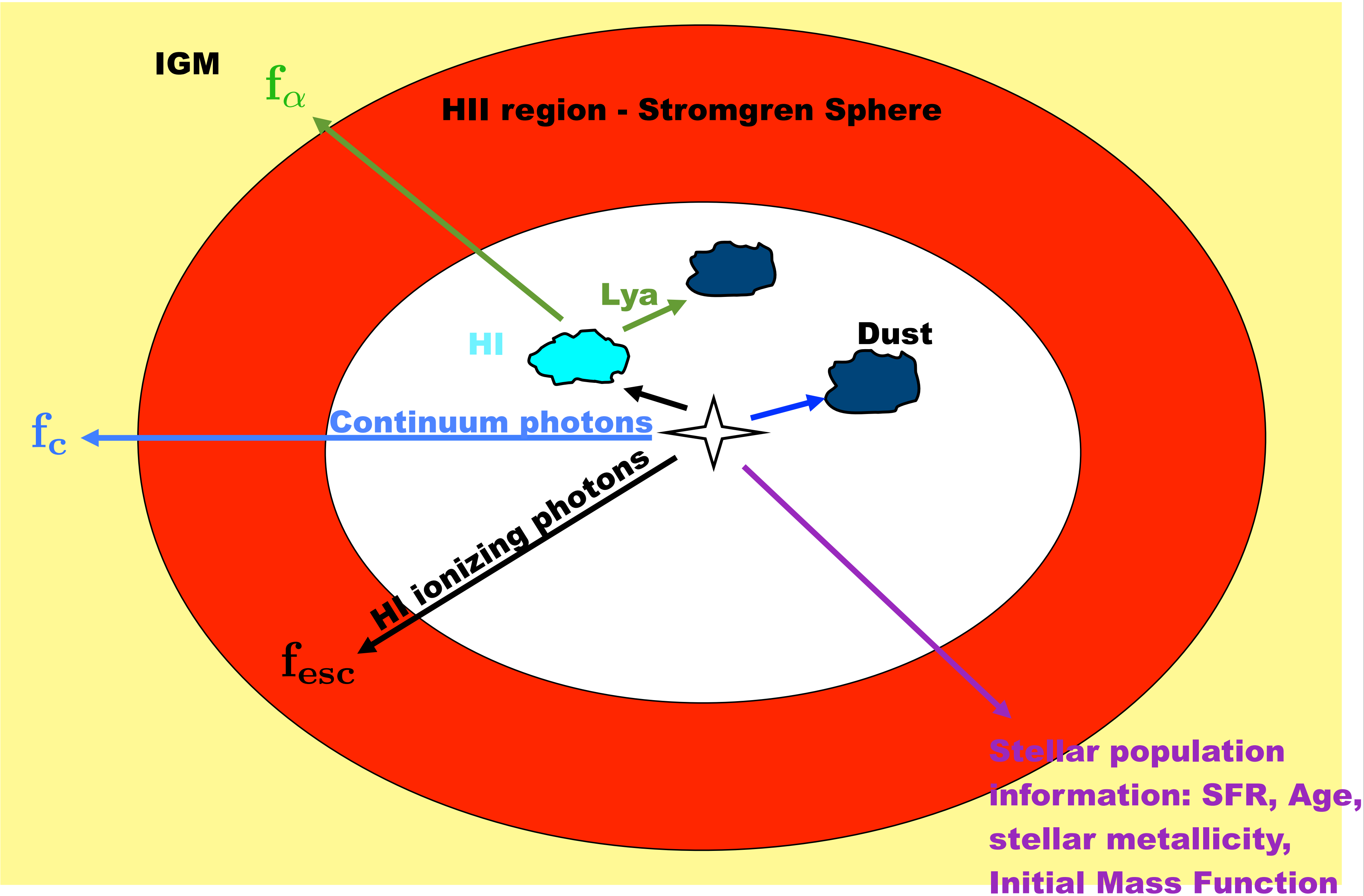
Kashikawa+2006 - z~6.5 LAE



LBGs - Broad Band photometric band in which galaxy drops-out used to obtain redshift.

Oesch+2010 - z~7 dropouts

Modelling LAEs and LBGs : the ingredients



A panchromatic view of high-z galaxies: theorist's wish list

- **Explaining the observables and constraints on reionization**

- **Connecting diverse galaxy populations : Lyman Alpha Emitters (LAEs) & Lyman Break Galaxies (LBGs)**

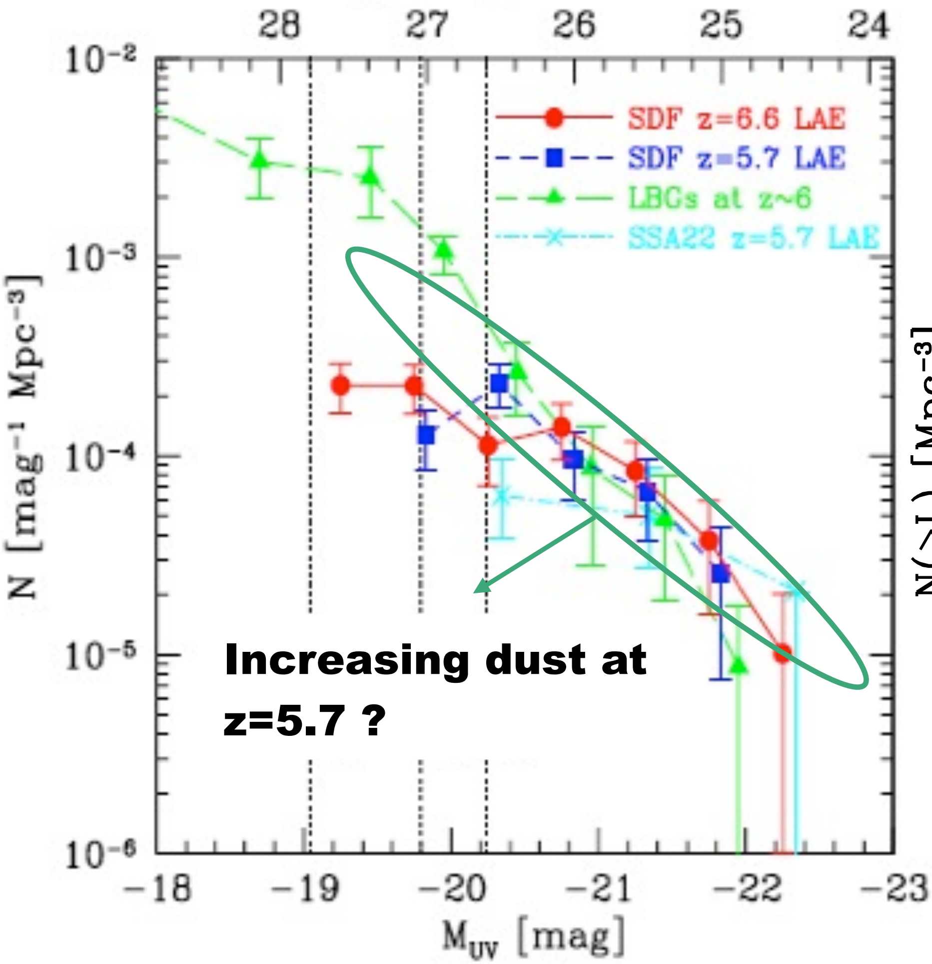
- **The evolution of the Luminosity function (LF): density or luminosity driven?**

- **Linking these high-z galaxies to the local Universe**

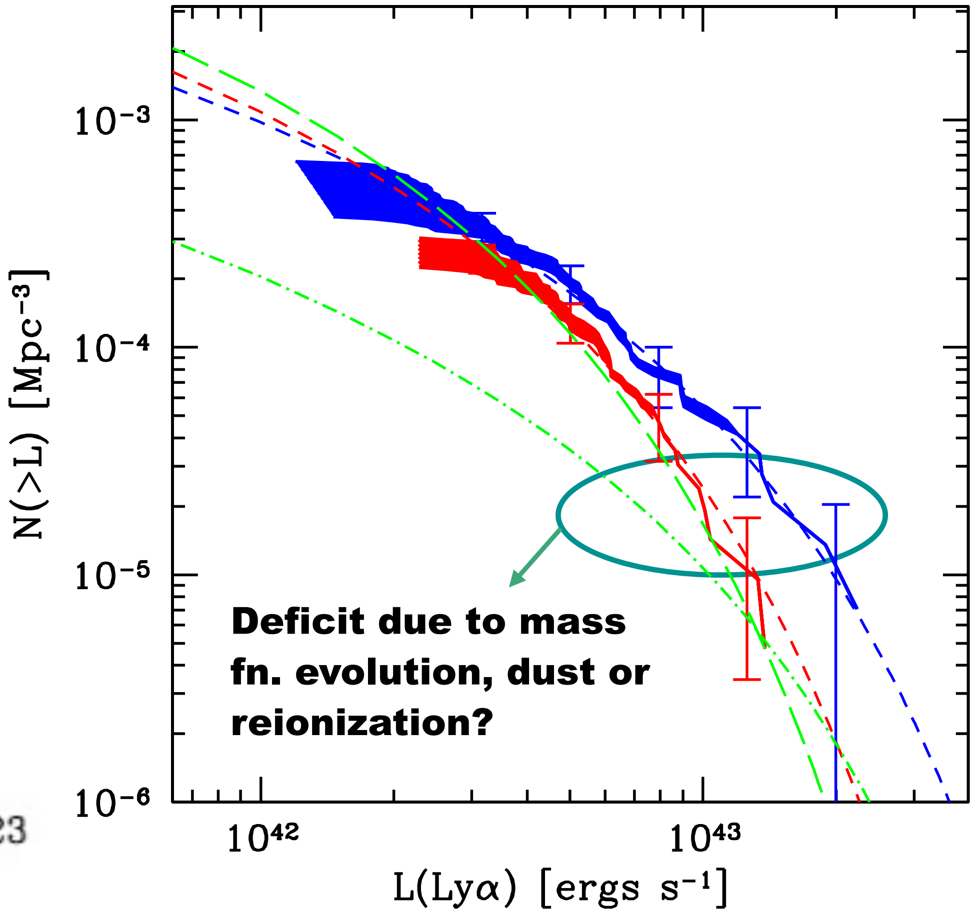
Understanding Lyman Alpha and UV data: constraints on reionization

LAE Luminosity functions

UV LF - shaped by ISM dust



Cumulative Lya LF - shaped by ISM dust & IGM transmission

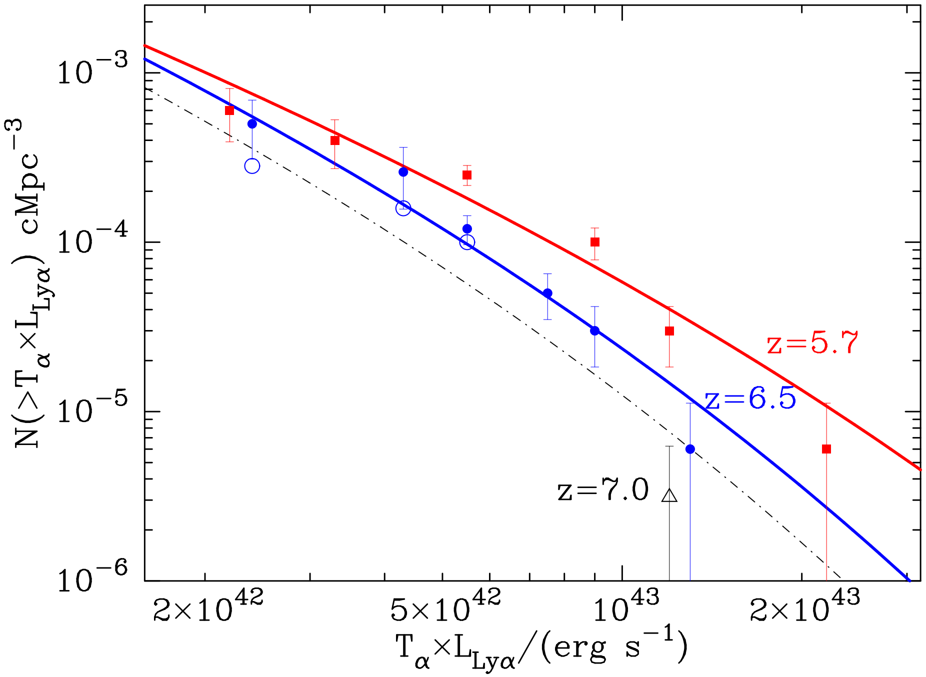


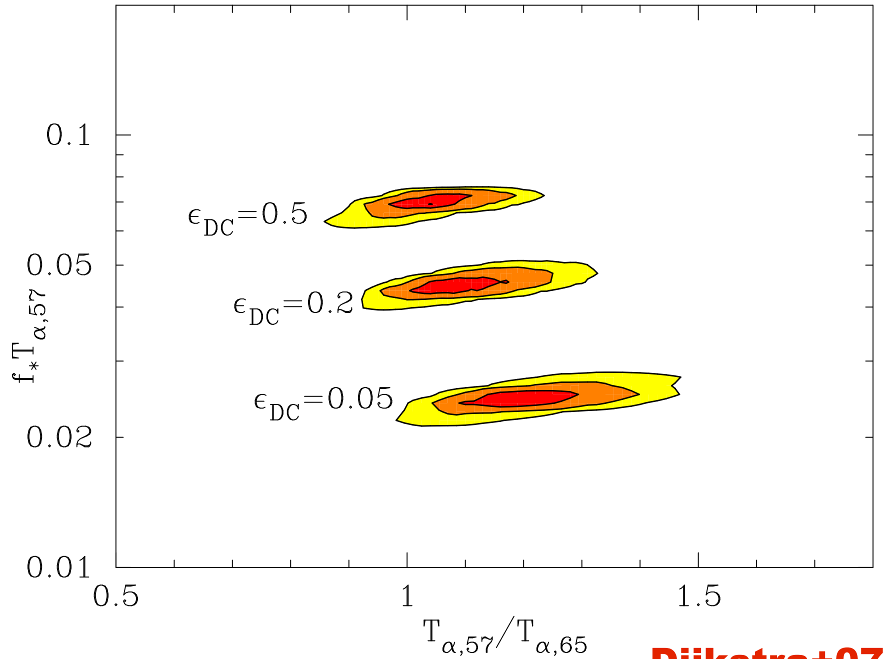
Kashikawa+06,11; Shimasaku+06; Ouchi+08

Theoretical models: interpreting the data

1. Semi-analytics: reionization over by z~6.6

Dijkstra+07, Dayal+08, Tilvi+09





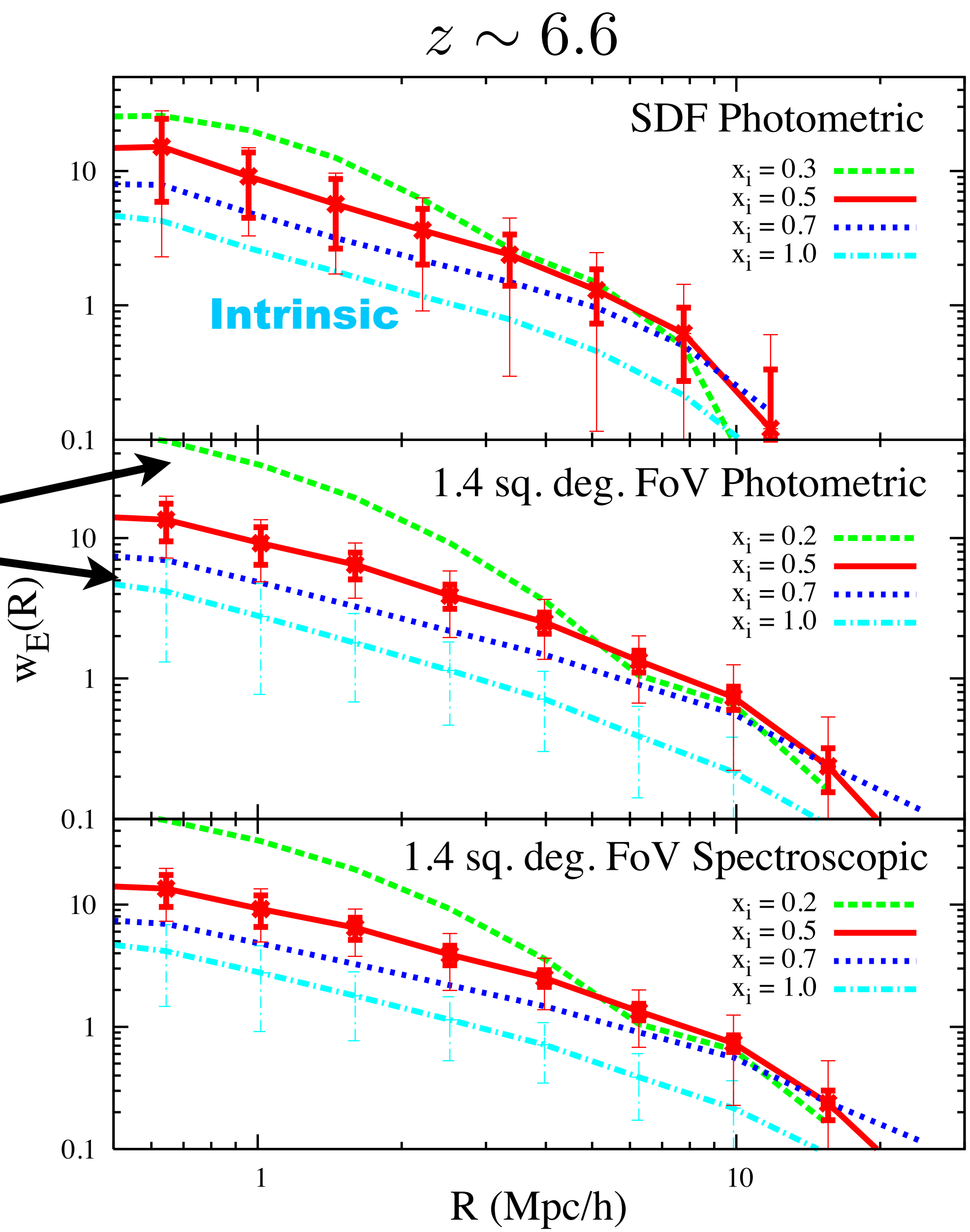
Dijkstra+07

- **Lya LF at z~5.7,6.6 perfectly explicable solely with an evolution of the underlying mass function**
- **About 20% decrease in IGM Lya transmissivity between z~5.7 and 6.6 consistent with a pure IGM density evolution (~30%).**
- **Reionization does NOT shape the Lya LFs between z~5.7 and 6.6 (contrary results found by Kobayashi+2007).**

2. N-body simulations : reionization effects on LAE clustering

McQuinn+08, Orsi+09

Increasing neutral IGM increases the measured clustering of LAEs



58 LAEs

250 LAEs

190 LAEs

McQuinn+08

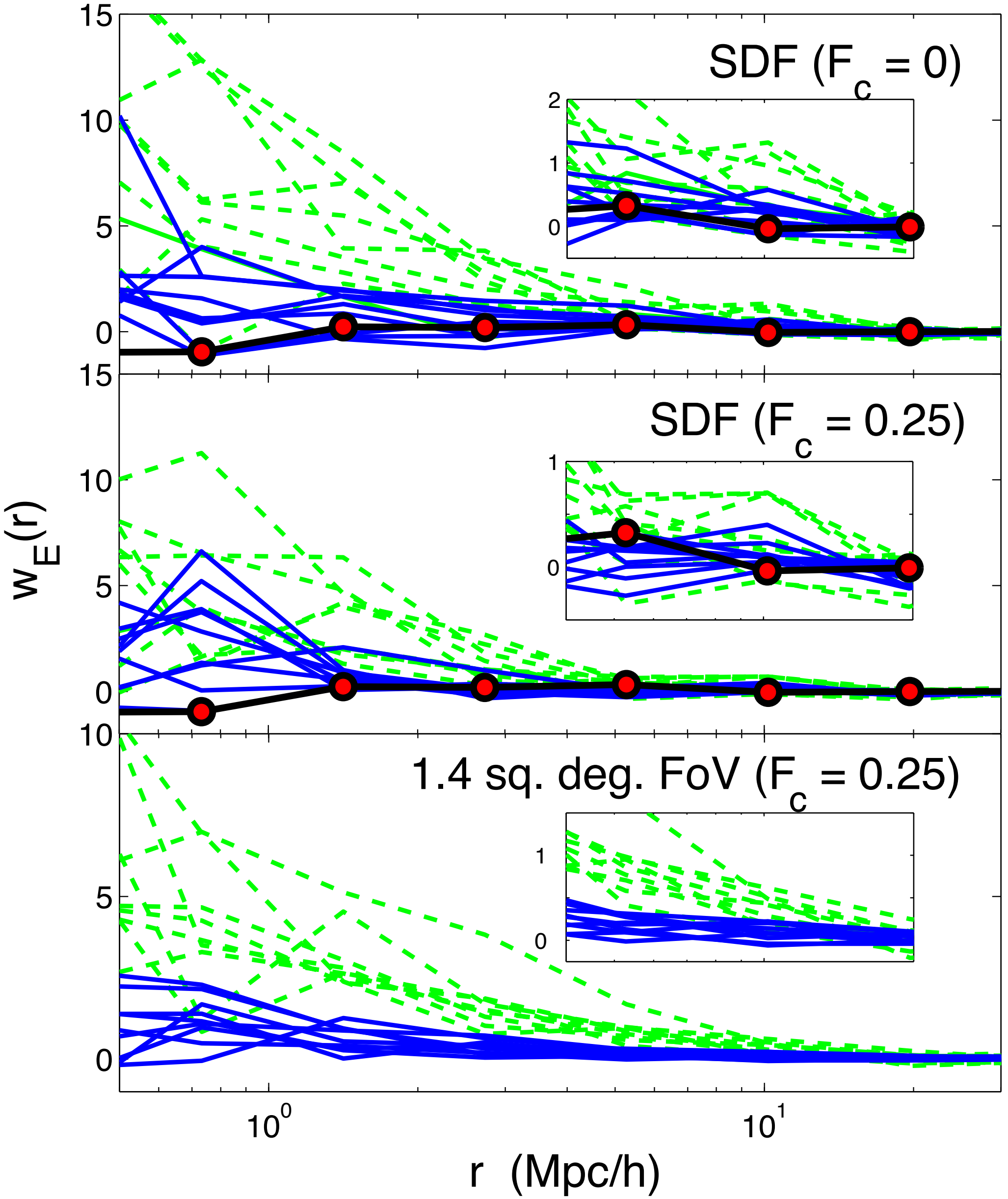
2. N-body simulations : reionization effects on LAE clustering

McQuinn+08, Orsi+09

$\chi_i = 1.0$

$\chi_i = 0.5$

At 2-sigma level, LAE data at z~6.6 more compatible with a fully ionized IGM as compared to one that is half neutral.

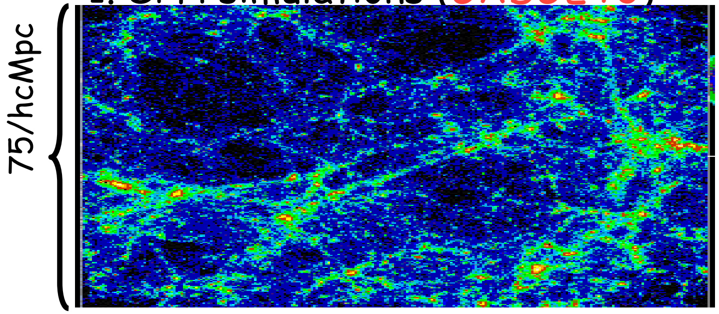


McQuinn+08

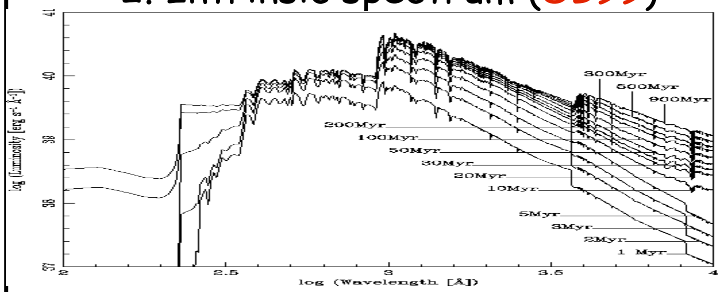
3. Cosmological SPH simulations : dust and reionization

Iliev+08; Nagamine+10; Jensen+12; Jeeson-Daneil+12; Baek+12; Zheng+11,12

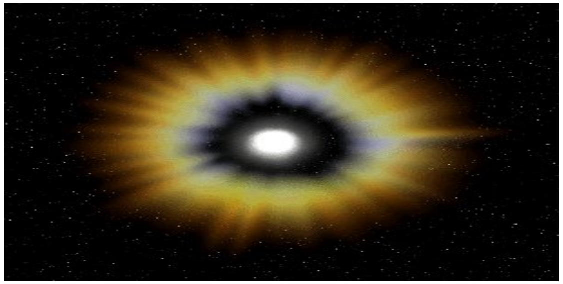
1. SPH simulations (GADGET3)



2. Intrinsic spectrum (SB99)



3. SNII dust enrichment

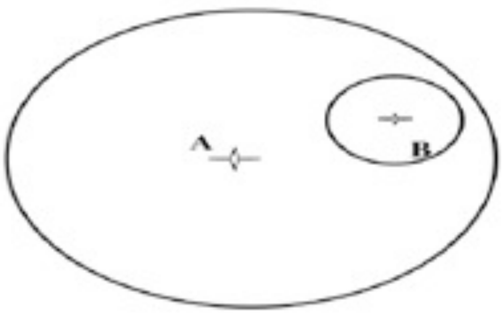


Obtain the escape fraction of UV photons, f_c

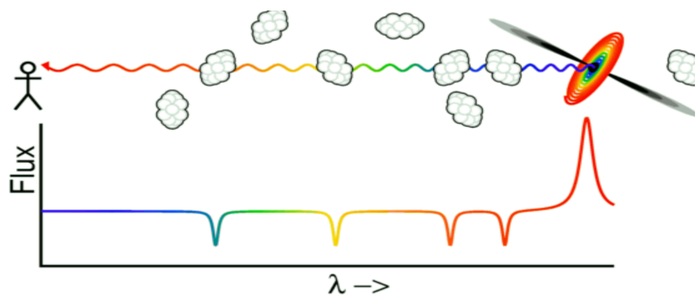
This fixes the UV luminosities of all galaxies.

Only free parameter to match LAE Lya LF is f_α / f_c

4. Clustered galaxies



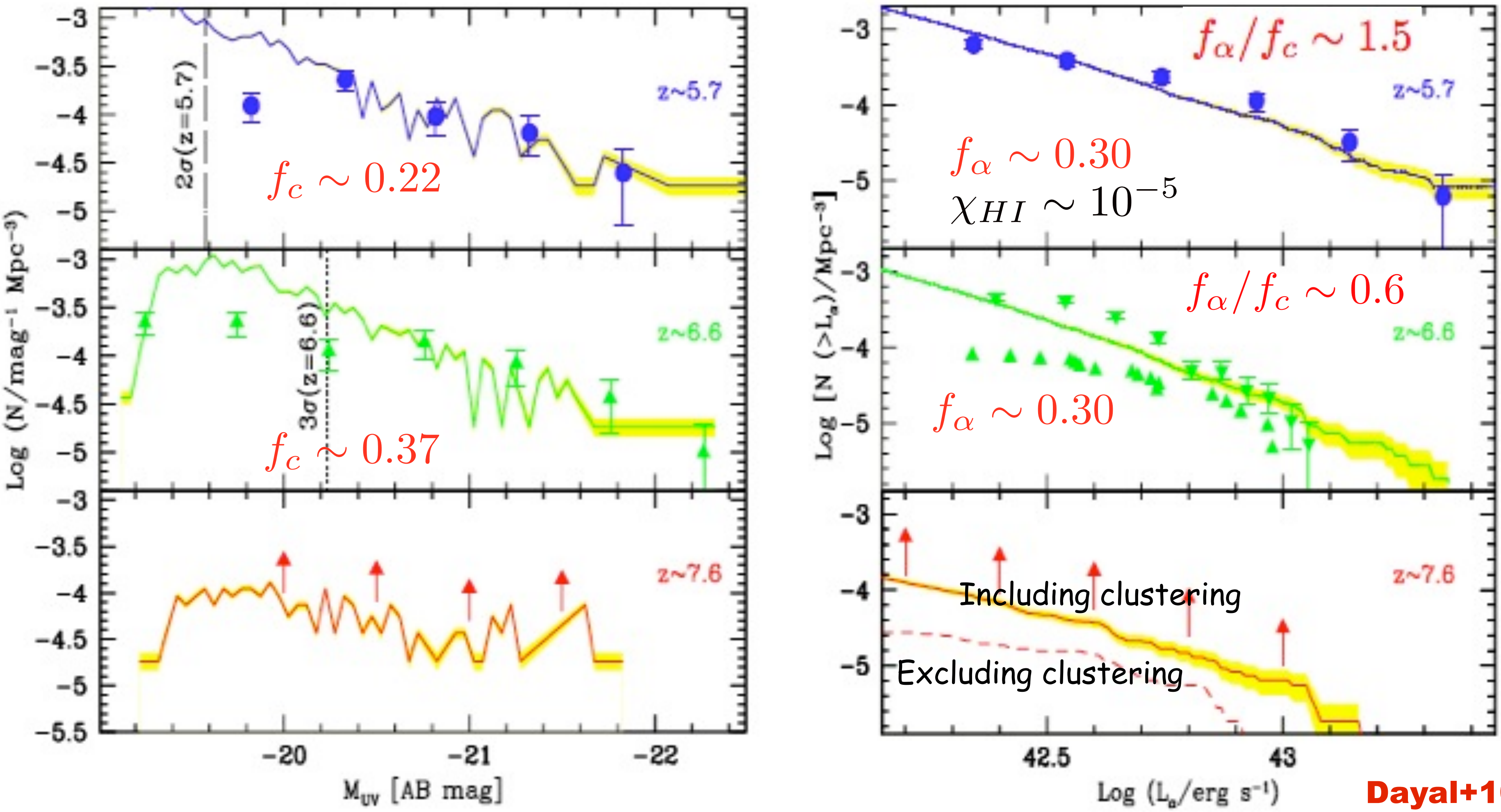
5. IGM Transmission



Dayal+09,10,11,12

3. Cosmological SPH simulations : dust and reionization

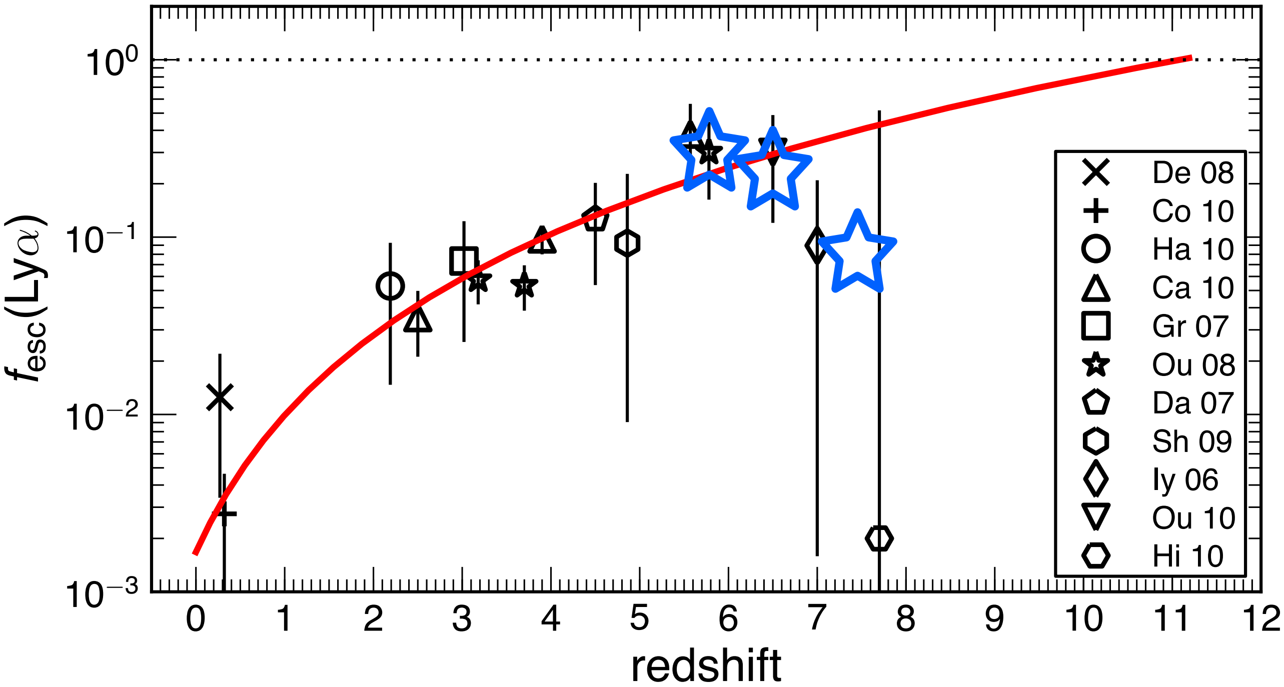
Dayal+09,10,11; Nagamine+08; Forero-Romero+11



Dayal+10

- **Clustering effects negligible for a fully ionized IGM (z~6.6) but important even for a neutral fraction of 10% (z~7.6).**
- **To explain z~5.7 data, require a larger escape fraction of continuum photons wrt Lya: hints of clumped dust (e.g. Neufeld 1990)?**

Lya escape fraction



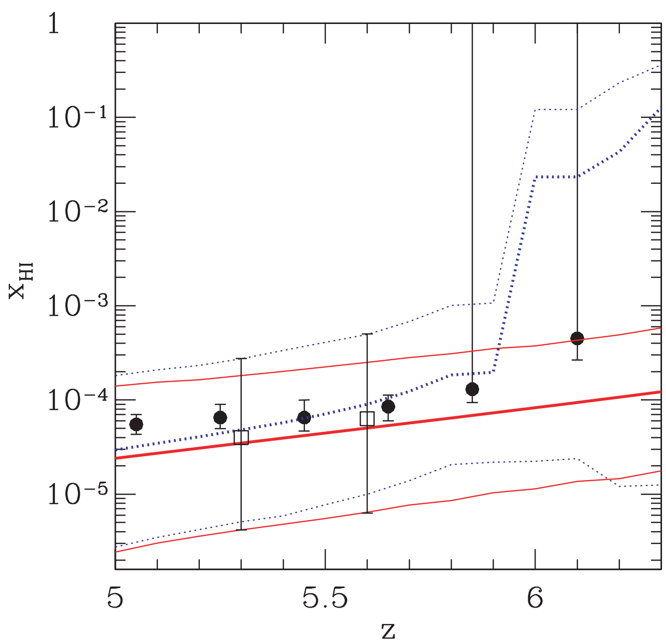
Dayal+10

Hayes+10

Drop in Lya escape fraction between z~7-8: effect of increasingly neutral IGM

Early Reionization model

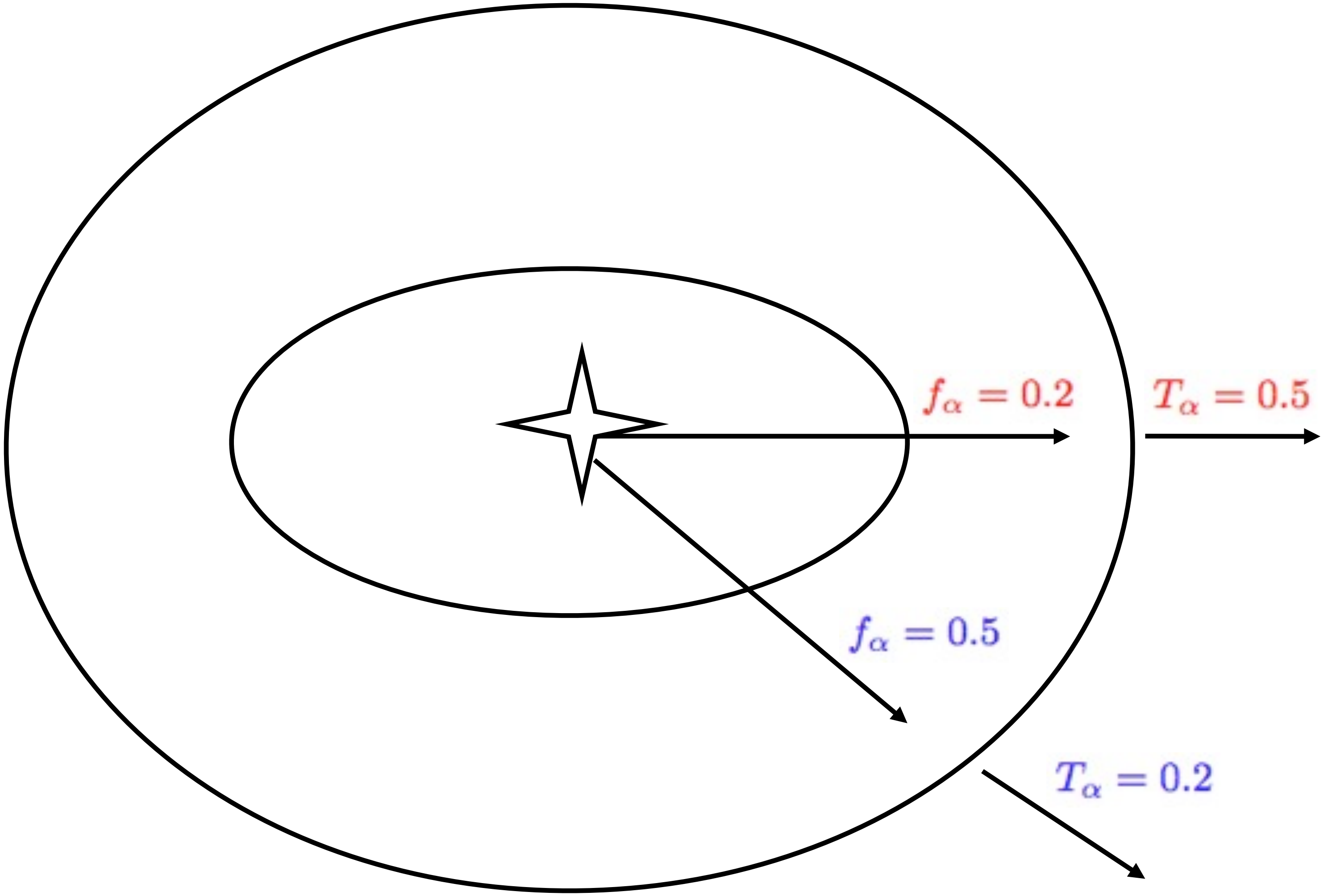
Late Reionization Model



LAE data so far perfectly consistent with the Early Reionization Model where reionization ends at z~7

Gallerani+08

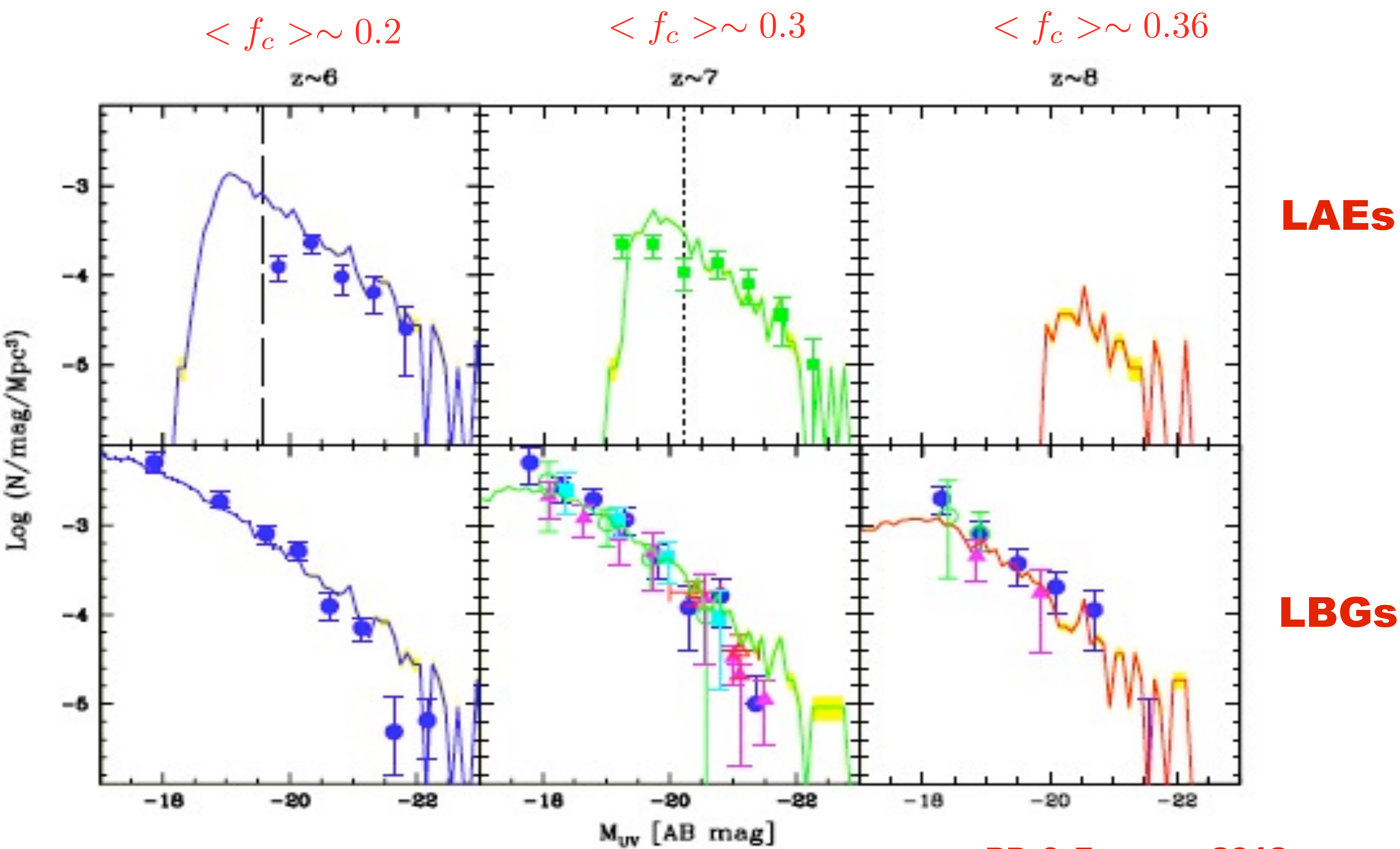
Caveat: Dust & reionization degenerate



There is a degeneracy between the ionization state of the IGM and the fraction of Lyα photons emerging out of the galaxy - see Andreas Sandberg's work for ways on understanding the Lya escape.

Dichotomous twins: the nature of LAEs and LBGs

The LAE & LBG UV Luminosity Functions

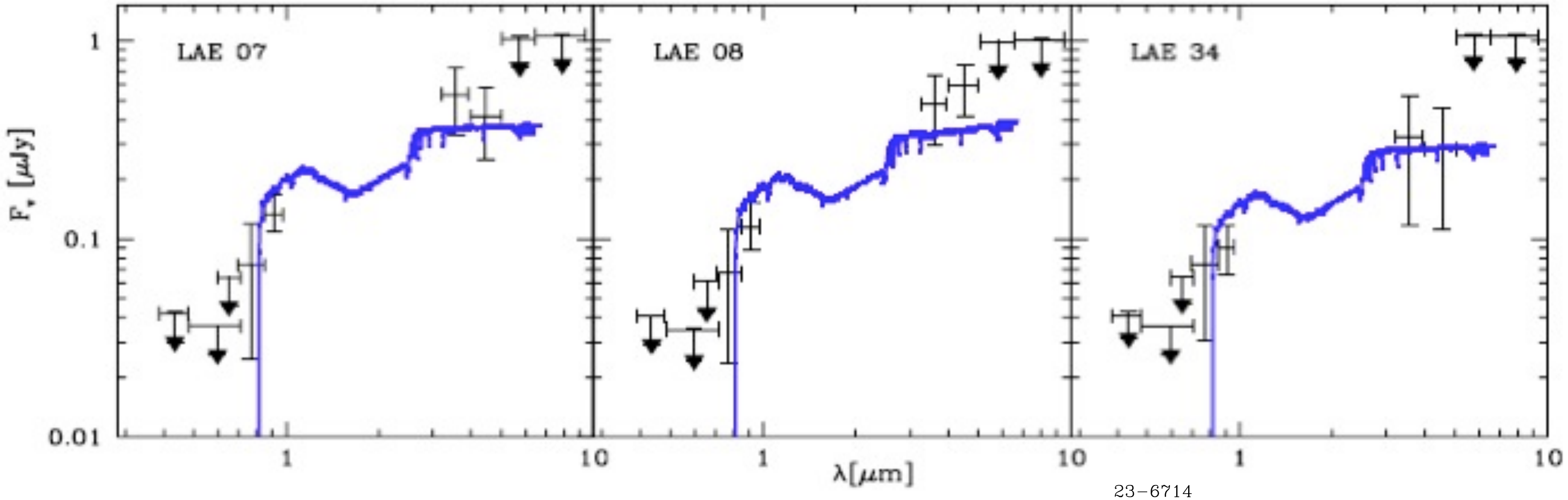


PD & Ferrara, 2012

• A single model that couples SPH, dust and IGM transmission simultaneously reproduces both the LAE and LBG UV LFs.

LAE spectral energy distributions (SEDs)

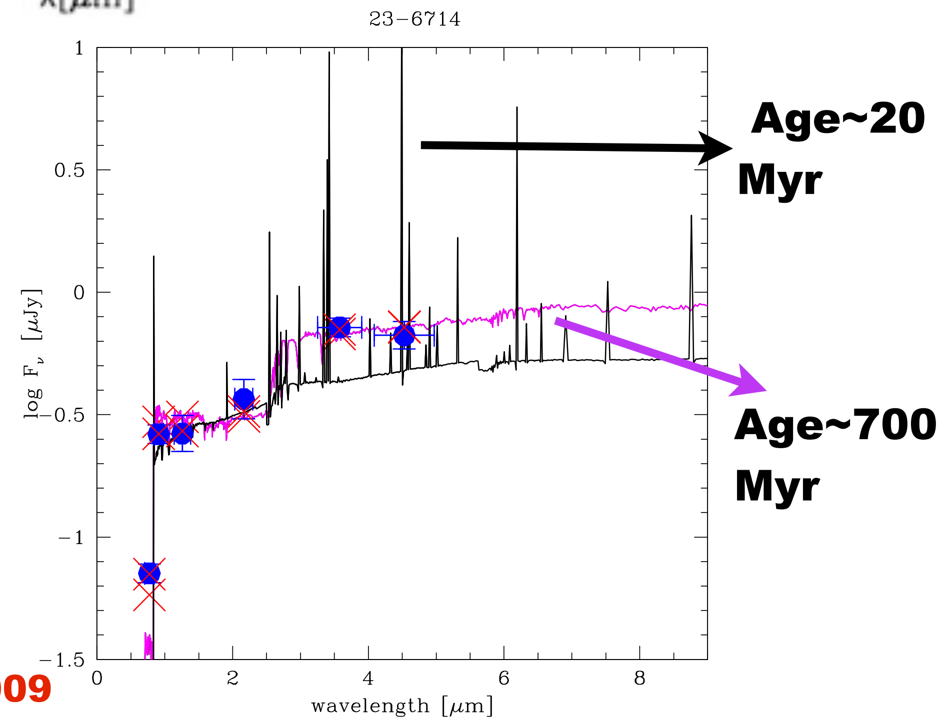
Dayal+10 ; SEDs from Lai+07



#LAE	t_* (Myr)	Z ($Z_\odot$)	$\dot{M}_*$ ($M_\odot yr^{-1}$)	E(B – V)
07	191	0.23	9.7	0.15
08	182	0.32	9.6	0.15
34	220	0.23	7.3	0.15

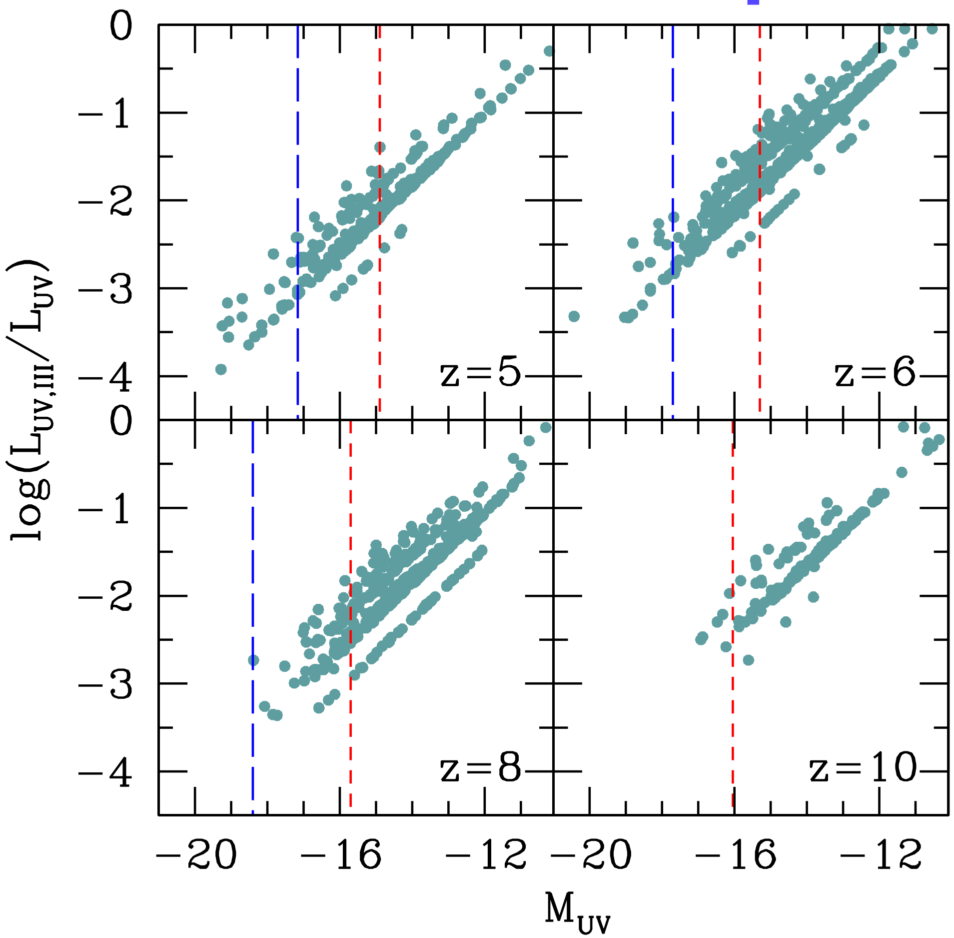
CAUTION

Including nebular emission lines can lead to a stellar age significantly lower than that inferred from a pure stellar spectrum.



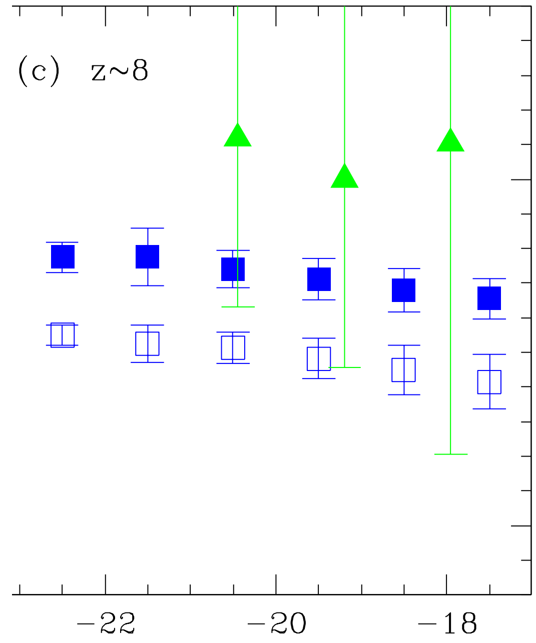
Schaerer & deBarros, 2009

The LBG UV spectral slopes



PD & Ferrara, 2012

Also see Forero-Romero+10

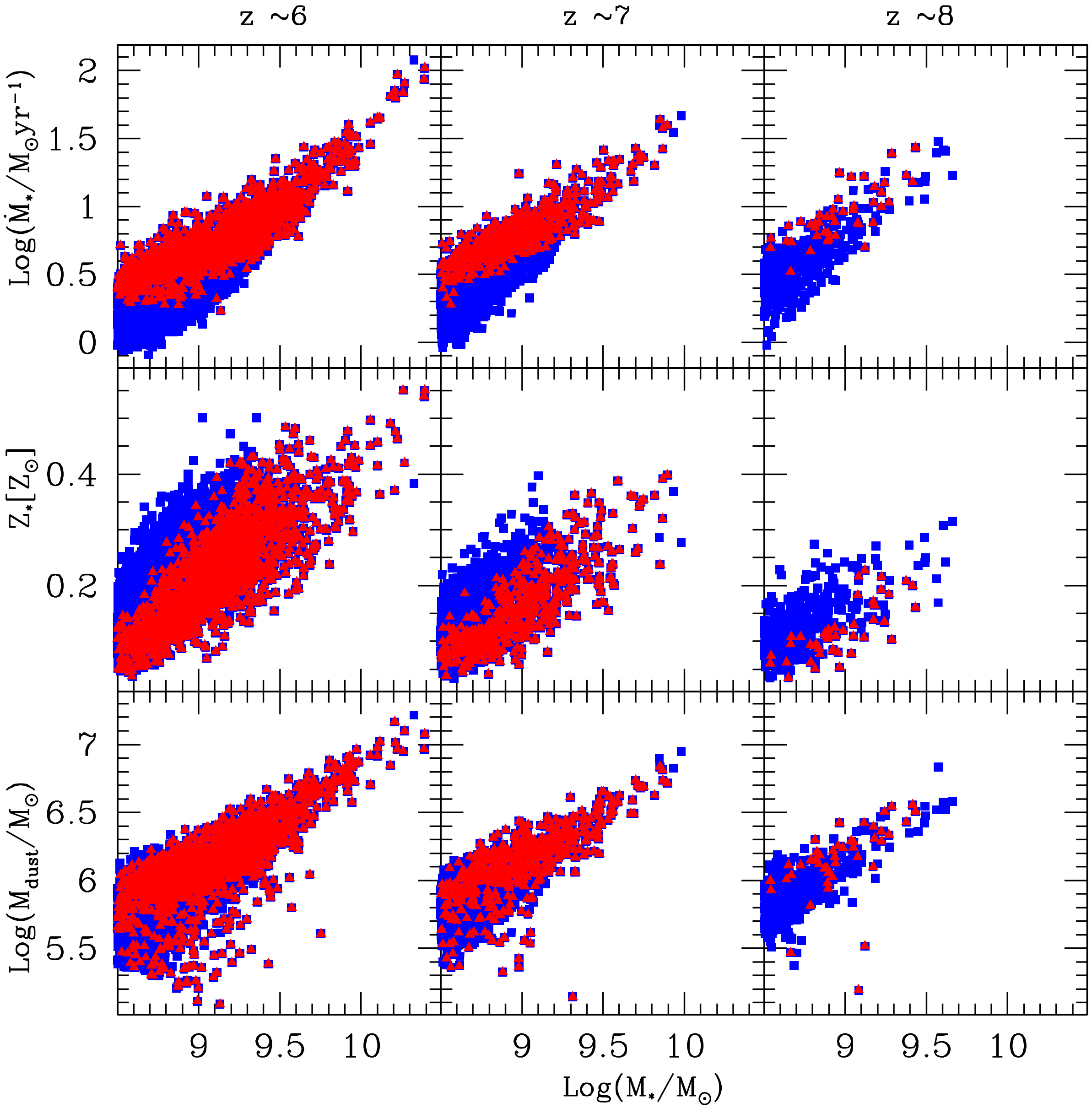


Salvaterra+11

- **Intrinsic UV spectral slope, beta, becomes slightly bluer with increasing magnitude and redshift.**
- **At all z, observed beta consistent with a value ~ -2.2.**
- **Negligible (no) contribution from PopIII stars even at z~8 in galaxies detectable with JWST (HST).**

The physical nature of LAEs and LBGs

PD & Ferrara, 2012, MNRAS, 421, 2568



SFR scales with stellar mass, ranging between 1-200 solar mass/yr at z~6.

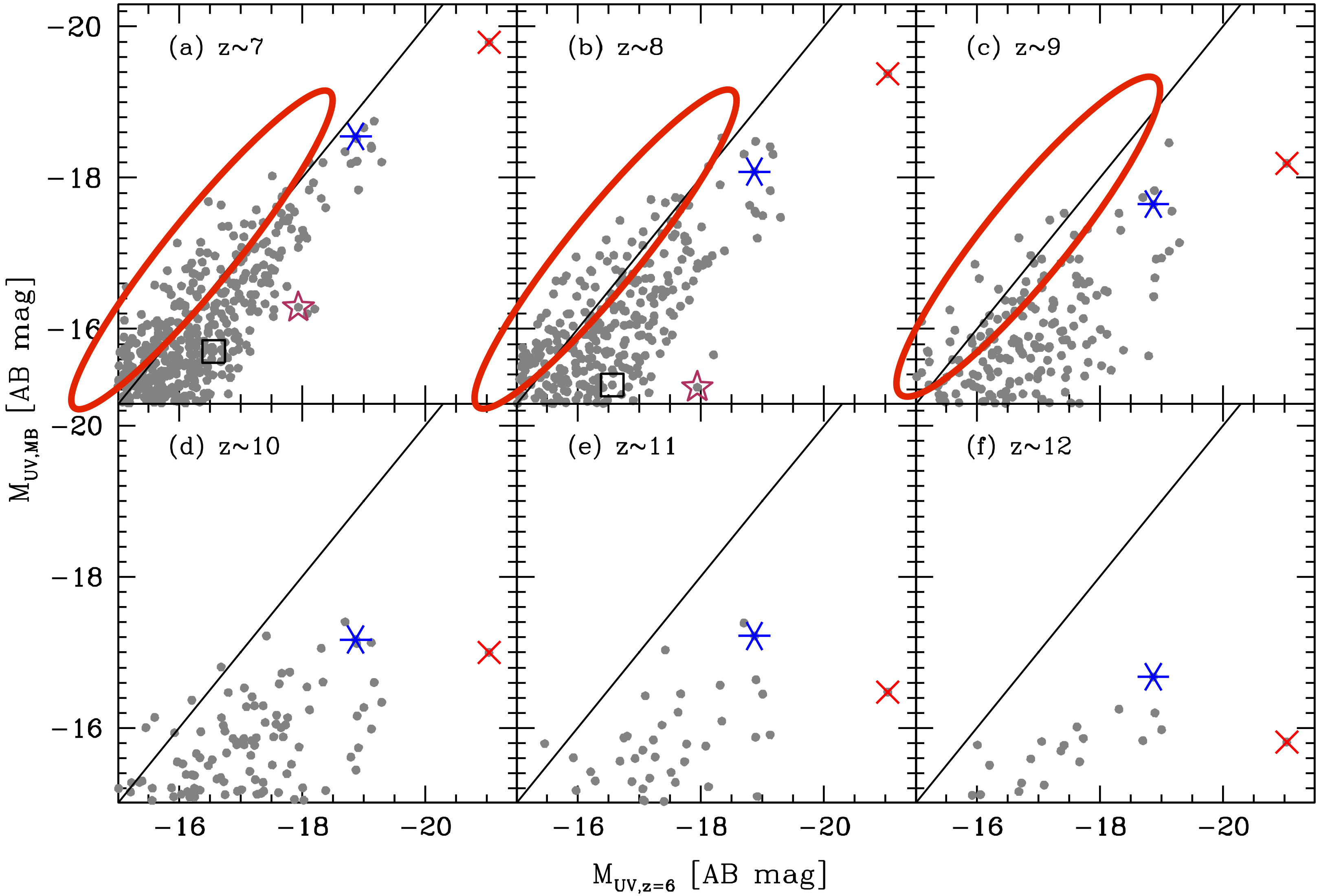
Stellar metallicity scales with stellar mass, ranging between 0.02-0.5 of solar value at z~6.

Dust masses of about 10^5-7.3 solar masses at z~6.

Evolution of the UV LF

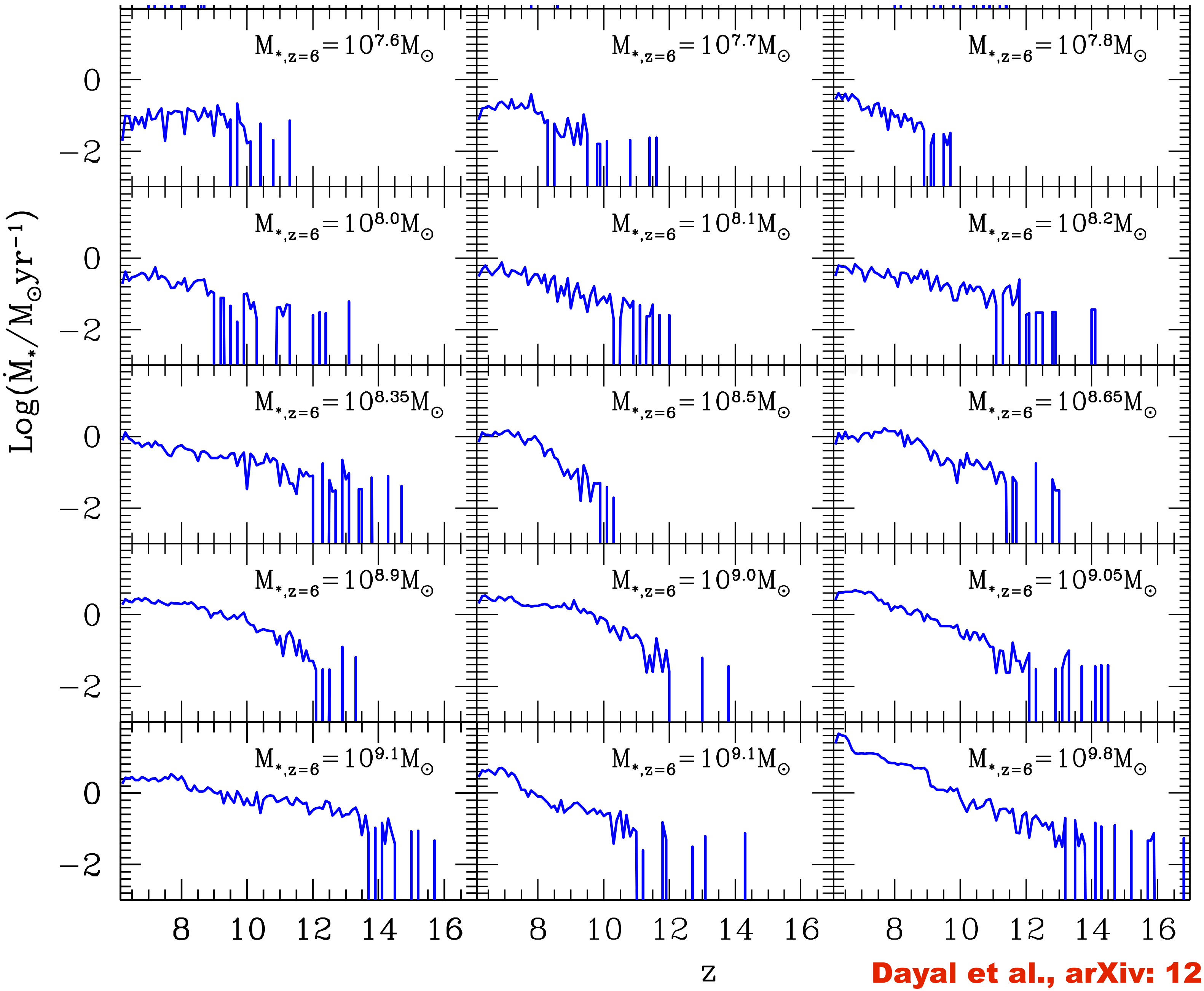
Building up the major branch luminosity

Dayal et al., arXiv: 1211.1034



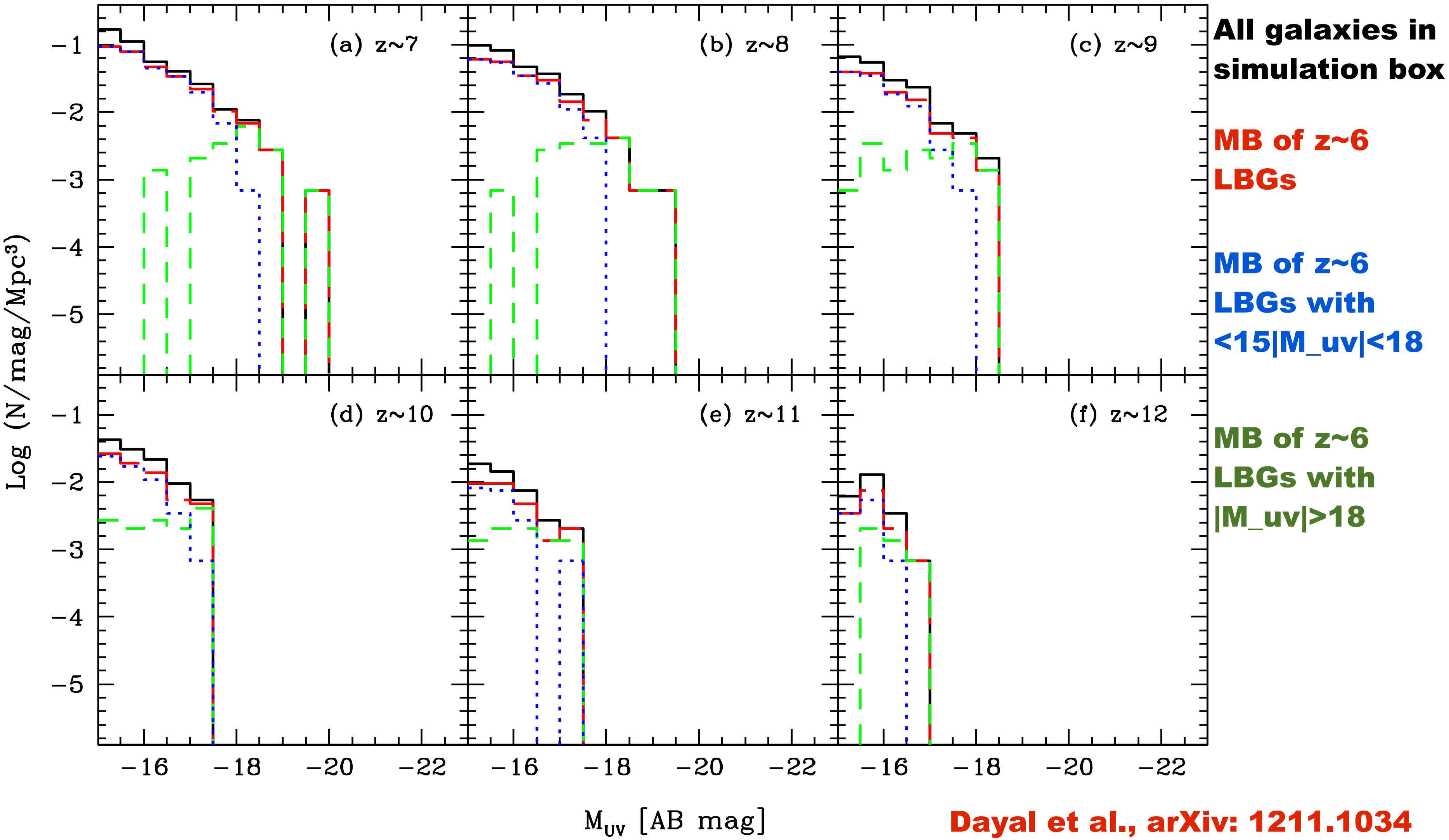
Galaxies at the bright end gently build up their luminosity i.e. a positive luminosity evolution while galaxies at the faint end undergo a positive and negative luminosity evolution as they brighten and fade

A story of all galaxies: stochastic SF



Dayal et al., arXiv: 1211.1034

The evolving UV LF: density + luminosity evolution

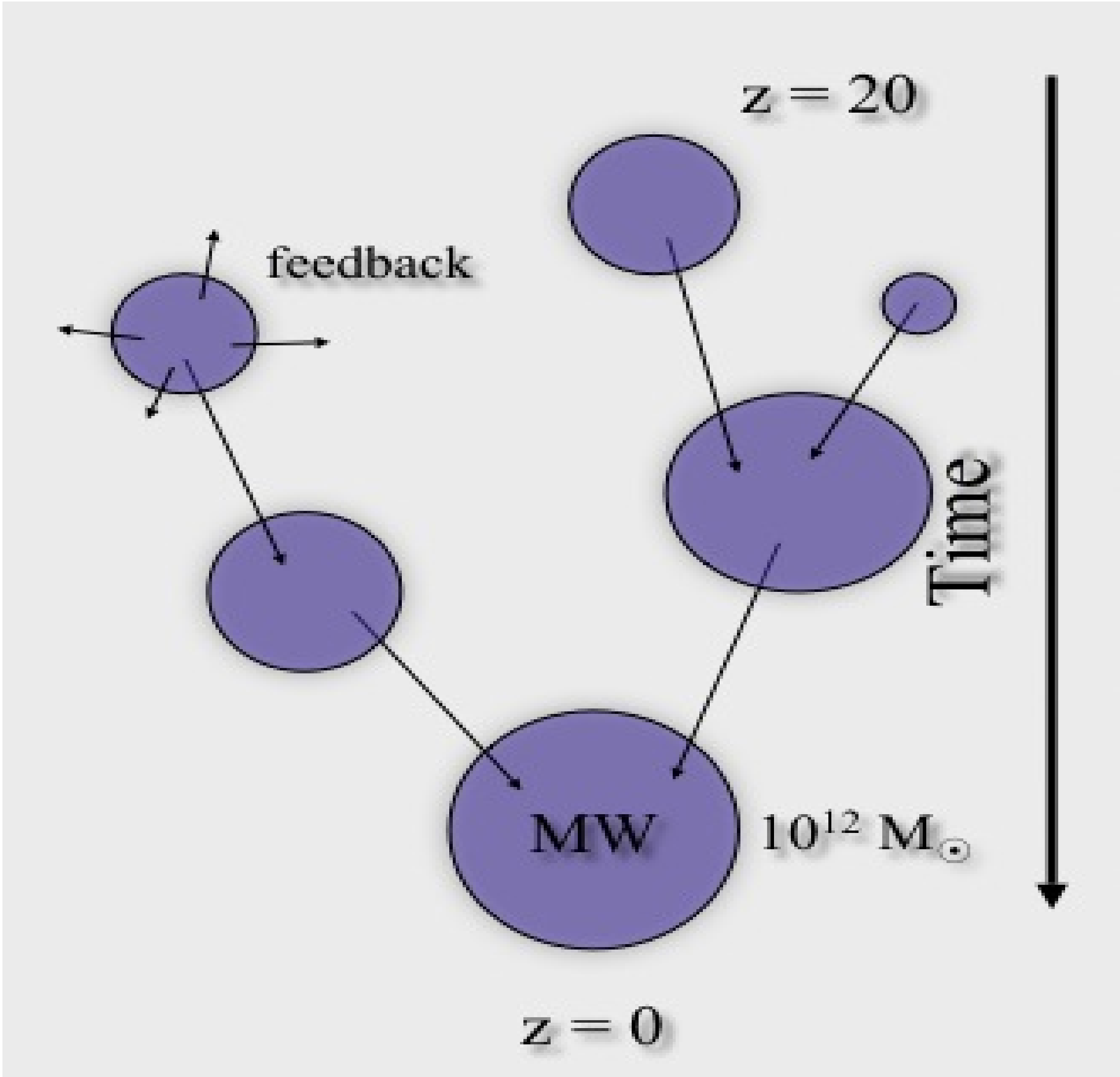


Dayal et al., arXiv: 1211.1034

- **Evolution of the bright end solely due to an increase in the luminosity**
- **Evolution of the faint end due to an evolution in both the luminosity and number density**

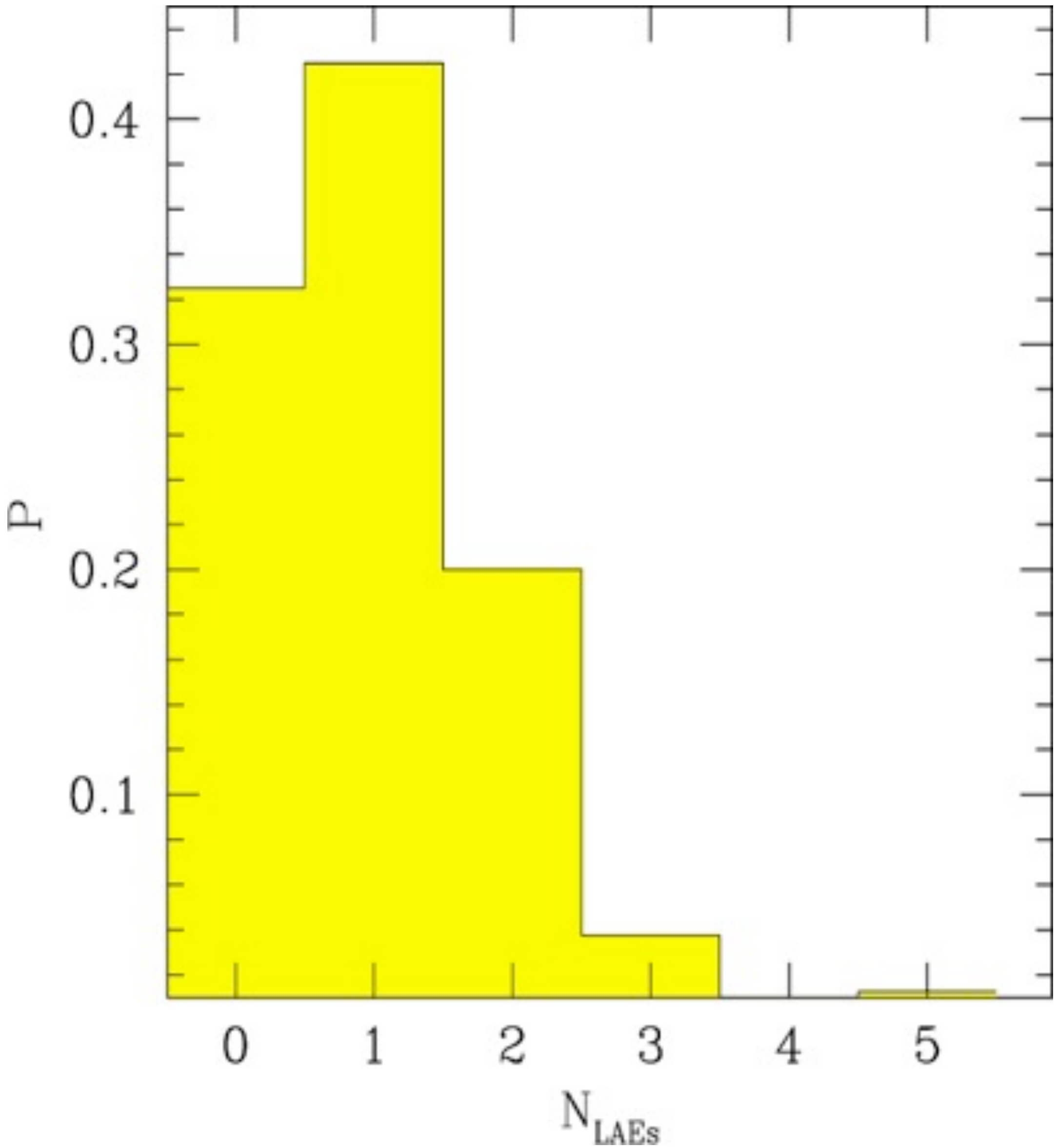
High-z galaxies: clues on local galaxies?

The LAE model + GAMETE



Nagamine 2002; Adelberger+ 2005; Salvadori+ 2010; Okrochkov & Tumlinson 2010; Guaita +2010; Dayal & Libeskind 2010; Yajima+ 2012

Probability of finding LAEs



- Probability of finding 1 LAE in any MW realization is ~ 42%. These correspond to the major branch of the merger tree.

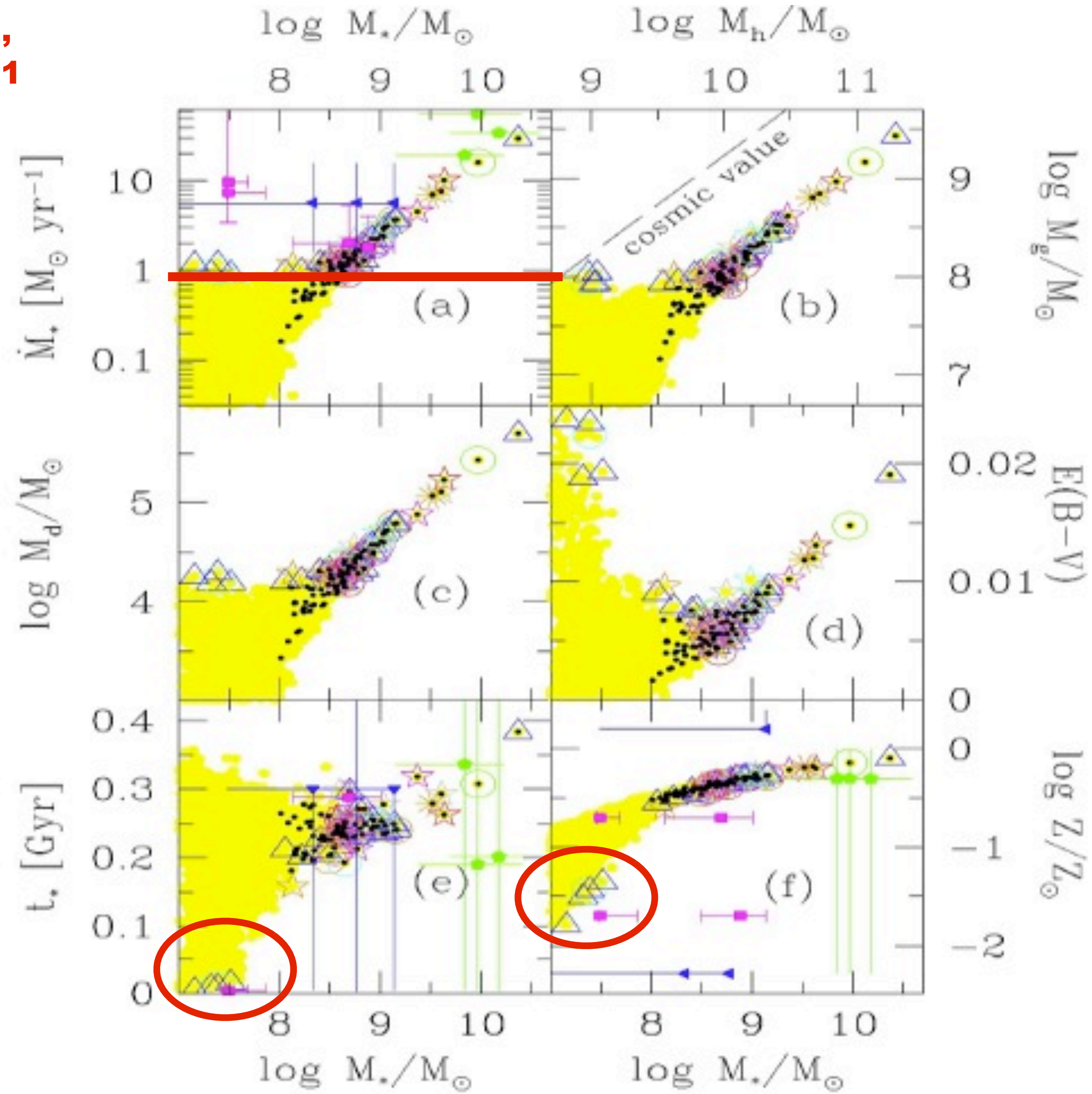
- Some realizations have more than 1 LAE, although the probability is just ~ 26%.

Salvadori, PD & Ferrara, 2010, MNRAS Let., 407, 1

Physical properties of MW progenitors visible as LAEs

Salvadori, PD & Ferrara, 2010, MNRAS Let., 407, 1

A SFR threshold to be visible as LAEs



Typical ages ~ 200 Myr but some very young objects make the cut as a result of large photon output

A panchromatic view of high-z galaxies: wish list

☑ **LAE data perfectly consistent with a model wherein reionization ends before z~6.6.**

☑ **LAEs and LBGs are essentially the same population: stellar masses between 10^8-10 solar masses, Stellar metallicities between 5-50% solar, ages of about a few hundred Myr, E(B-V)~0.15 at z~5.7.**

☑ **Evolution of the observed luminosity function depends on magnitude: while the evolution of the bright end is purely luminosity driven, evolution at faint end is due to both a positive & negative evolution in luminosity and number density.**

☑ **Major branch of milky Way could be amongst the brightest LAEs seen as of now.**