Sources of Cosmic Reionization

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The Dark Ages VIrtual Department

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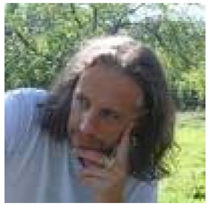

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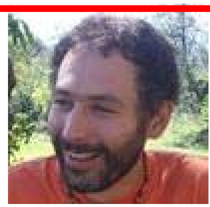

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SOURCE LIST

- Stars: Pop II and/or (massive) Pop III

  In what proportion ? (4, 30, 100)$\times 10^3$ phot/baryon into stars

- Quasars

  Too rare, too late; key sources for HeII reionization

- Supernova explosions

  Filling factor too small; Compton-y limited

- Dark Matter: decays/annihilations

  Light particles (LDM, sterile neutrinos) can produce a $\tau_e < 0.01$
  Heavy particles (neutralinos, gravitinos) totally negligible

- Mini-quasars

  Limited by unresolved SXRB
  Only 3 phot/baryon in IGM in 10 Salpeter times

- Structure formation

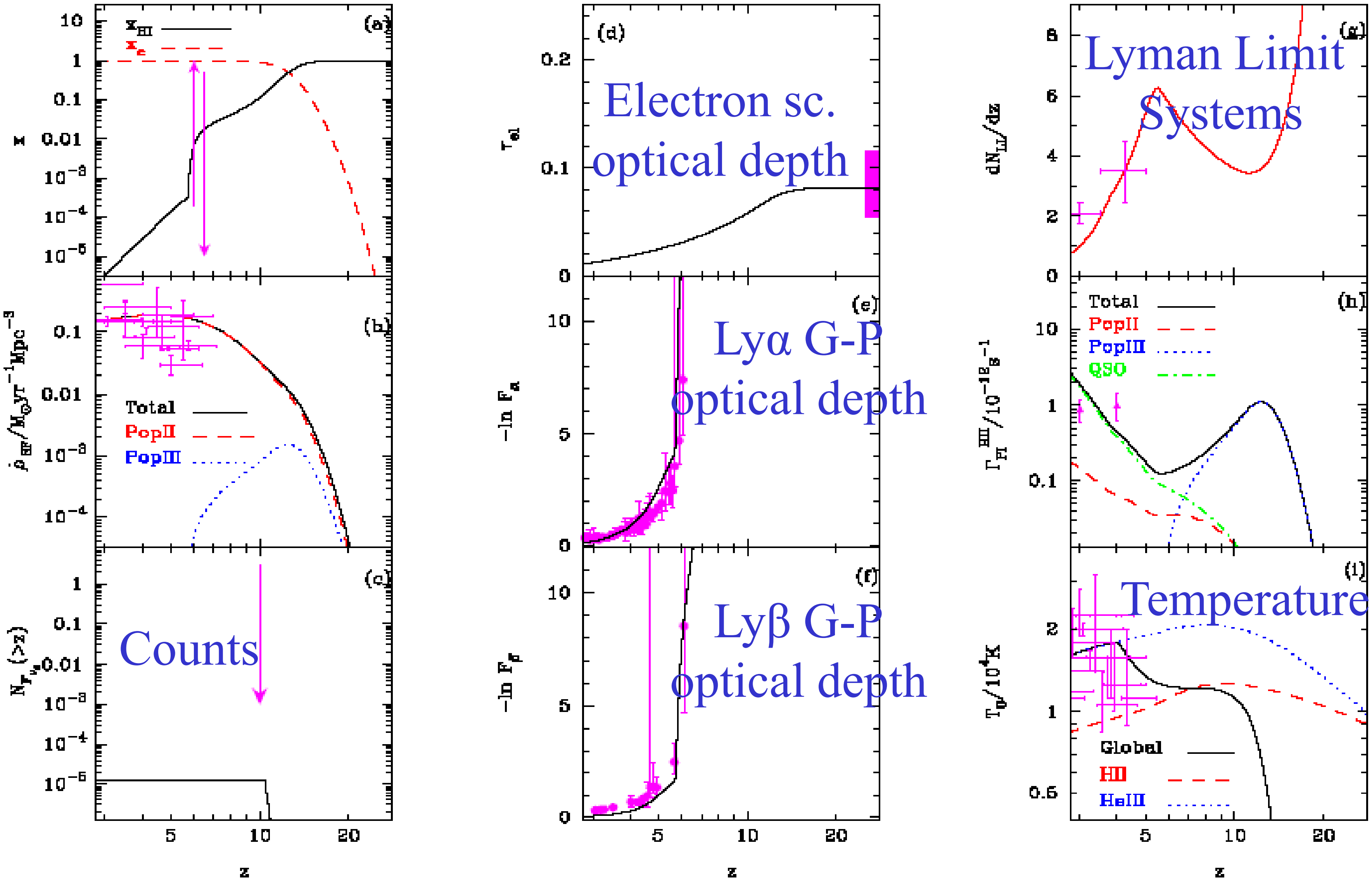
  Important for HeII reionization, bremsstrahlung has $f_{esc} \approx 1$!

EXPERIMENTAL CONSTRAINTS

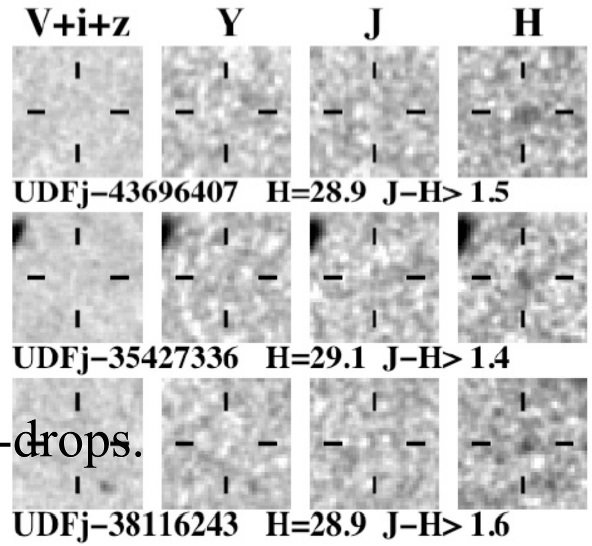
- Lyα Gunn-Peterson opacity
- Electron scattering optical depth
- Lyβ Gunn-Peterson opacity
- UV Background intensity
- Redshift evolution of Lyman Limit Systems
- IGM Temperature evolution
- IGM Metallicity
- Cosmic star formation history
- High-z galaxy counts
- Near Infrared Background

REIONIZATION HISTORY

Choudhury & AF 2005-2008



SEARCH TECHNIQUES

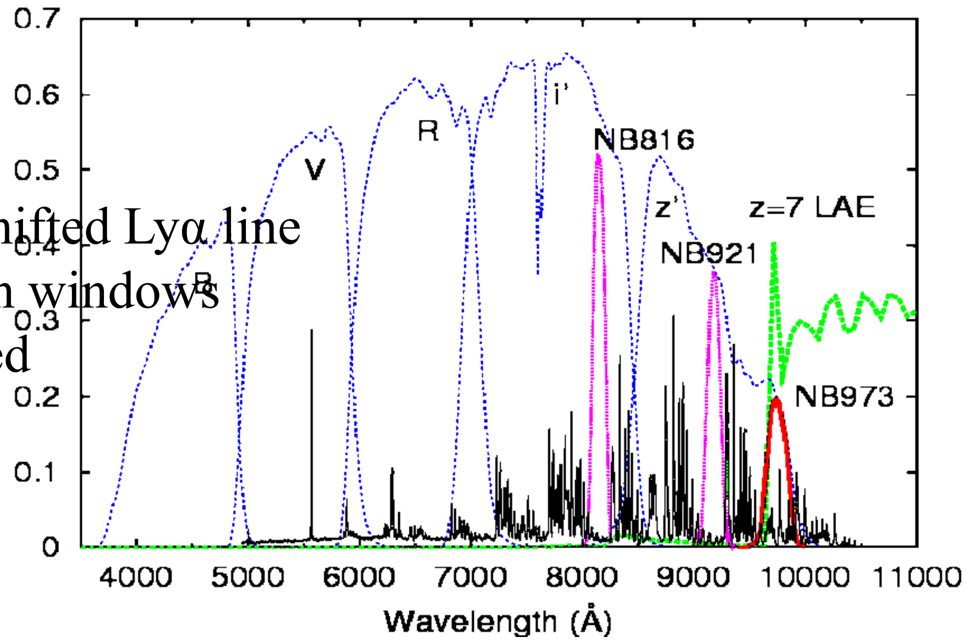


DROP-OUTS

- 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

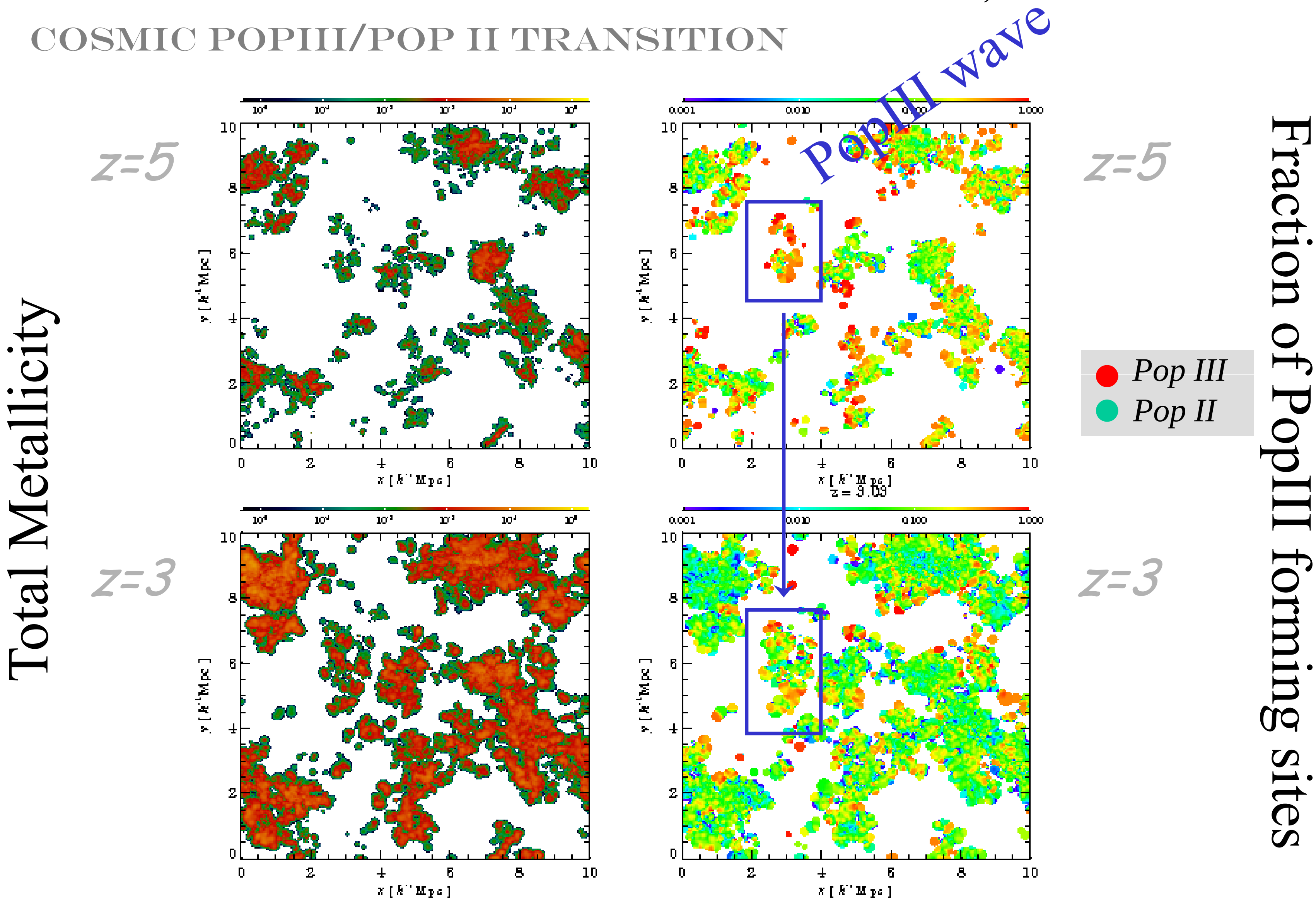
LYMAN ALPHA EMITTERS

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



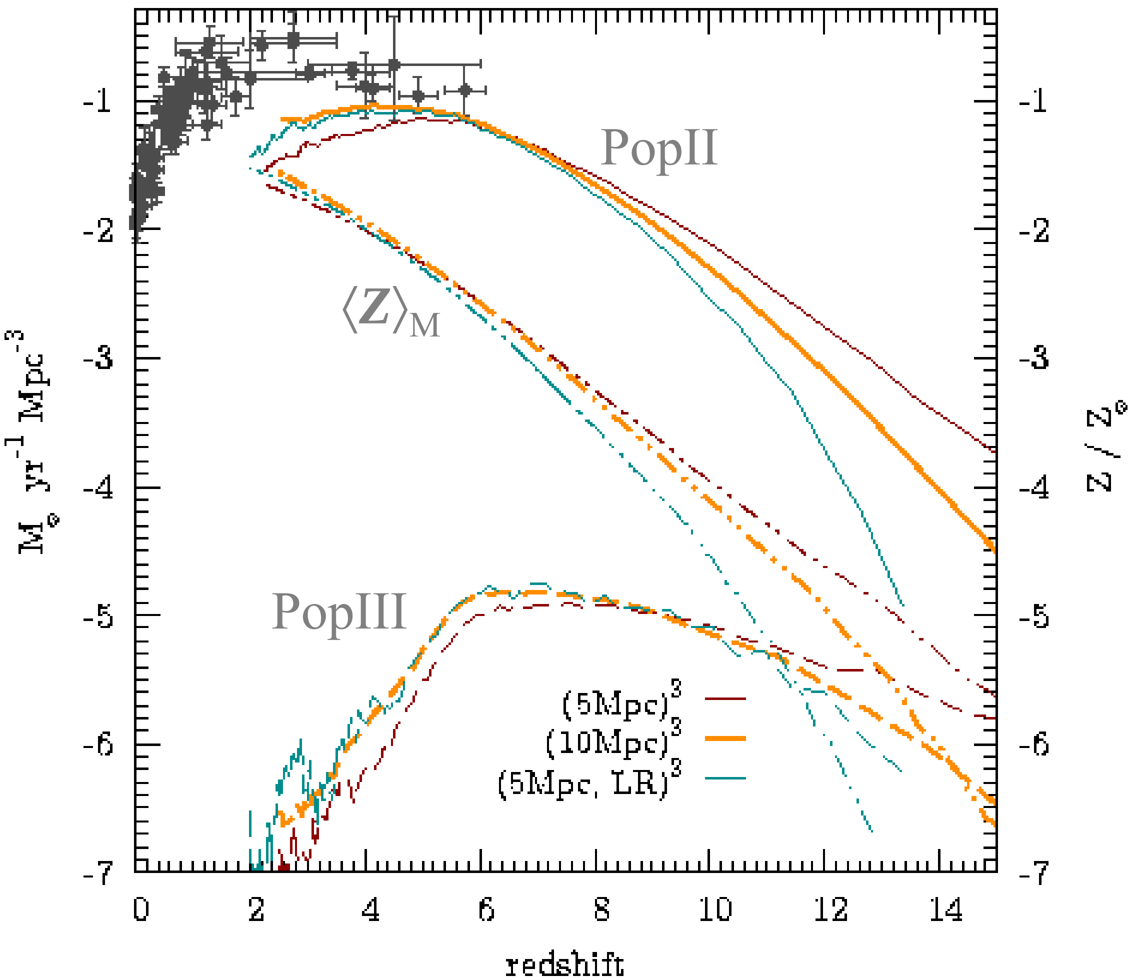
Tornatore, AF & Schneider 2007

COSMIC POPIII/POP II TRANSITION



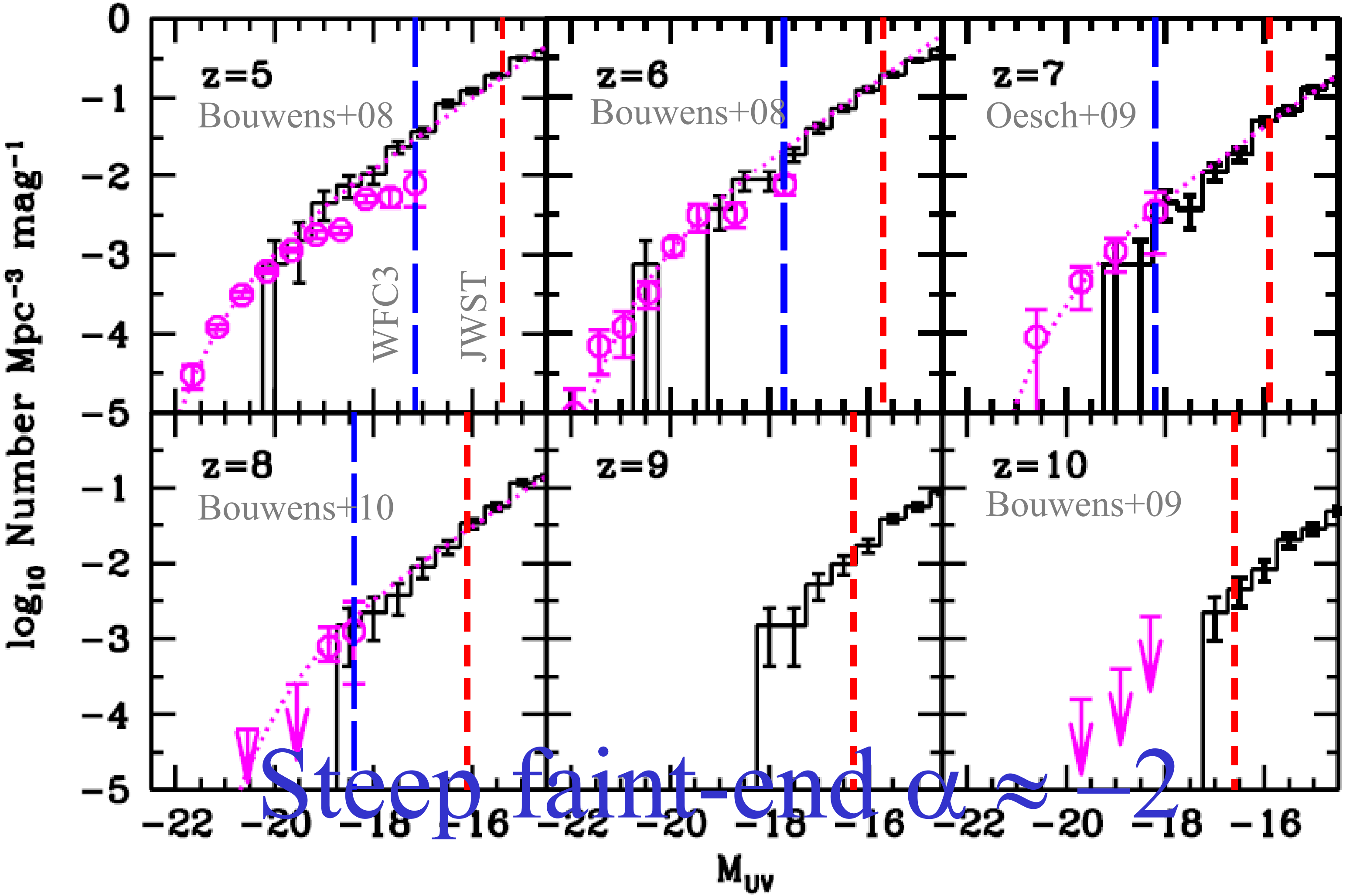
Tornatore, AF & Schneider 2007; Schneider+2008

STAR FORMATION RATES



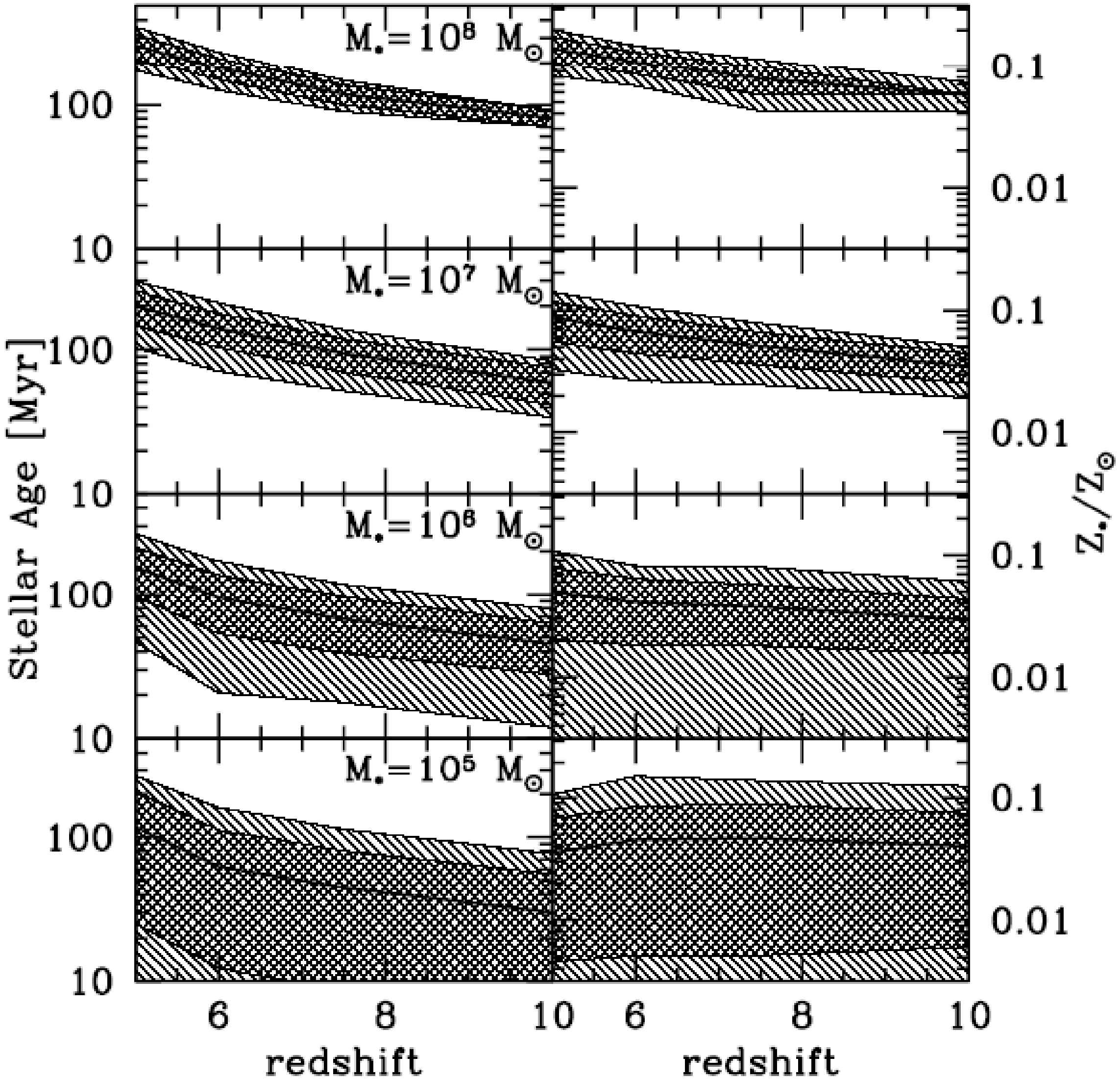
HIGH-Z LUMINOSITY FUNCTIONS

Simulations: Salvaterra+2010, submitted



Steep faint-end $\alpha \simeq -2$

HIGH-Z GALAXY PROPERTIES



PROPERTIES

LYMAN ALPHA EMITTERS

- Halo masses $10^{10\text{-}12}$ $M_\odot$
- SFR = 1-100 $M_\odot$ yr^{-1}
- Ages > 40 – 400 Myr
- Lya LF evolves; UV LF does not in z=5.7-6.6
- Large EW (> 200Å) often observed
- Can be due to (a combination of)::

  ✧ *top-heavy IMF*

  ✧ *differential dust Lya/continuum extinction*

  ✧ *outflows //infall (also affecting line shape)*

LAEs IONIZING POWER

@ $z = 6.6$

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

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

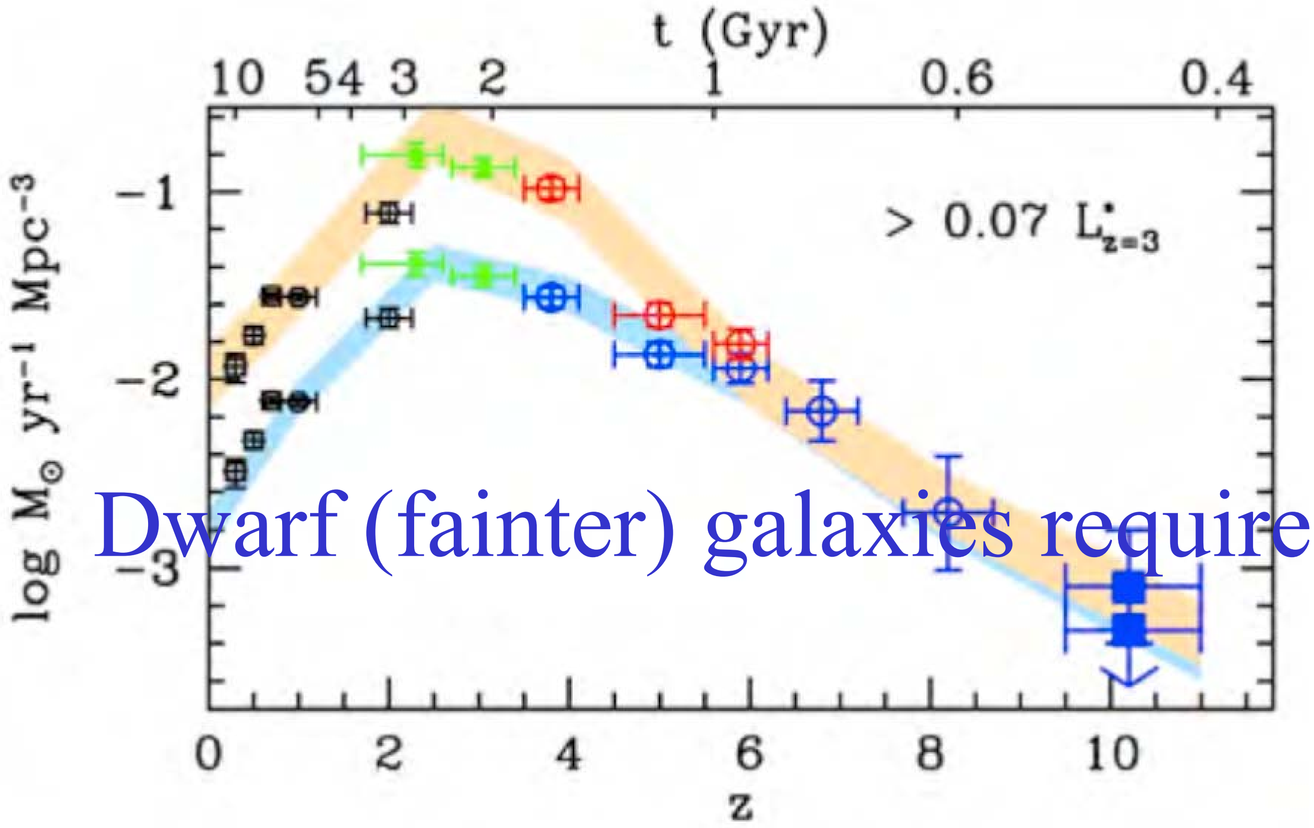
LAE contribute $\approx$ 1% of ionizing budget

PASSIVE TRACERS OF REIONIZATION ?

Bouwens+2009

DROPOUTS CONSTRAINTS

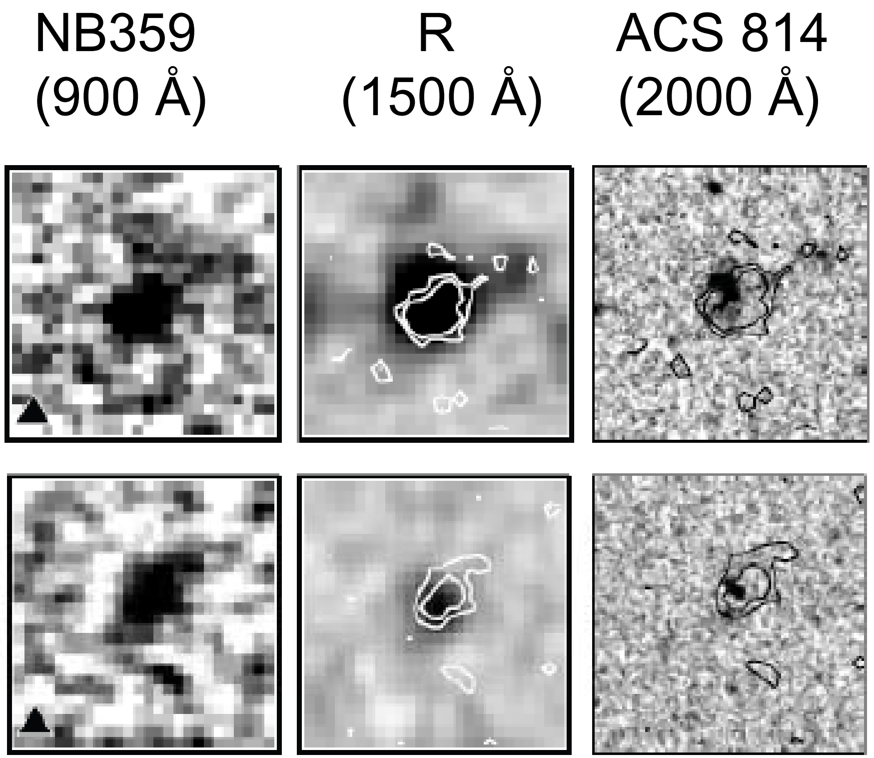
$$\dot{\rho}_{\rm SFR} \approx 0.013\, f_{\rm esc}^{-1} \left(\frac{1+z}{6}\right)^3 \left(\frac{\Omega_b\, h_{50}^2}{0.08}\right)^2 C_{30}\, M_\odot\, {\rm yr}^{-1}\, {\rm Mpc}^{-3}$$



Dwarf (fainter) galaxies required ?

Inoue+2008; Siana+2010

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?

REIONIZATION SOURCES

Choudhury & AF 2008

SMALL OR LARGE ?

Searching for the reionization sources

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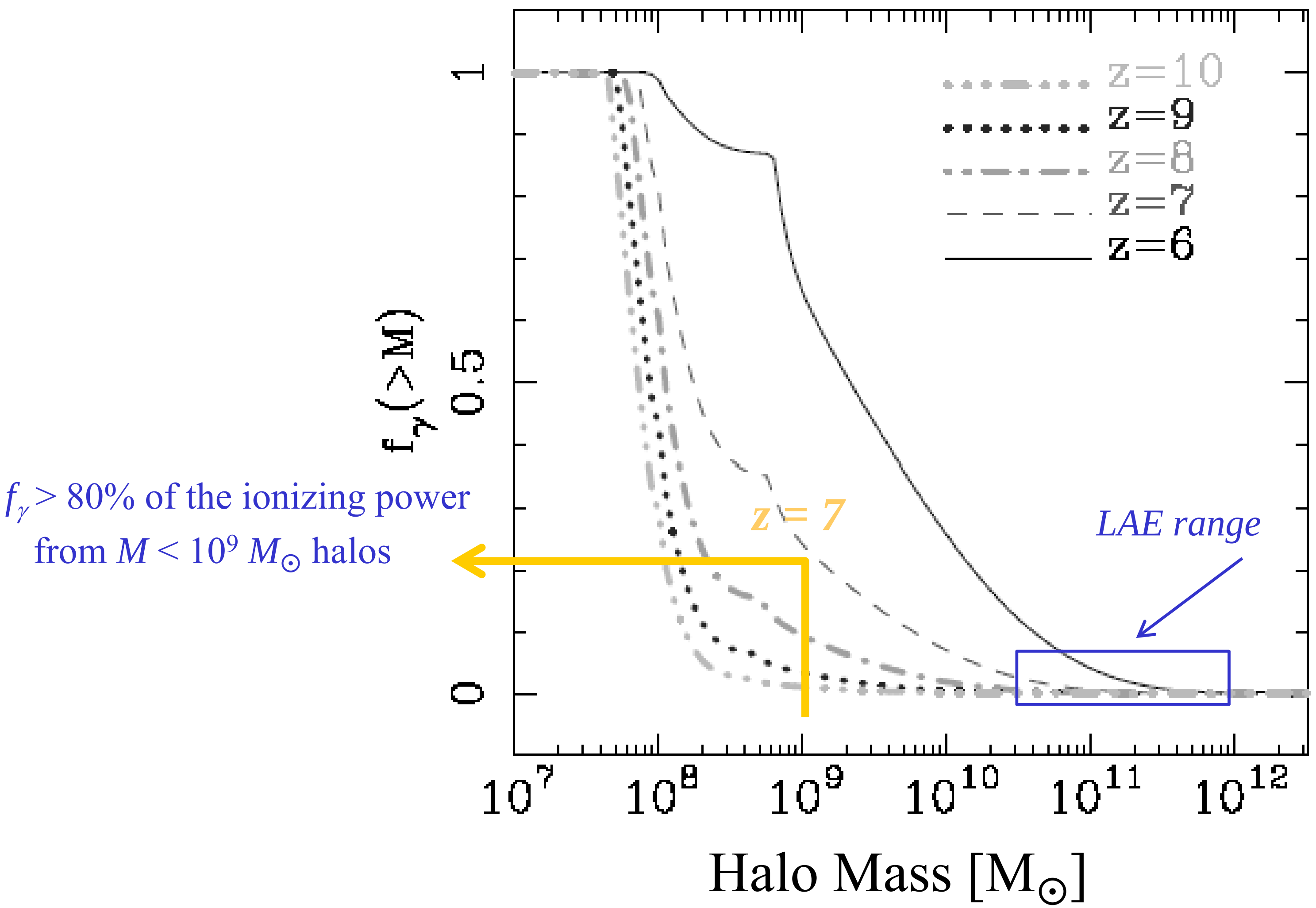
5 February 2008

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.

Choudhury & AF 2007

IONIZING PHOTON BUDGET

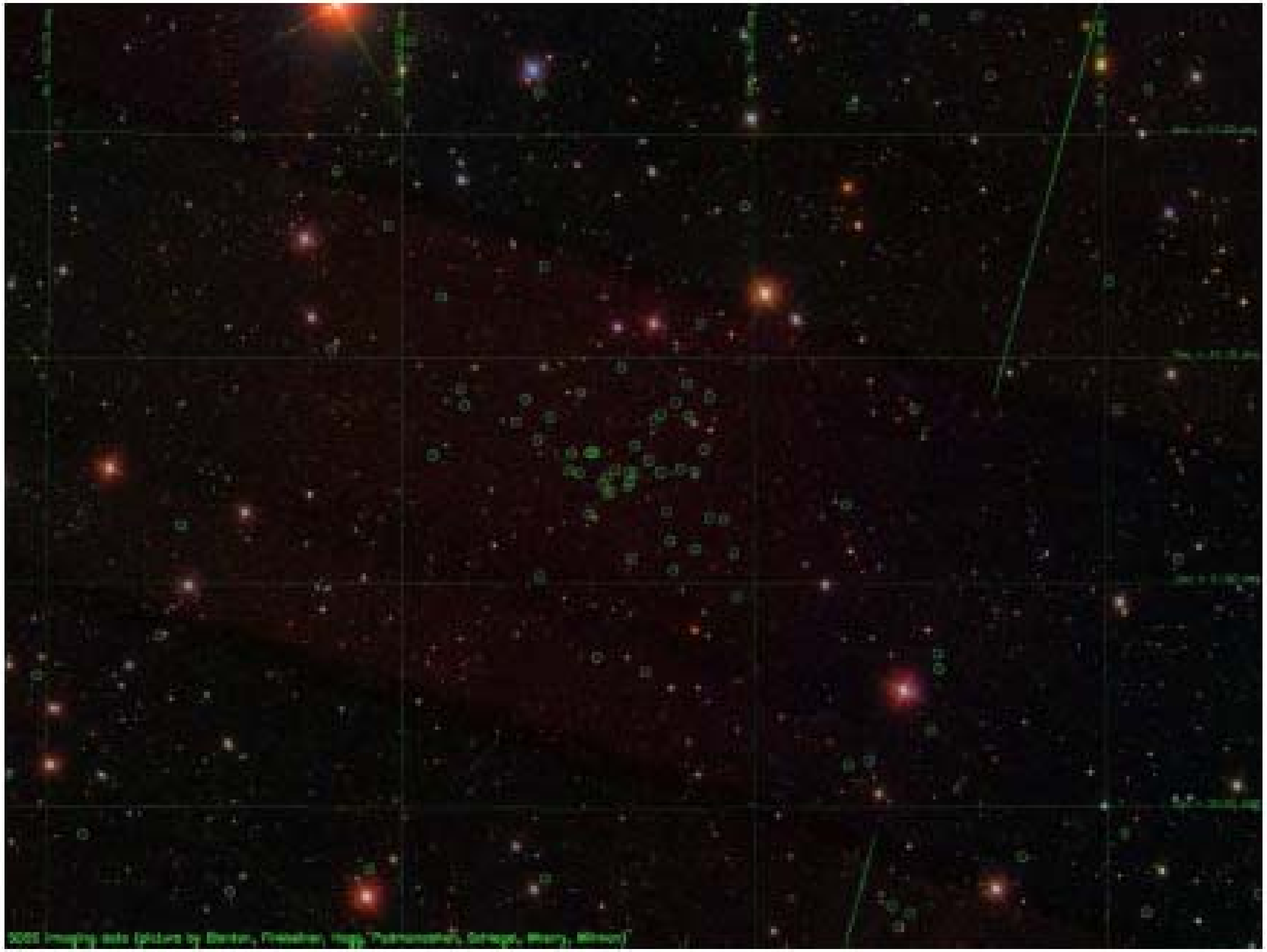


Salvadori & AF 2009

WHAT ARE THEY ?

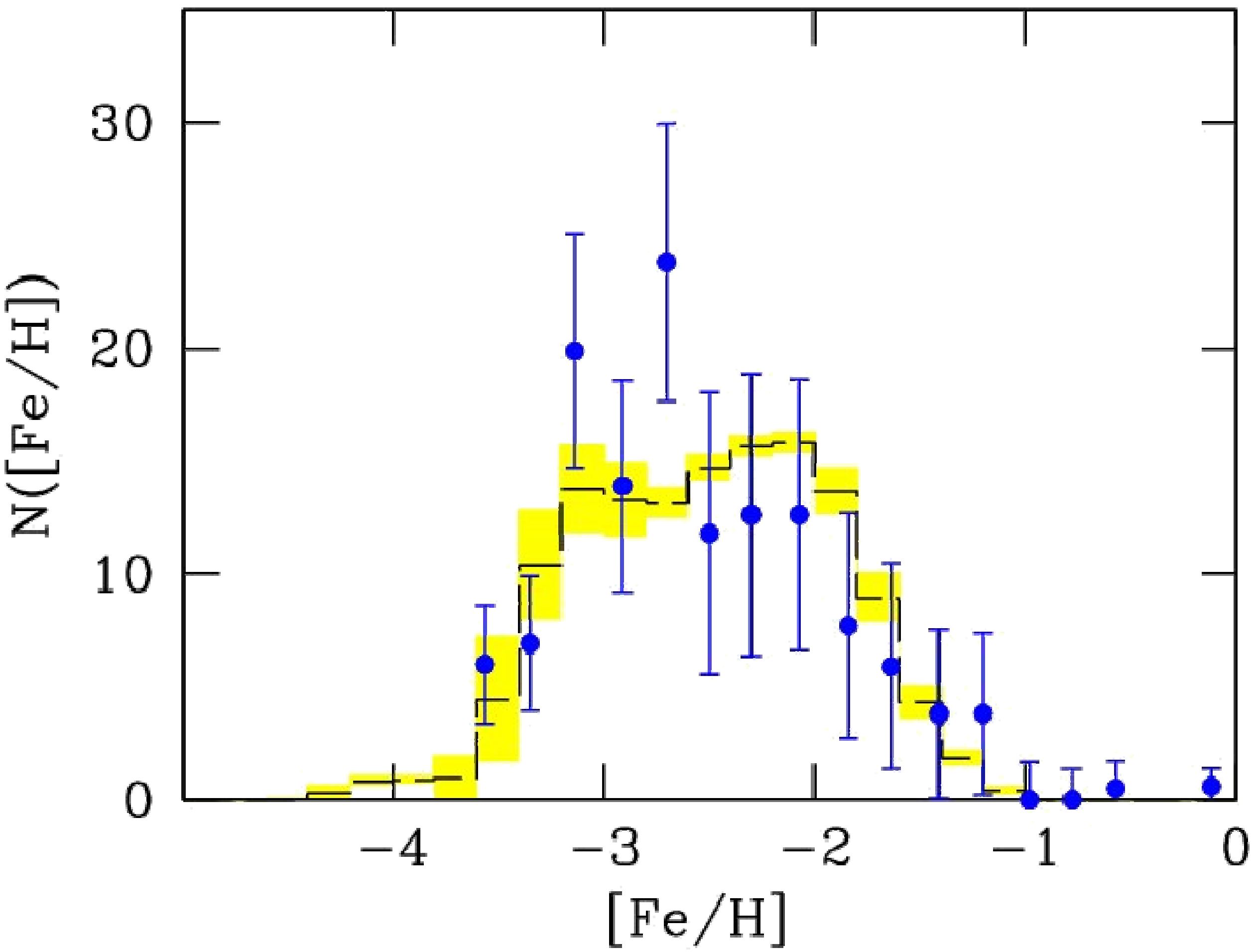
Ultra Faint Dwarf Spheroidals

Willman+ 2006, Simon & Geha 2007



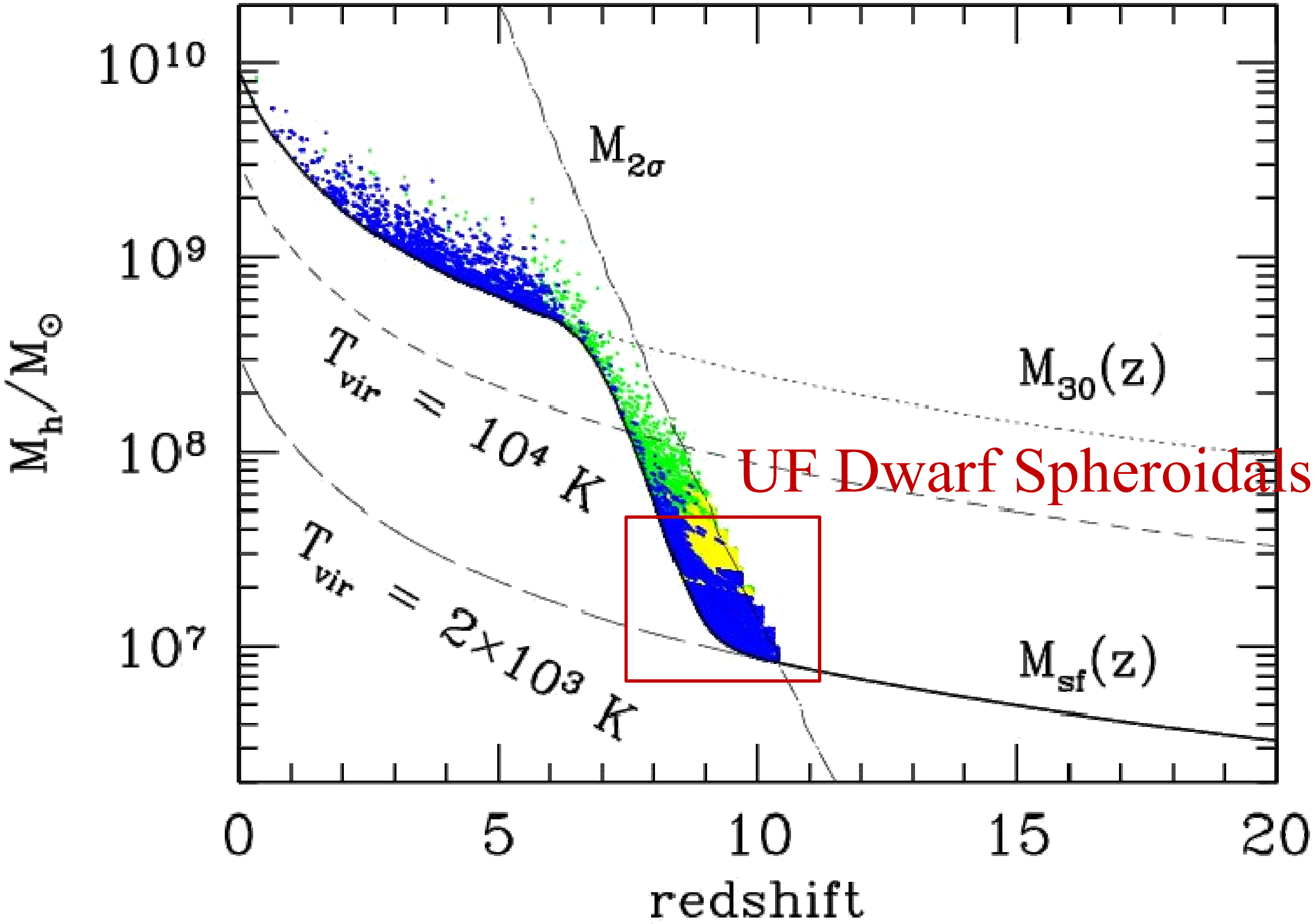
Salvadori & AF 2009

ULTRA FAINT DSPHs: METALLICITY



Salvadori & AF 2009

UFs: MASS & FORMATION EPOCH



SUMMARY OF MAIN POINTS

- Stars dominate the reionization photon budget (mini-QSO/DM negligible contributors)
- Reionization started by metal-free stars @ z=20; 90% complete @ z=8
- Early reionization ($z > 7$) not in contrast with any experimental data
- $f_\gamma > 80\%$ of the ionizing power at $z > 7$ from halos of $M < 10^9\ M_\odot$
- Current drop-out high-z candidates are not the reionization sources
- LAEs are passive tracers of reionization provided we break the dust-IGM HI degeneracy
- 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