The Most Distant Galaxies

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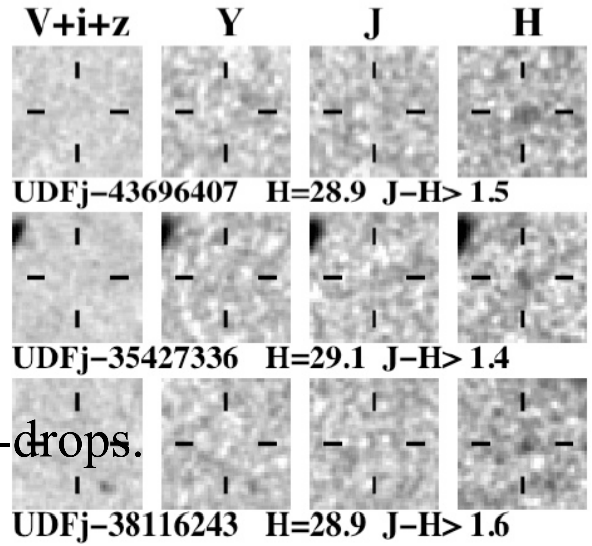
SEARCH TECHNIQUES

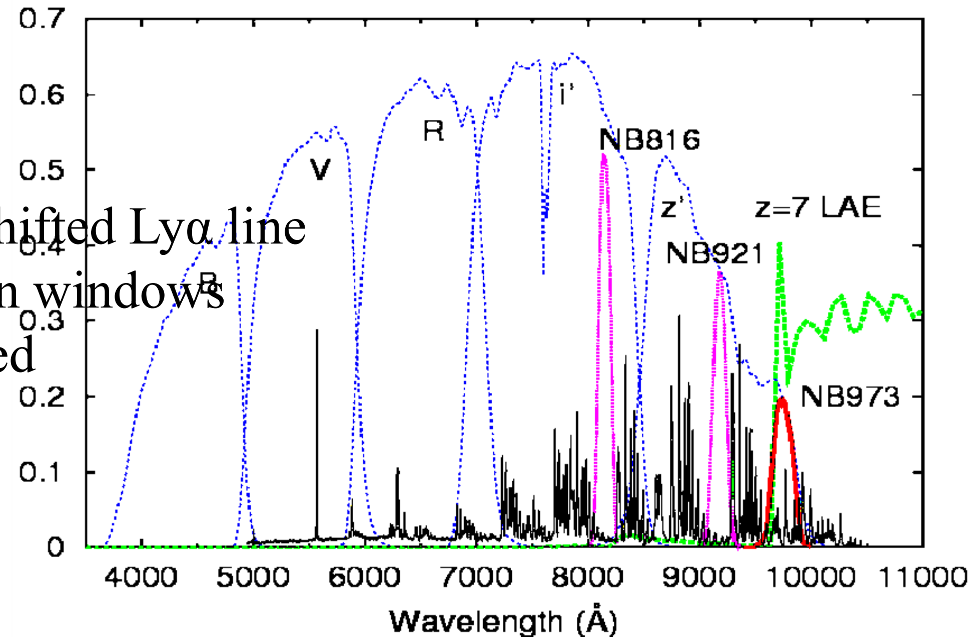


DROP-OUTS

- Sharp drop in flux shortwards than Lya line
- Finding galaxy candidates at z>6 : using *i, z, Y, J*-drops.
- Contamination by stars and low-z ellipticals

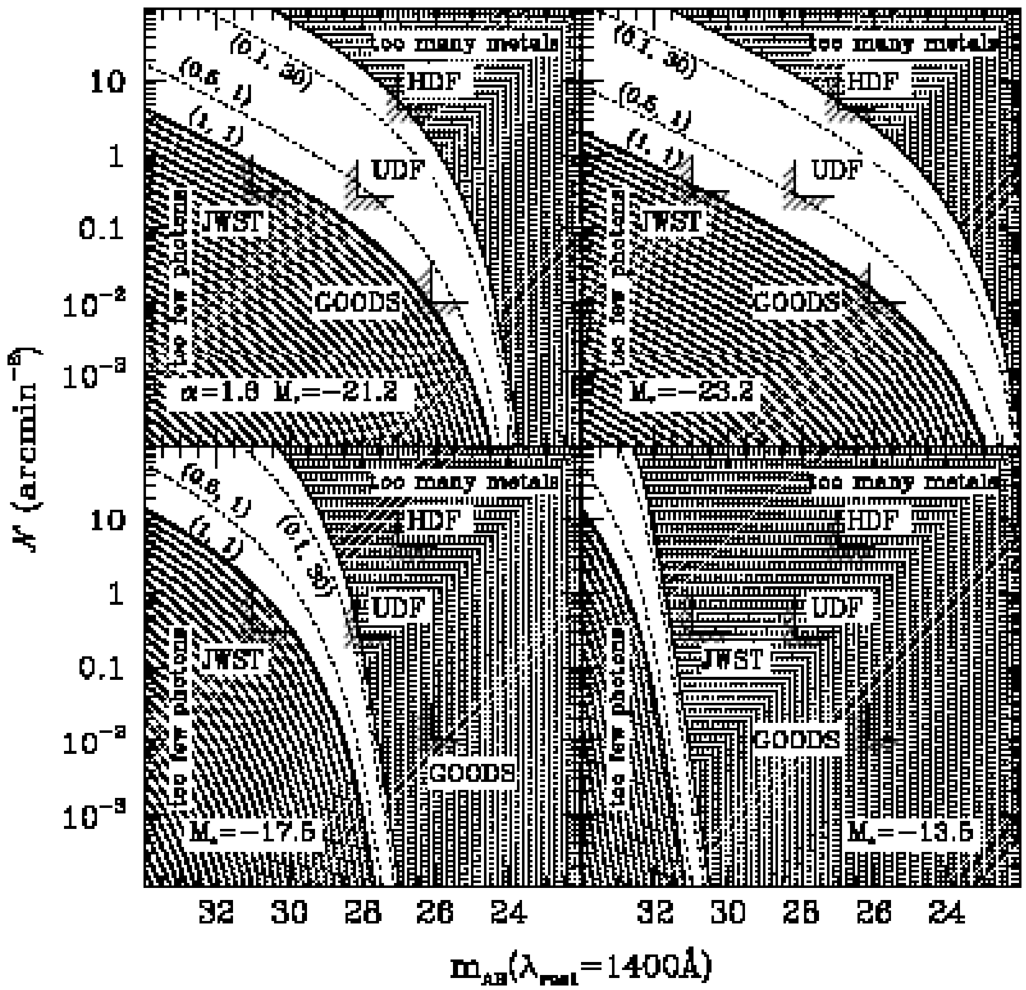
LYMAN ALPHA EMITTERS

- Narrow band filters tuned on redshifted Lyα line
- Few and narrow atmospheric clean windows
- Not all spectroscopically confirmed



Stiavelli+2004

SURFACE DENSITY



Choudhury & AF 2006, 2008

SMALL OR LARGE ?

Searching for the reionization sources

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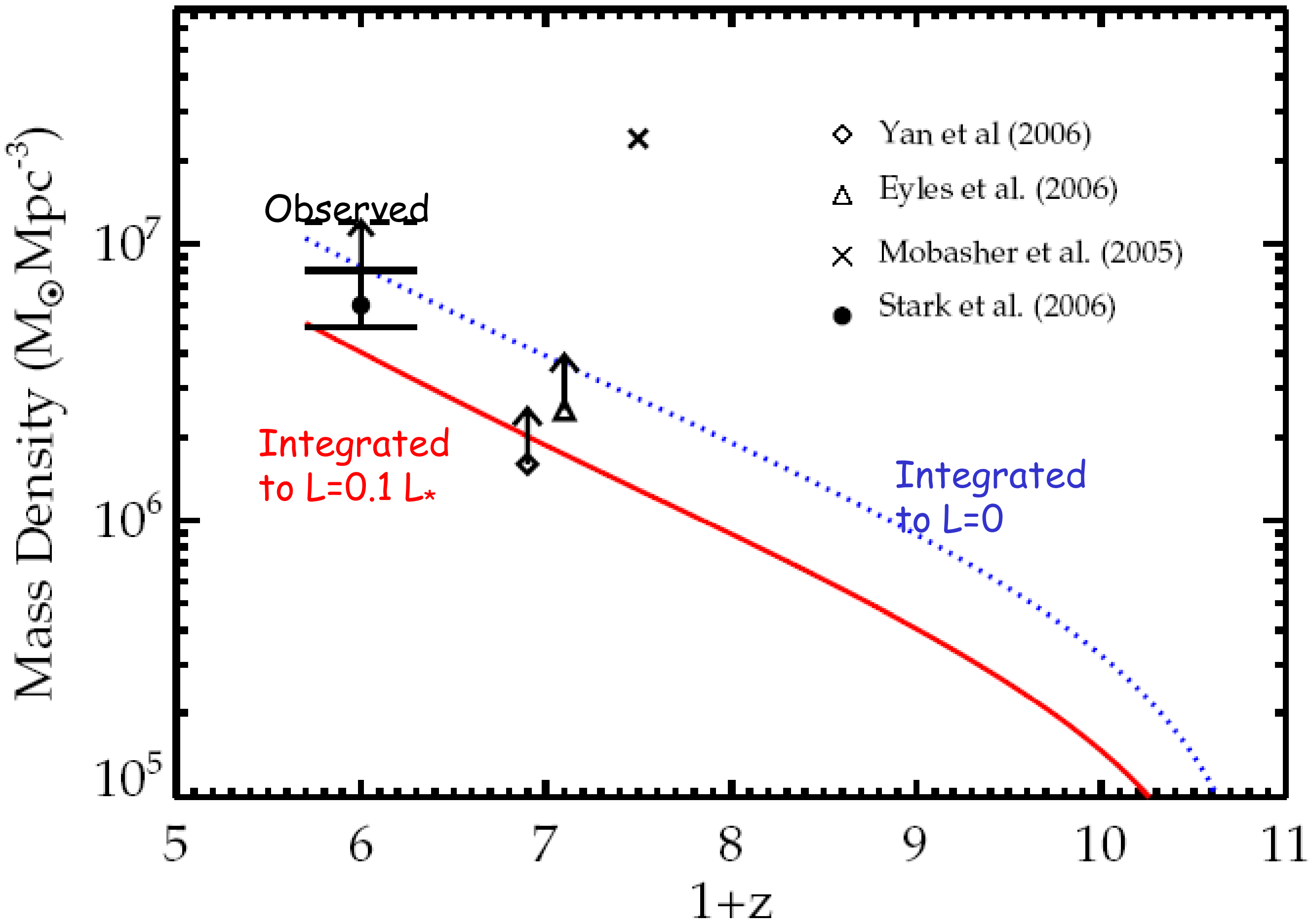
ABSTRACT
Using a reionization model simultaneously accounting for a number of experimental data sets, we investigate the nature and properties of reionization sources. Such model predicts that hydrogen reionization starts at $z \approx 15$, is initially driven by metal-free (PopIII) stars, and is 90% complete by $z \approx 8$. We find that a fraction $f_\gamma > 80\%$ of the ionizing power at $z \geq 7$ comes from haloes of mass $M < 10^9 M_\odot$ predominantly harboring PopIII stars; a turnover to a PopII-dominated phase occurs shortly after, with this population, residing in $M > 10^9 M_\odot$ haloes, yielding $f_\gamma \approx 60\%$ at $z = 6$. Using Lyman-break broadband dropout techniques, J-band detection of sources contributing to 50% (90%) of the ionizing power at $z \sim 7.5$ requires to reach a magnitude $J_{110,\mathrm{AB}} = 31.2(31.7)$, where $\sim 15(30)$ (PopIII) sources/arcmin^2 are predicted. We conclude that $z > 7$ sources tentatively identified in broadband surveys are relatively massive ($M \approx 10^9 M_\odot$) and rare objects which are only marginally ($\approx 1\%$) adding to the reionization photon budget.

Stark+2007

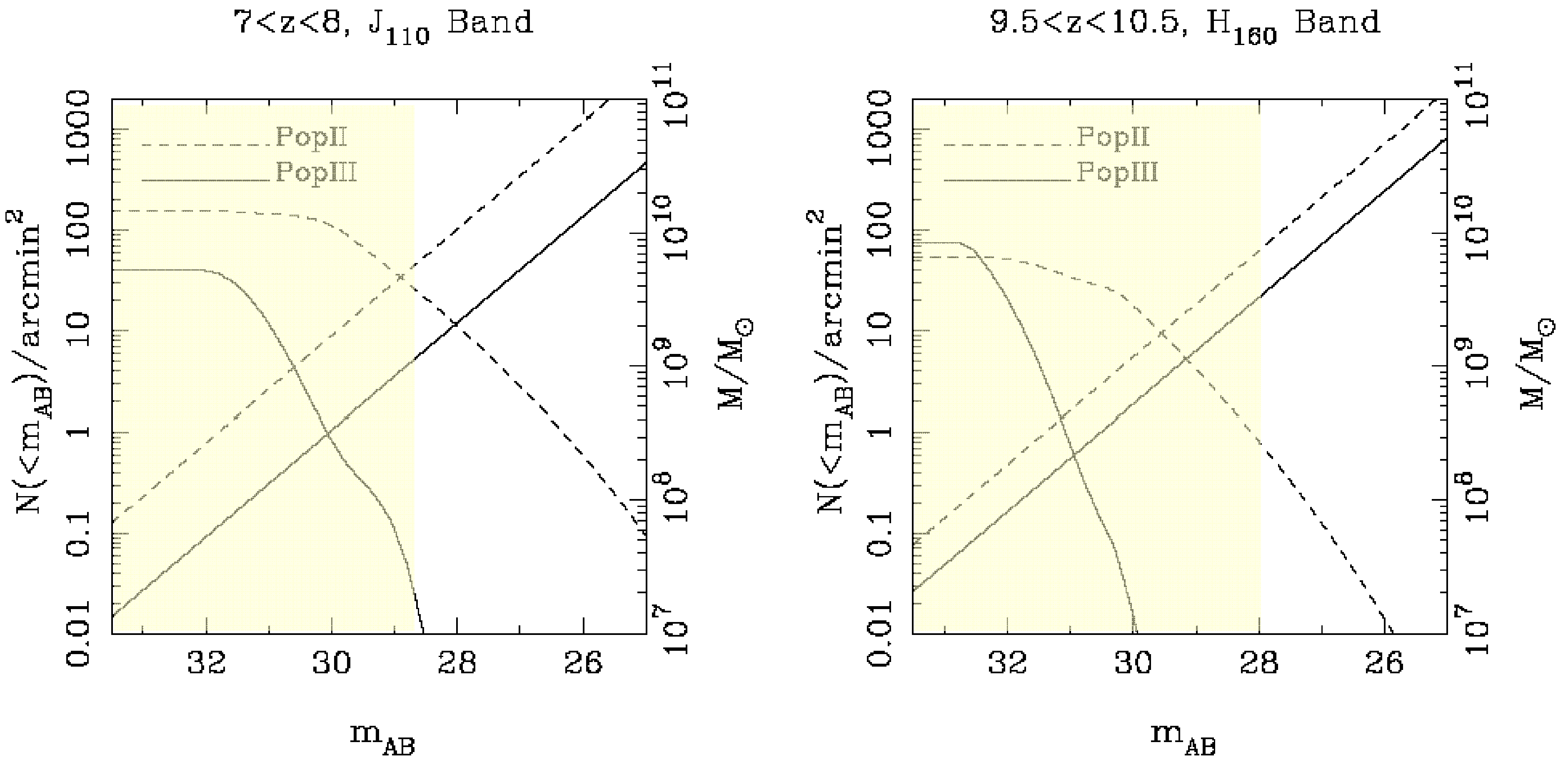
HIGH-Z STAR FORMATION



Lots of hidden/missing high-z star formation

Choudhury & AF 2008

NUMBER COUNTS OF HIGH-Z GALAXIES



Lyman Alpha Emitters

LAEs IONIZING POWER

@ $z = 6.6$

$$\log [Q_{LAE} / (s^{-1}\,Mpc^{-3})] = 49.32$$

$$\log [Q_{ion} / (s^{-1}\,Mpc^{-3})] = 51.54 + \log C_{30}$$

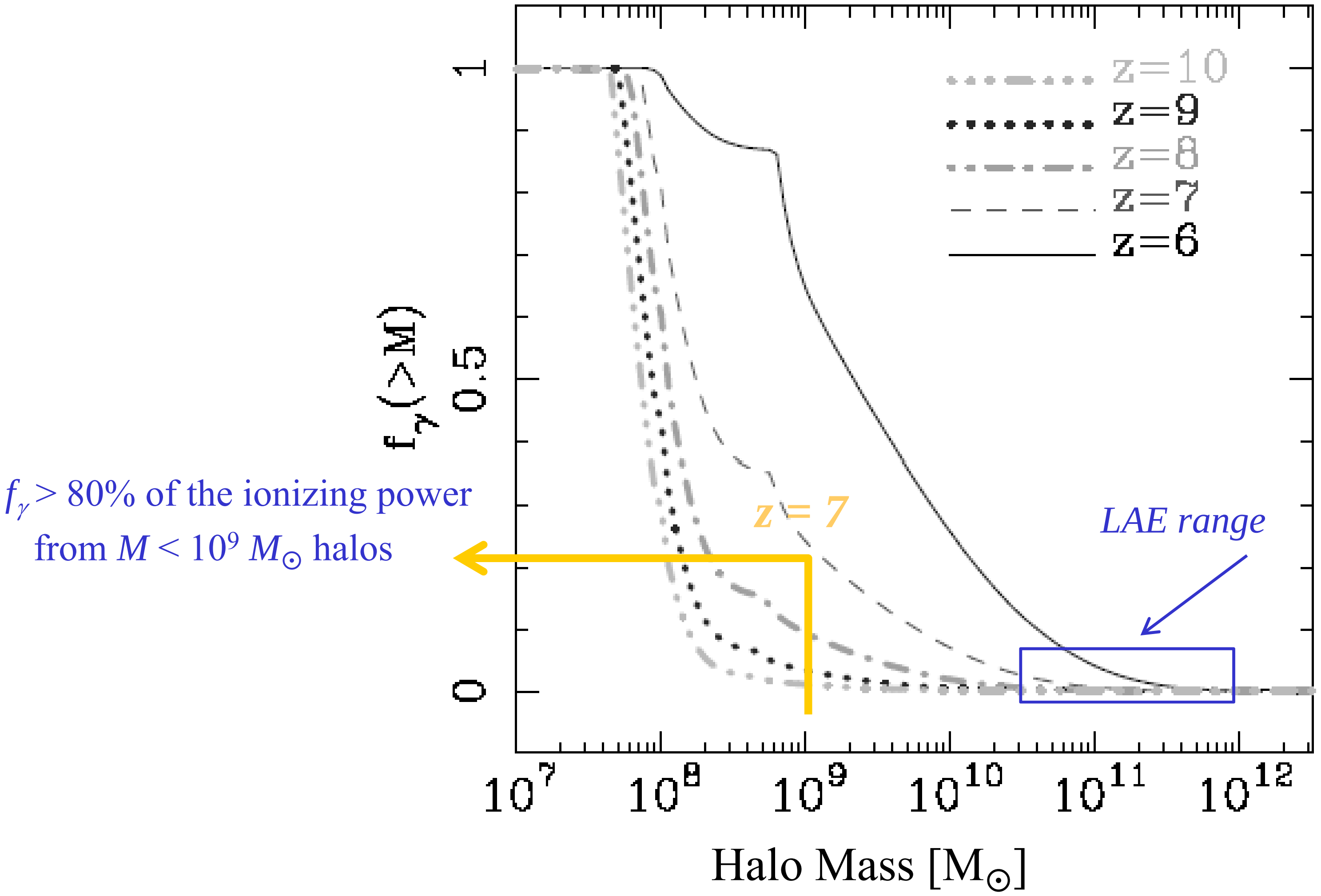
LAE contribute ≈ 1% of ionizing budget

Ages ≈ 200 Myr, star formation started at $z > 8$

PASSIVE REIONIZATION TRACERS

Choudhury & AF 2007

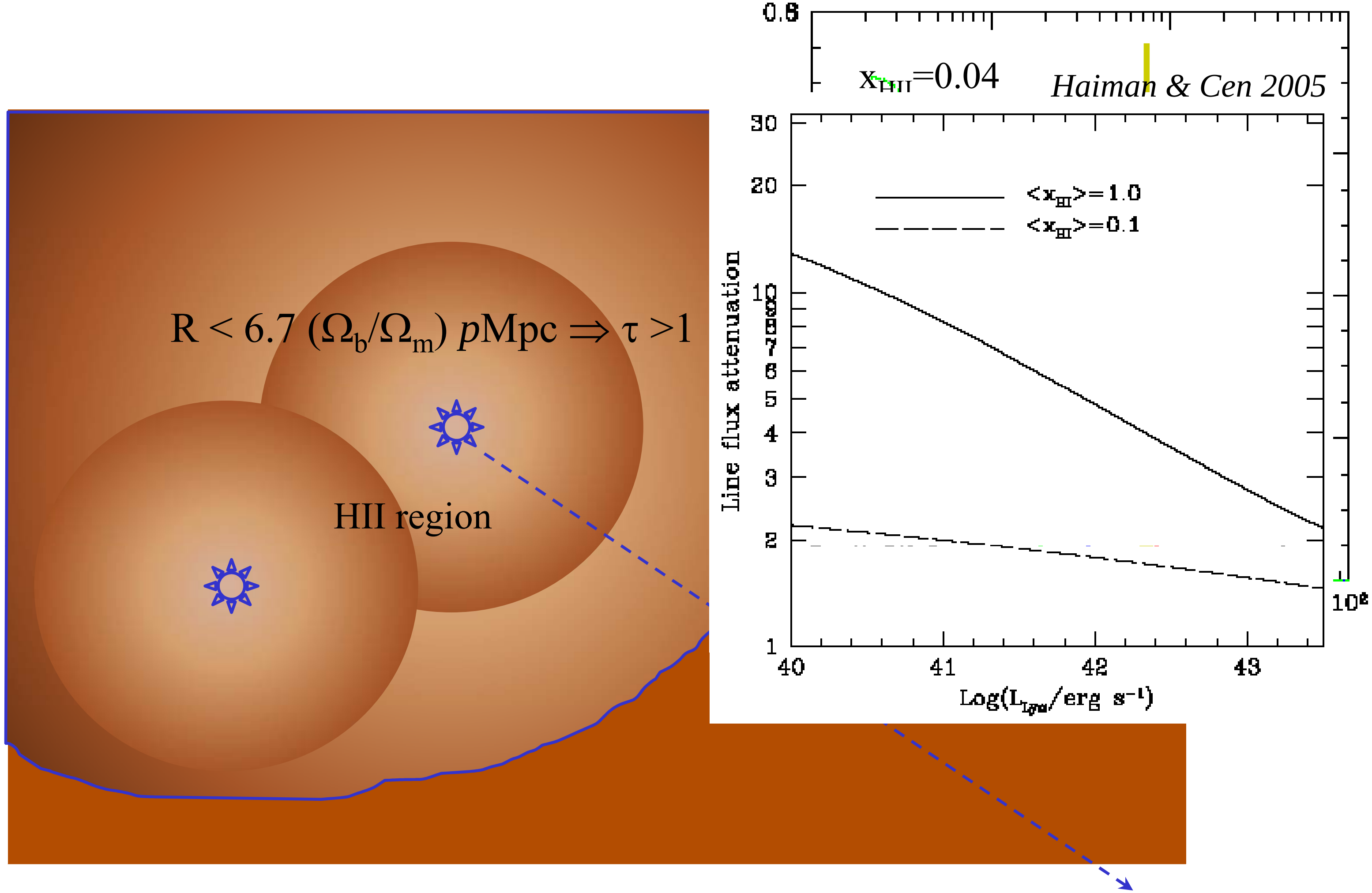
IONIZING PHOTON BUDGET



Santos 2004, Malhotra & Rhoads 2004, Gnedin & Prada 2004

BASIC IDEA

Furlanetto+2004, Salvaterra+2005

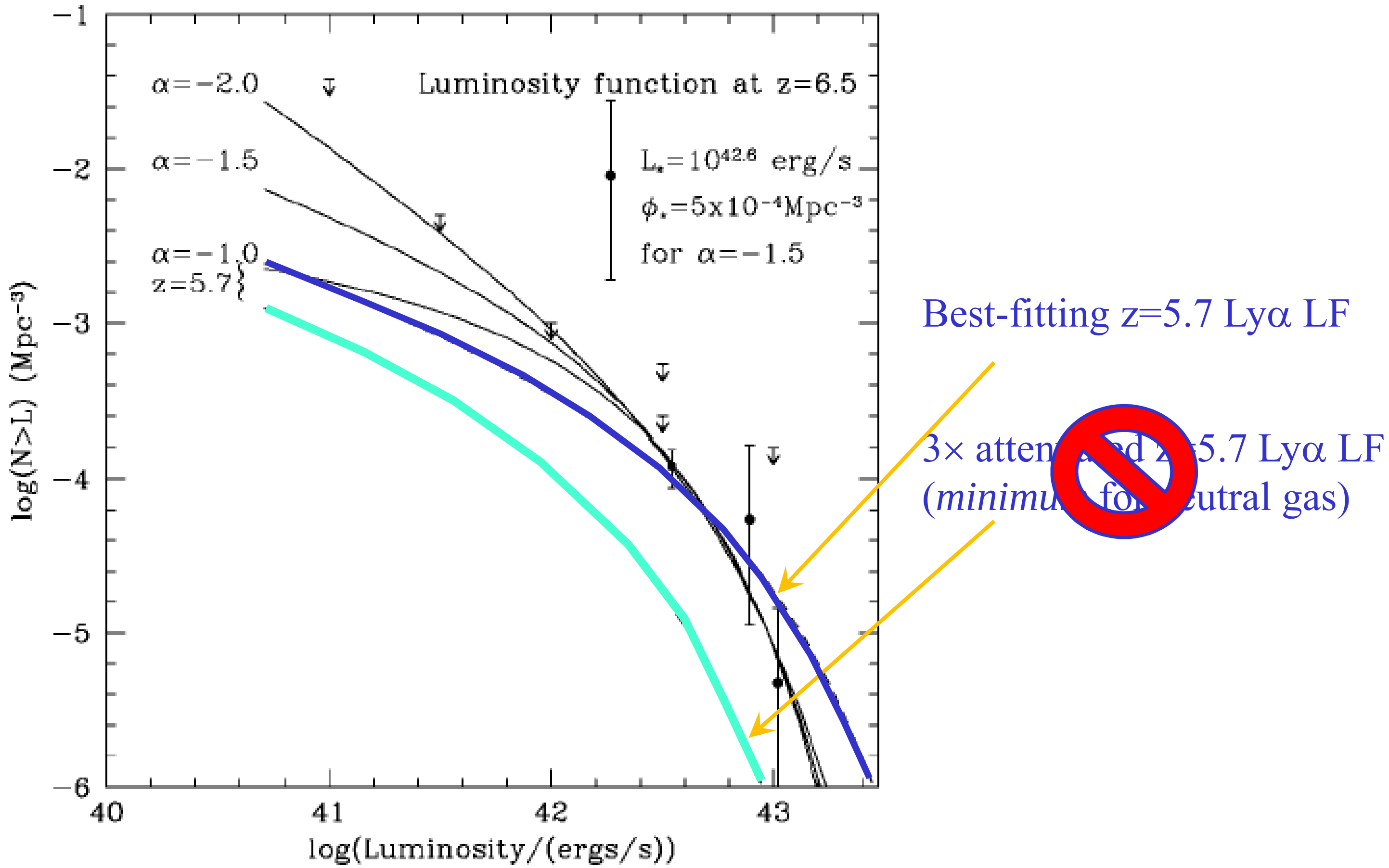


Malhotra & Rhoads 2004

USING THE LUMINOSITY FUNCTION

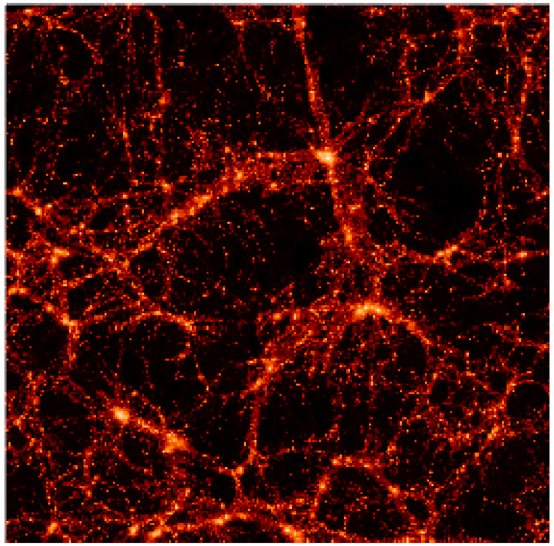
$x_{HI} < 0.3$

z ≈ 6.5

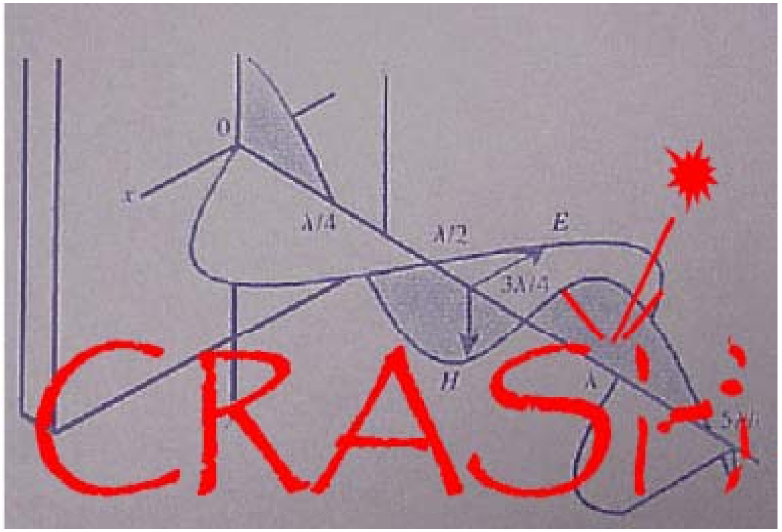


Dijkstra+2007, Zheng & Cen 2010, Dayal+2010

IS THE LF SHAPED BY DUST INSTEAD ?



$100\ h^{-1}$ cMpc



GADGET-2
$2\times(512)^3$ particles
$m_{dm} \approx 1.7\times10^8\ h^{-1}\ M_\odot$
Z-dependent cooling
Feedback, winds, metal enrichment by SNII & SNIa
Dust formation/destruction modelling

Hirashita & AF 2002; Dayal & AF 2009b

INCLUDING DUST

from simulations

production — destruction — astration

$$\frac{dM_{dust}}{dt} = y_d \gamma \dot{M}_* - \frac{M_{dust}}{\tau_{dest}} - \frac{M_{dust}}{M_{gas}} \dot{M}_*$$

continuum optical depth

$$\tau_c = \frac{3\Sigma_d}{4as}$$

continuum escape fraction

$$f_c = \frac{1 - e^{-\tau_c}}{\tau_c}$$

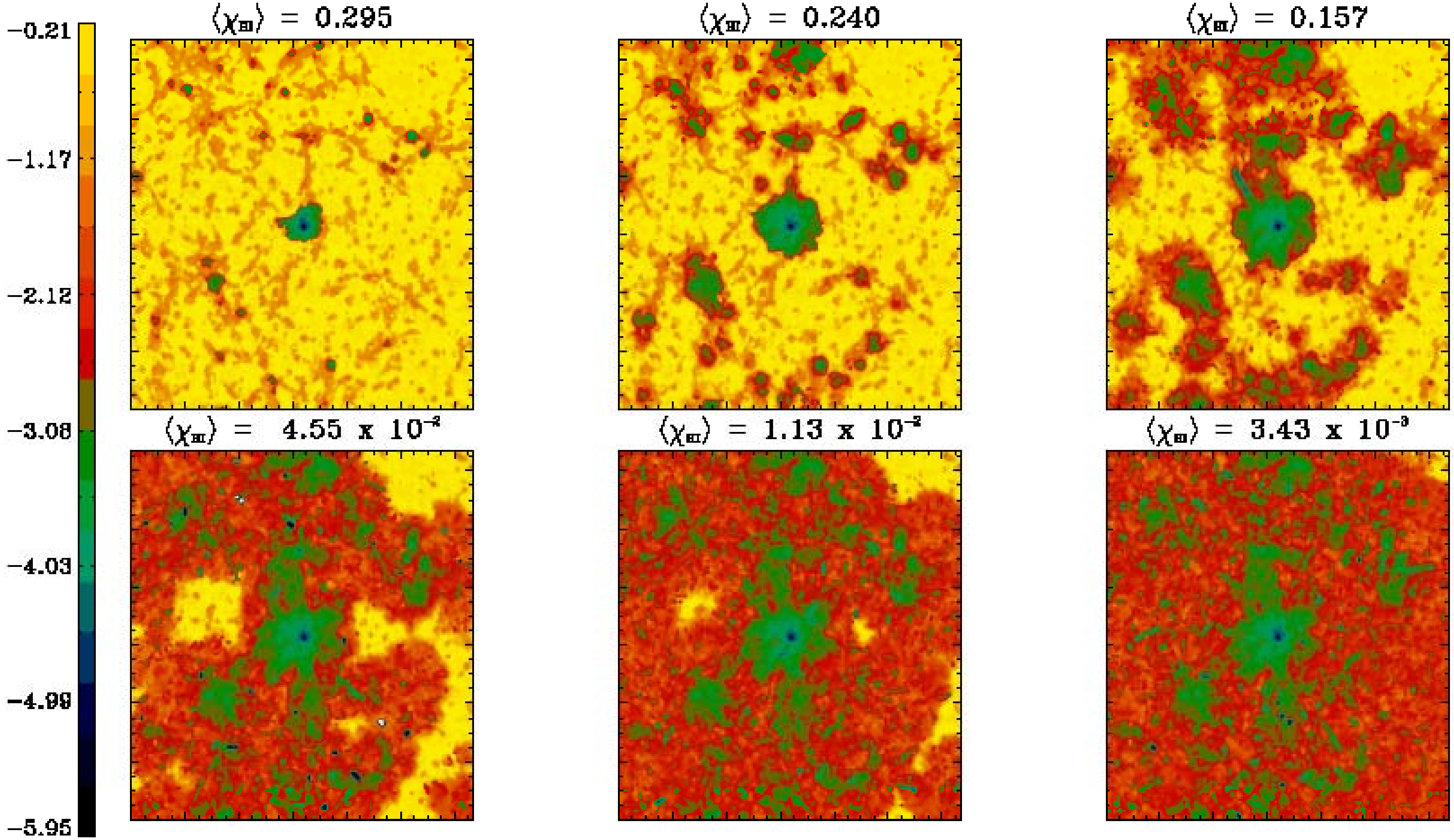
Lyα escape fraction

$$f_\alpha = q(A_\lambda, C)\, f_c$$

Lyα equivalent width

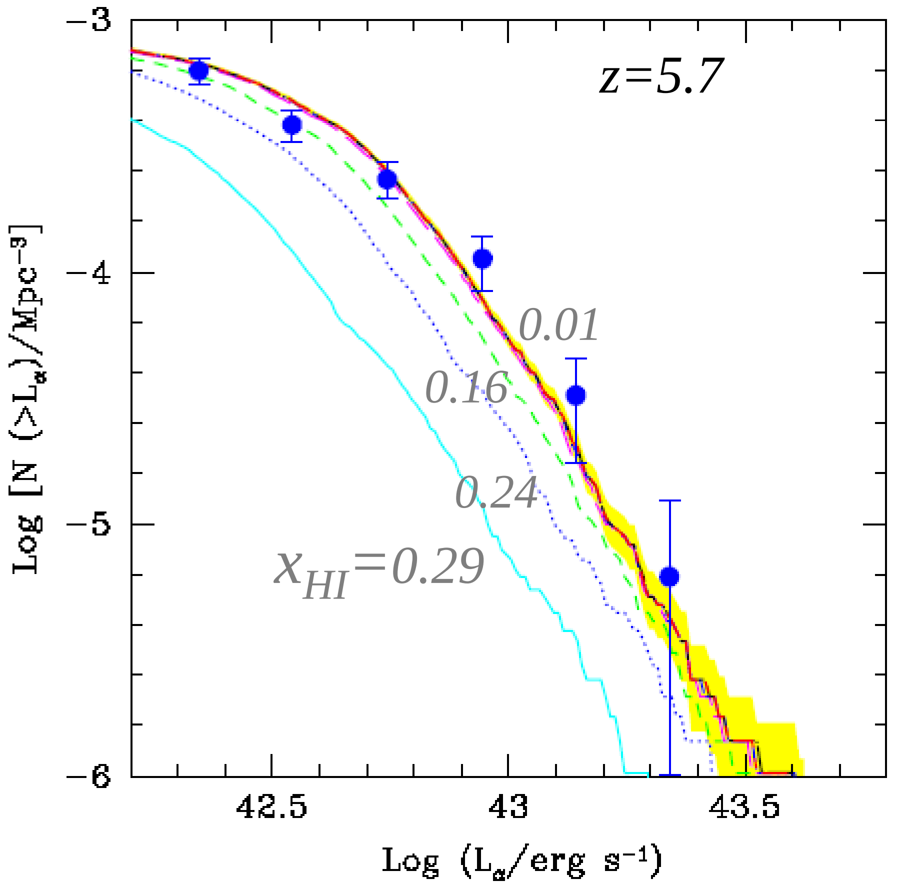
$$EW = EW^{int} \left(\frac{f_\alpha}{f_c}\right) T_\alpha$$

LAE VISIBILITY DURING REIONIZATION



Dijkstra+2007, Zheng & Cen 2010, Dayal+2010

IS THE LF SHAPED BY DUST INSTEAD ?

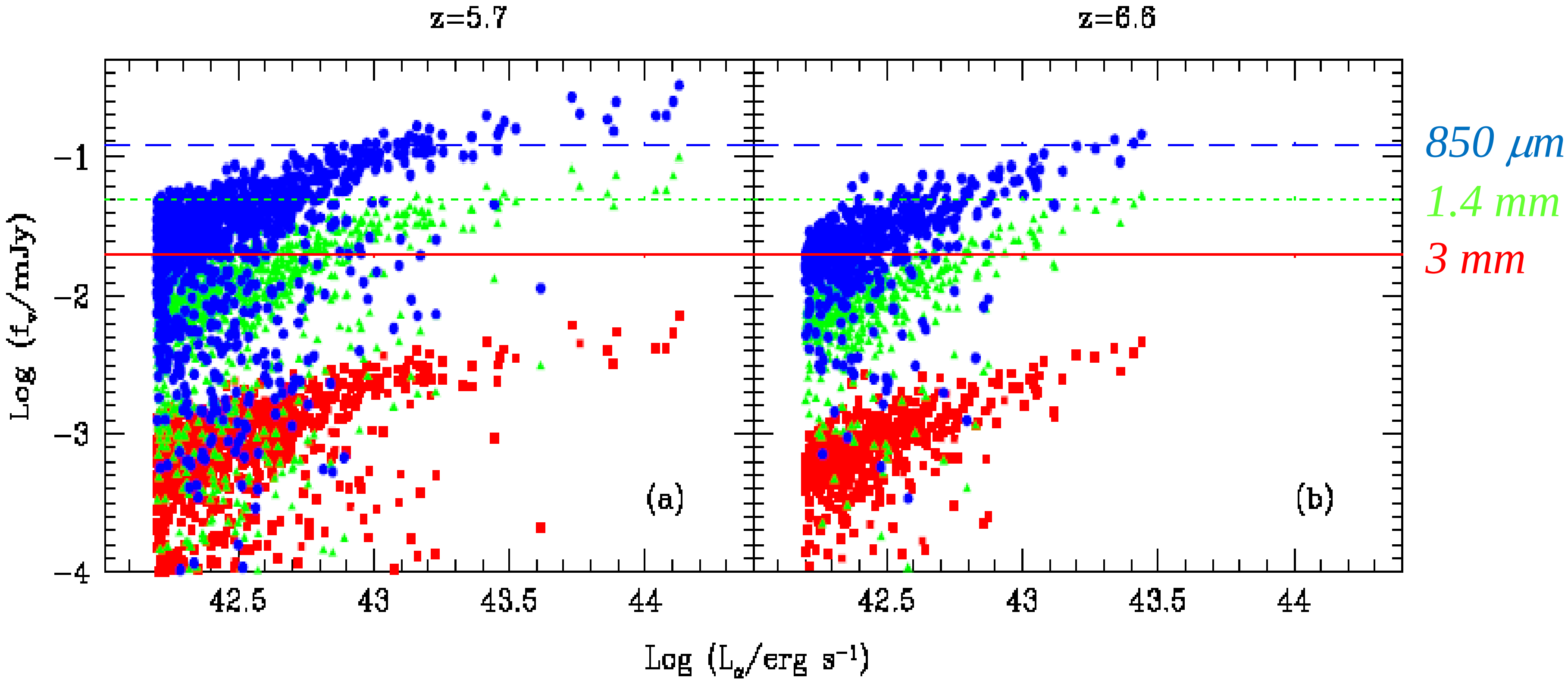


Reionization-dust degeneracy

Finkelstein+09; Dayal+09

DUST EMISSION WITH ALMA

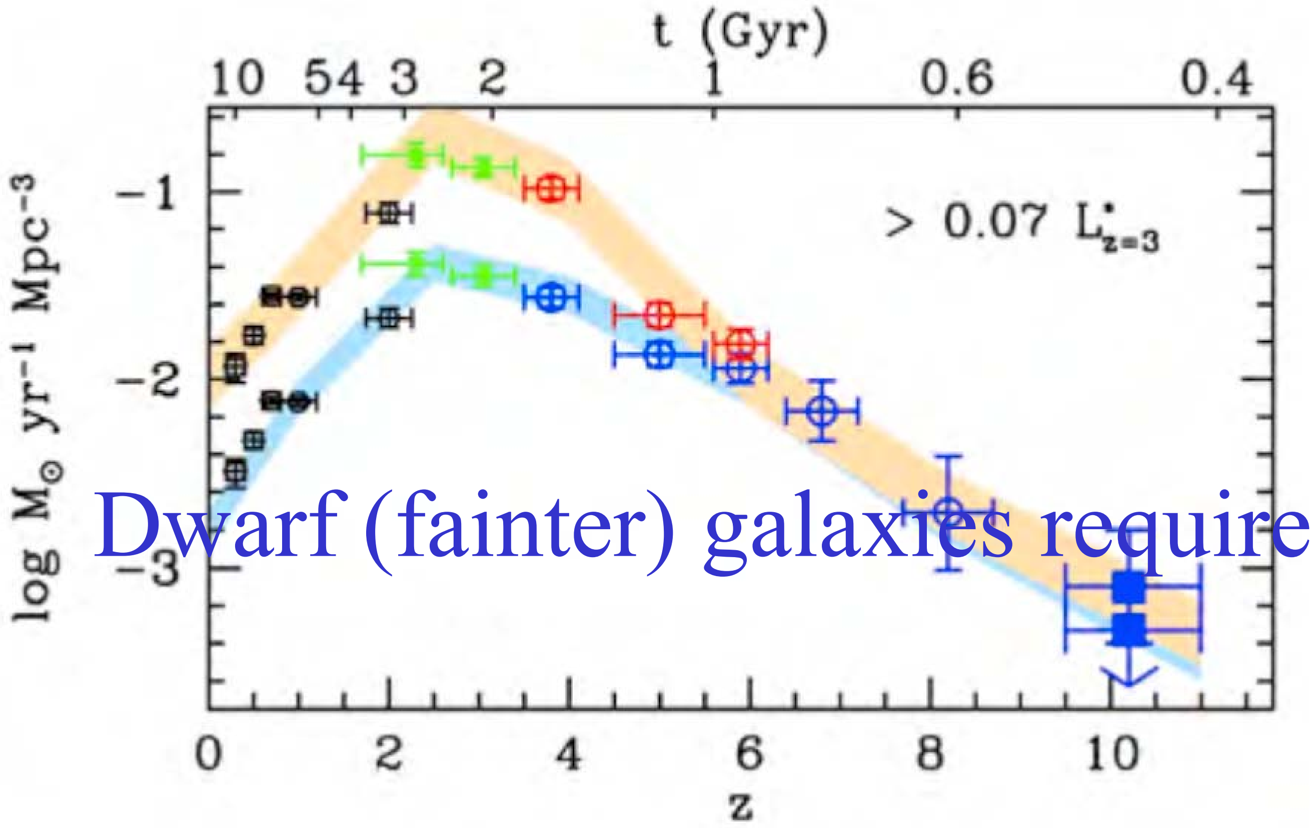
ALMA 5σ / 1h detection



Drop-out Galaxies

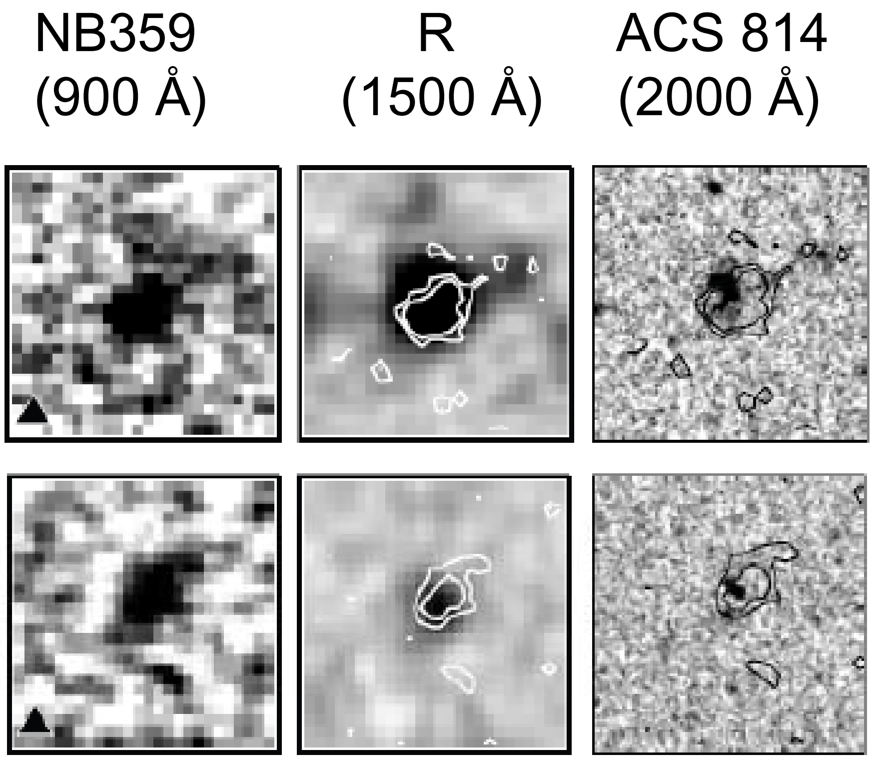
DROPOUTS CONSTRAINTS

$$\dot{\rho}_{\rm SFR} \approx 0.013\, f_{\rm esc}^{-1} \left(\frac{1+z}{6}\right)^3 \left(\frac{\Omega_b\, h_{50}^2}{0.08}\right)^2 C_{30}\, M_\odot\, {\rm yr}^{-1}\, {\rm Mpc}^{-3}$$



Dwarf (fainter) galaxies required ?

PERSISTING PUZZLES



$z = 3.09$

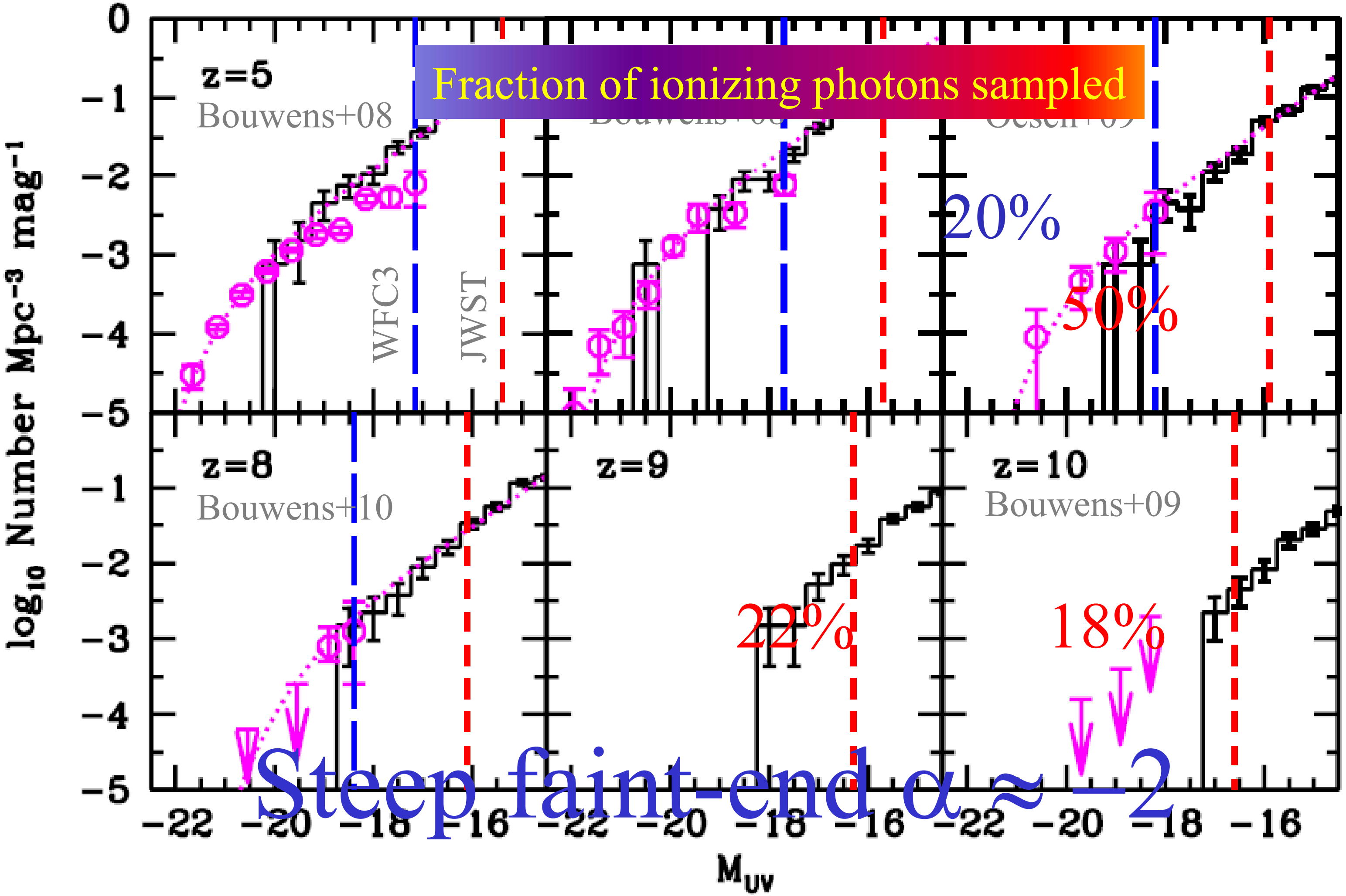
f_{esc}

- Increases from z=0 to z=3
- Increases for low mass objects
- Larger in LAEs than in LBGs
- Too many LCE for Salpeter IMF

Why?

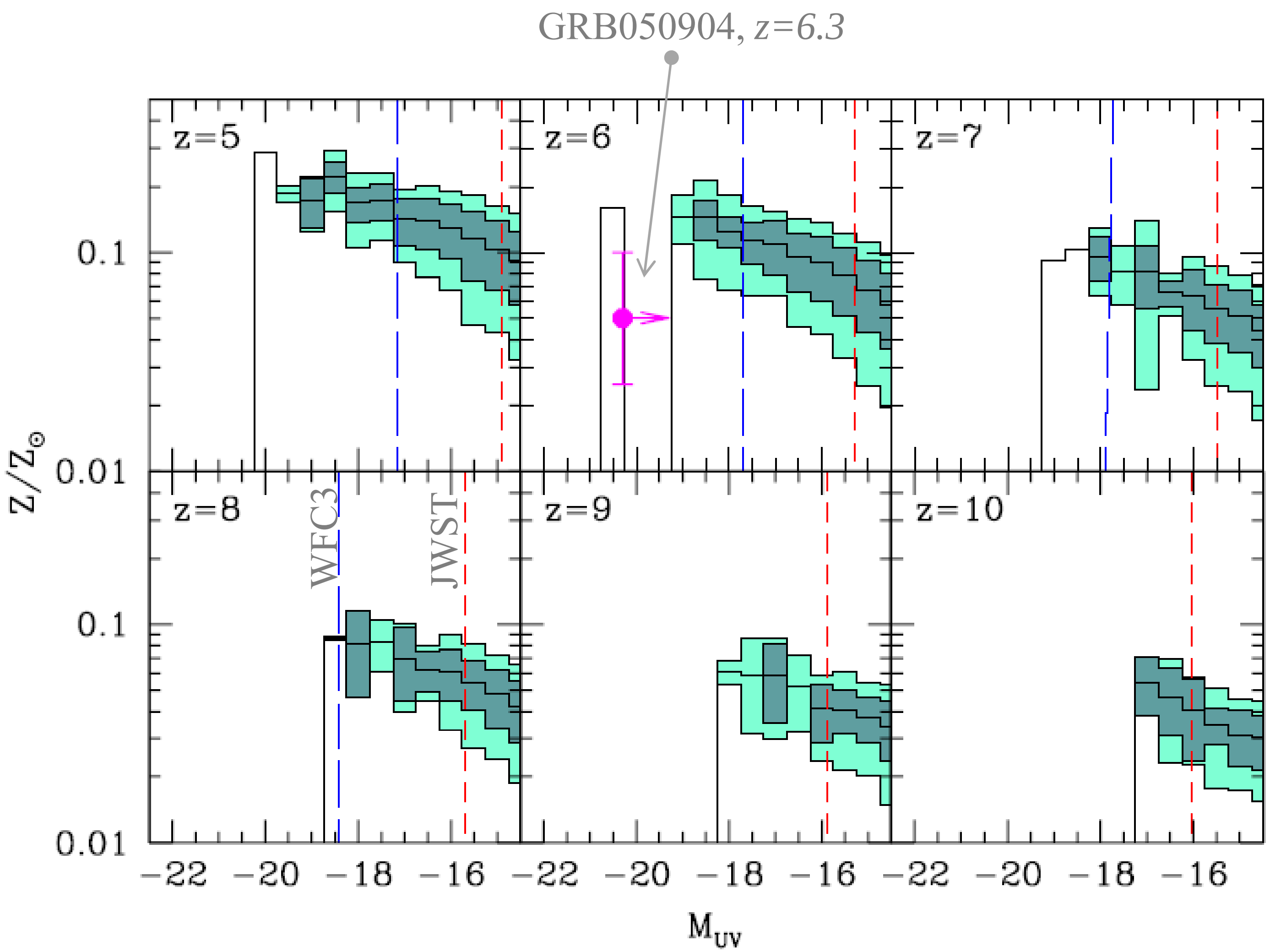
Salvaterra, AF, Dayal 2010

HIGH-Z LUMINOSITY FUNCTIONS

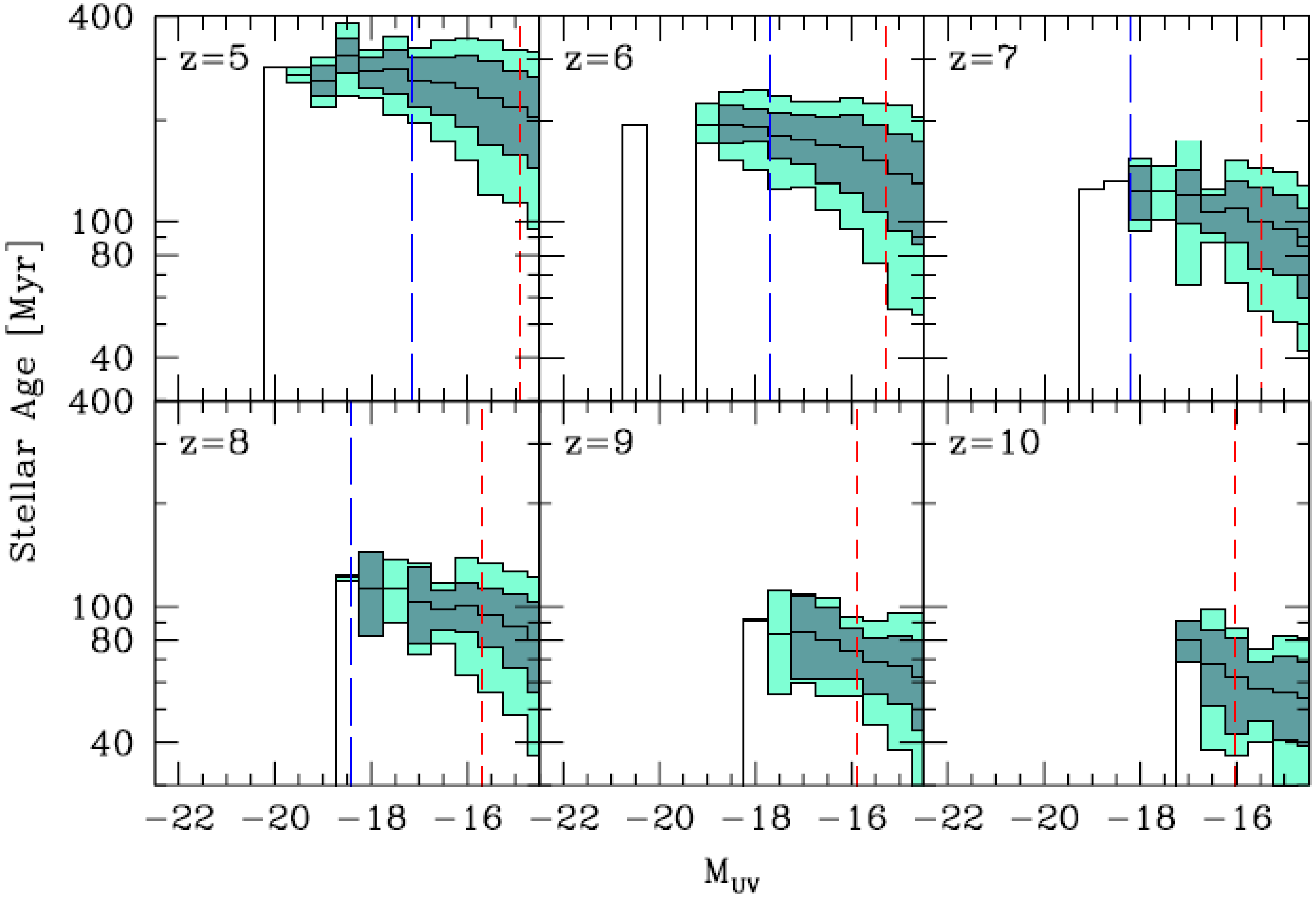


HIGH-Z GALAXY PROPERTIES

Salvaterra+2010



HIGH-Z GALAXY PROPERTIES

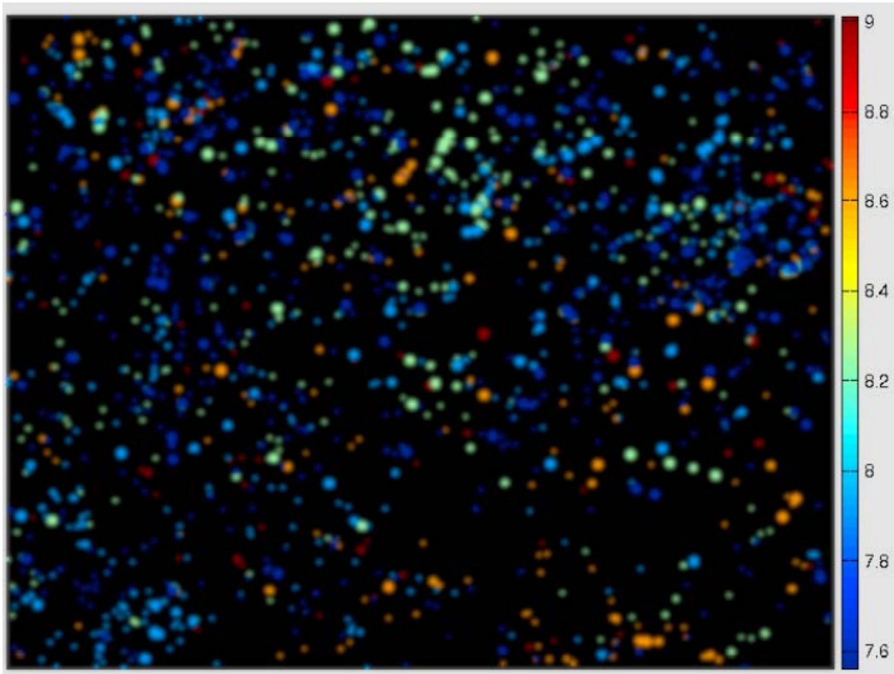


WHAT JWST WILL SEE

Salvaterra+2010

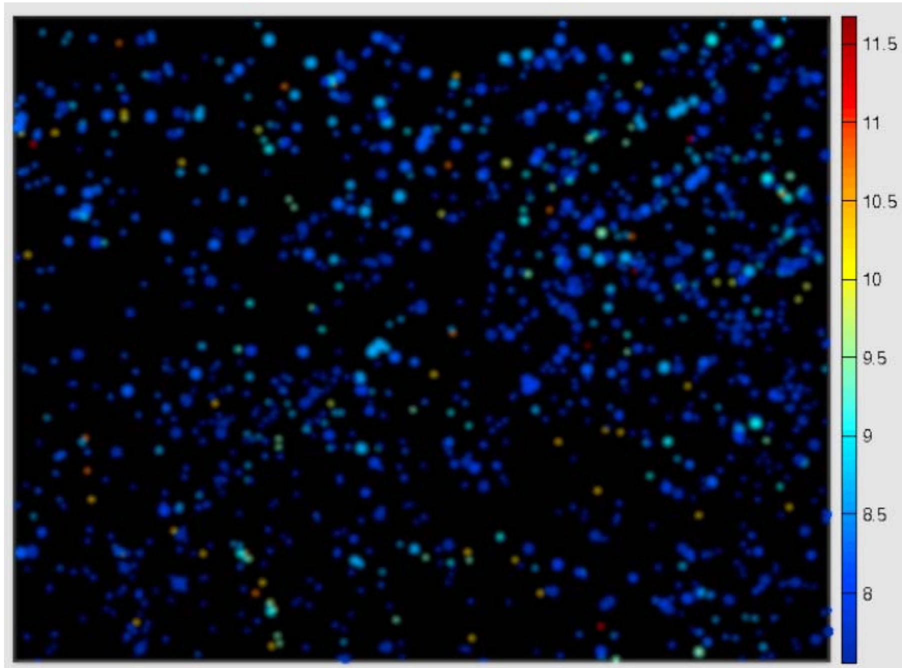
JWST: Exposure time: 10^6 s; Sensitivity limit: 1 nJy (10σ)

J-Band



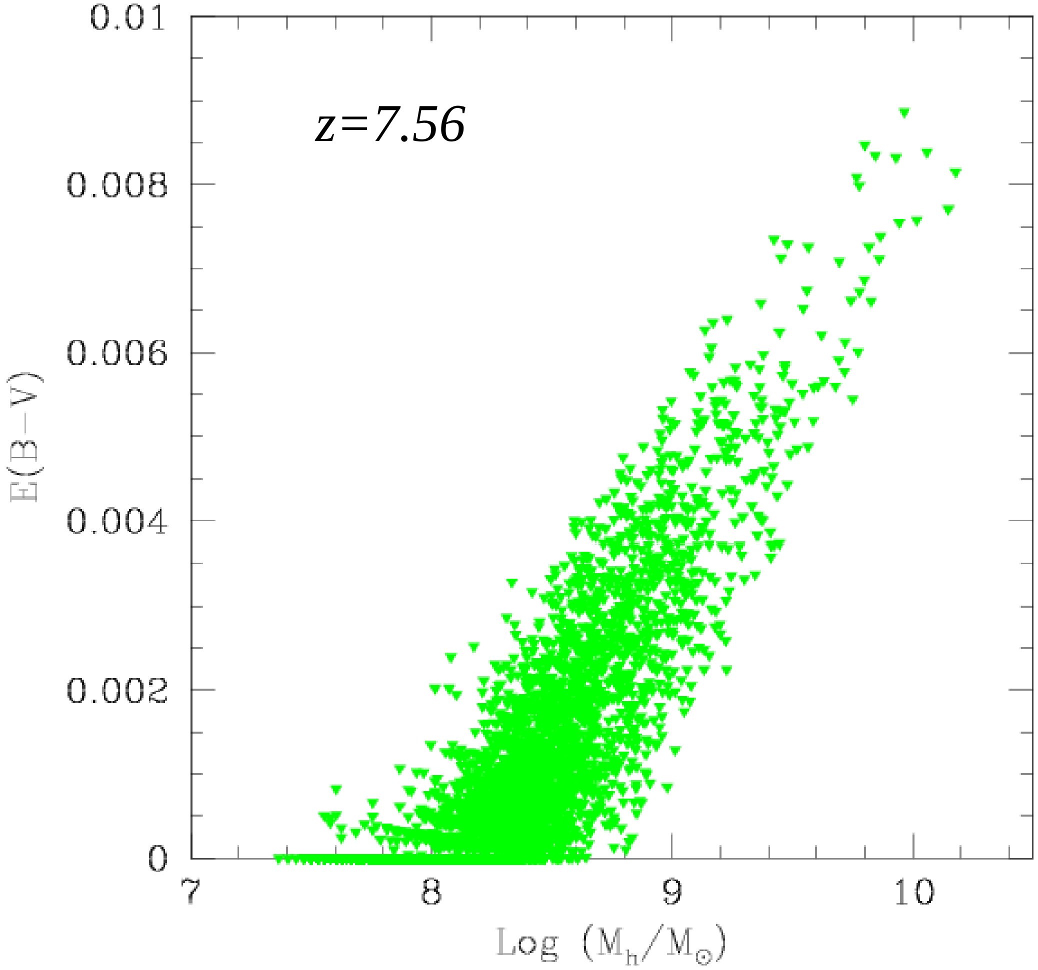
5.3 arcmin

H-Band



5.3 arcmin

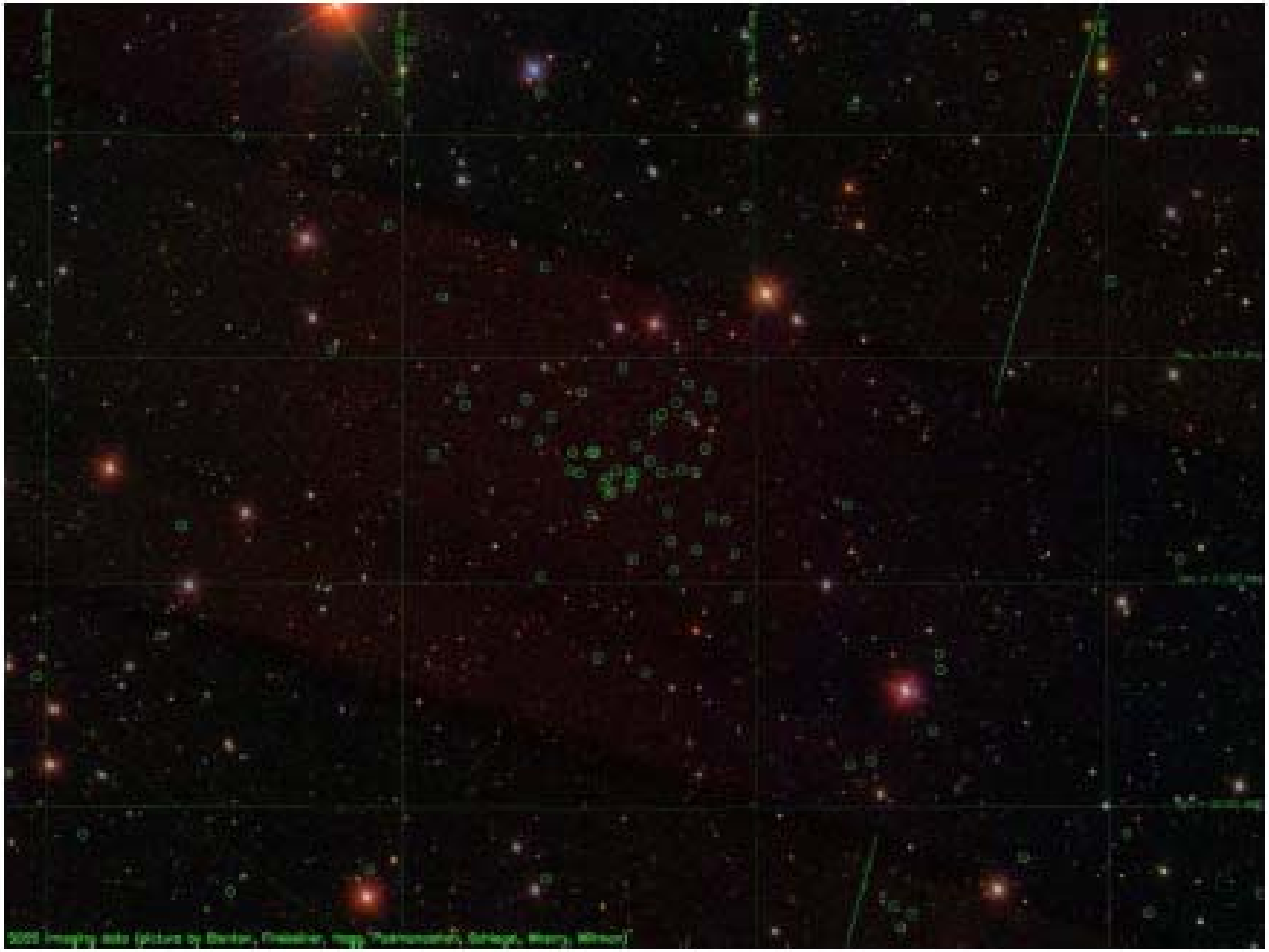
DUST CONTENT



The quest for reionization sources

WHAT ARE THEY ?

Willman+ 2006, Simon & Geha 2007

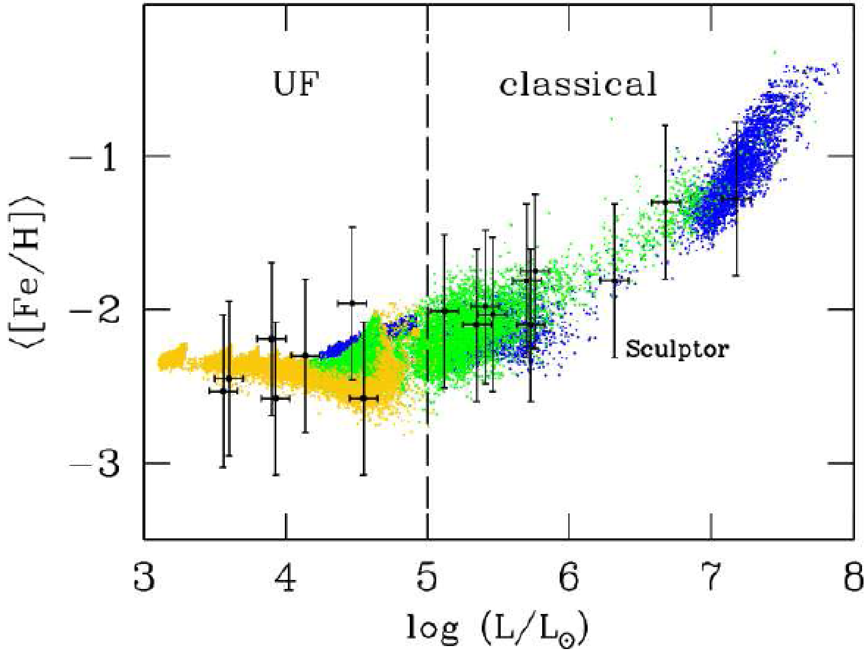


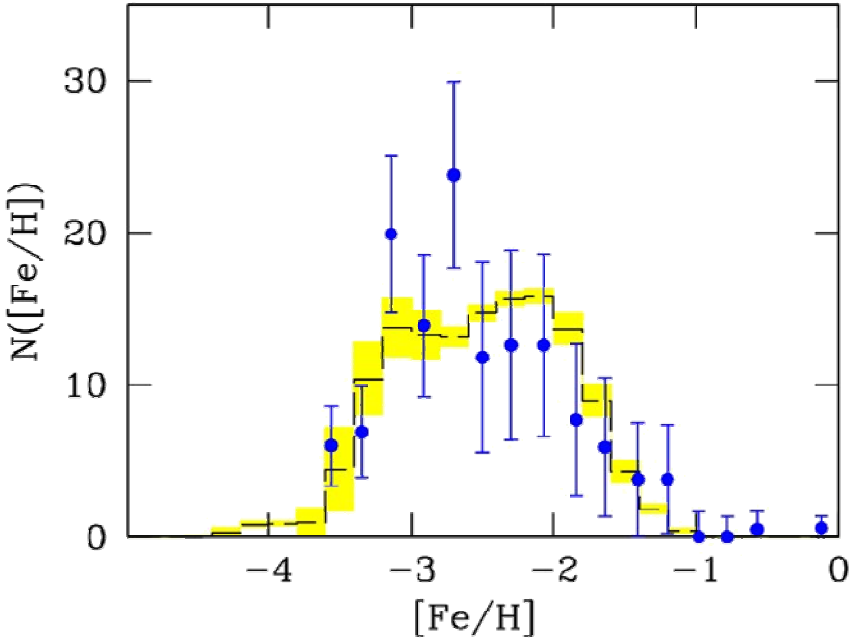
Salvadori & AF 2009, Bovill & Ricotti 2009, Wyse+2010

ULTRA FAINT DSPHs: METALLICITY

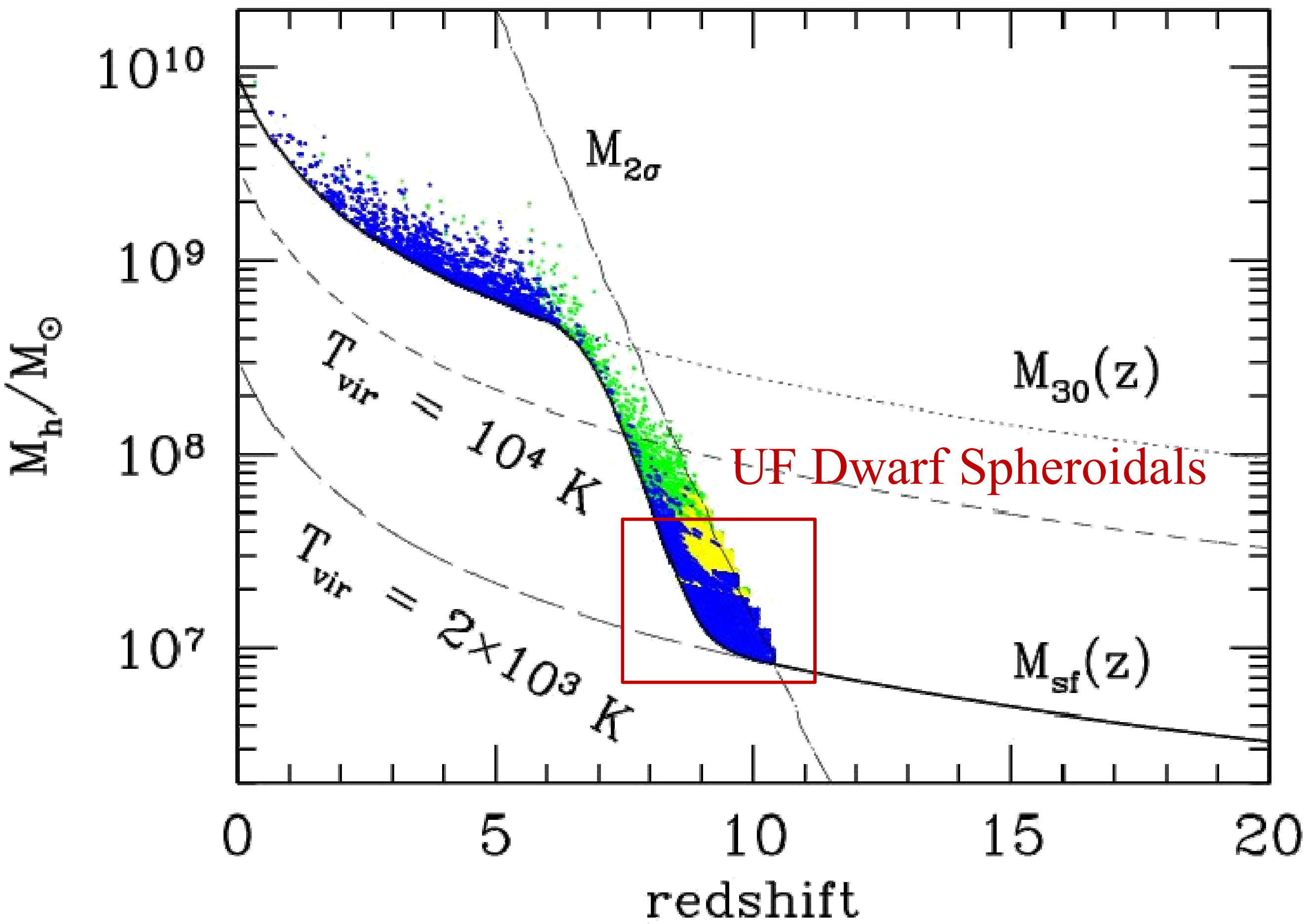
SEE POSTER BY
STEFANIA SALVADORI

data: Kirby+2007





UFs: MASS & FORMATION EPOCH



SUMMARY OF MAIN POINTS

- $f_\gamma > 80\%$ of the ionizing power at $z > 7$ from halos of $M < 10^9\ M_\odot$
- LAEs: passive reionization tracers; break the dust-IGM HI degeneracy with ALMA
- Current drop-out high-z candidates are not the reionization sources; JWST
- WFC3 galaxies @ z=7: ages: 200 Myr; metallicity: $0.1\ Z_\odot$; E(B-V) < 0.009
- WFC3 (JWST) candidates provide 20% (50%) of total ionizing photons at z=7
- Very/Ultra faint dwarfs are likely to be the dominant ionizing photons providers
- Ultra Faints are the oldest dSphs ($z > 8.5$) left-overs of H_2 cooling mini-halos