Hubble Frontier Fields First Complete Cluster Data: Faint Galaxies at z~5-10 for UV Luminosity Functions and Cosmic Reionization

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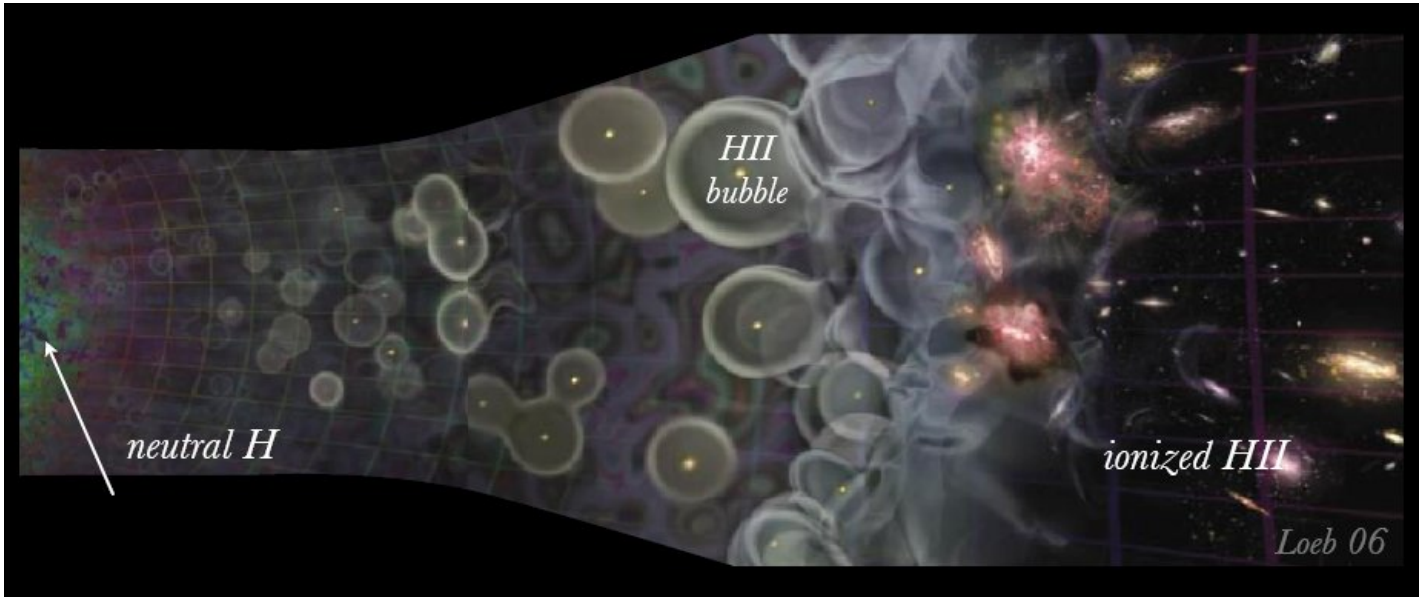
Outline

- Introduction
- Dropout selection at z~5-10
- UV luminosity function fitting with Monte Carlo simulations evaluating lensing effects
- Discussion of their contribution to the cosmic reionization

Cosmic reionization

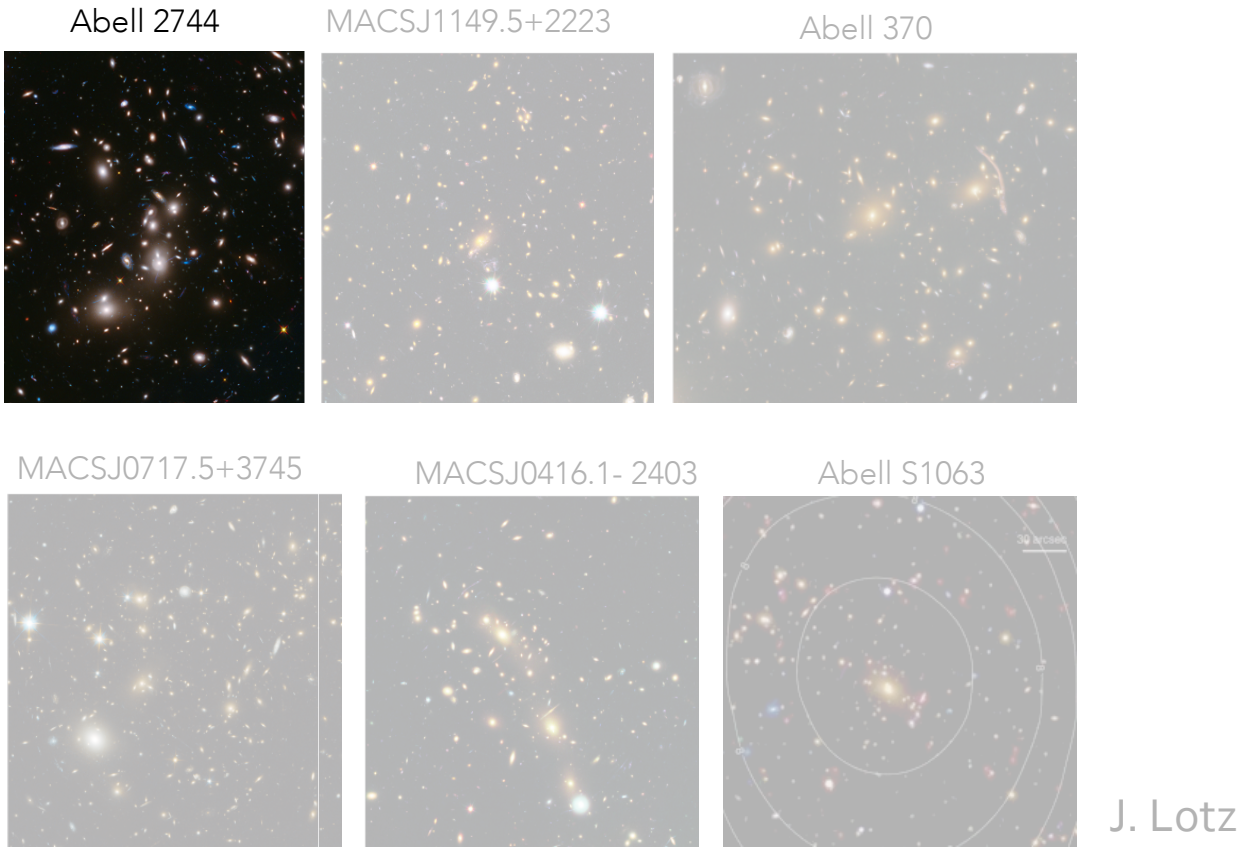
- From z ~ 15 to z ~ 6
- Source of reionization: photons from star-forming galaxies
- UV luminosity density decrease beyond z > 8 (e.g, Bouwens+2014)

Can UV photons from star-forming galaxies reionize the universe?



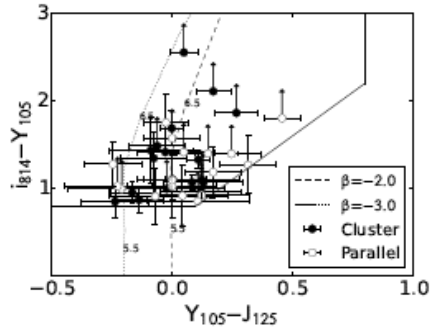
Loeb 2006

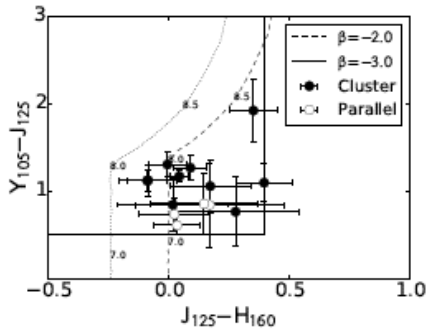
Hubble Frontier Fields

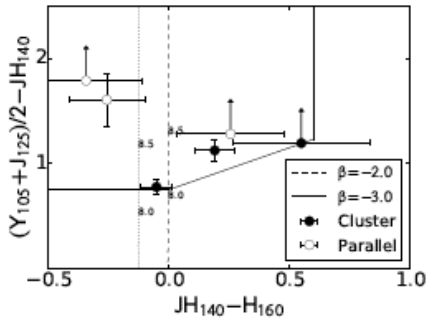


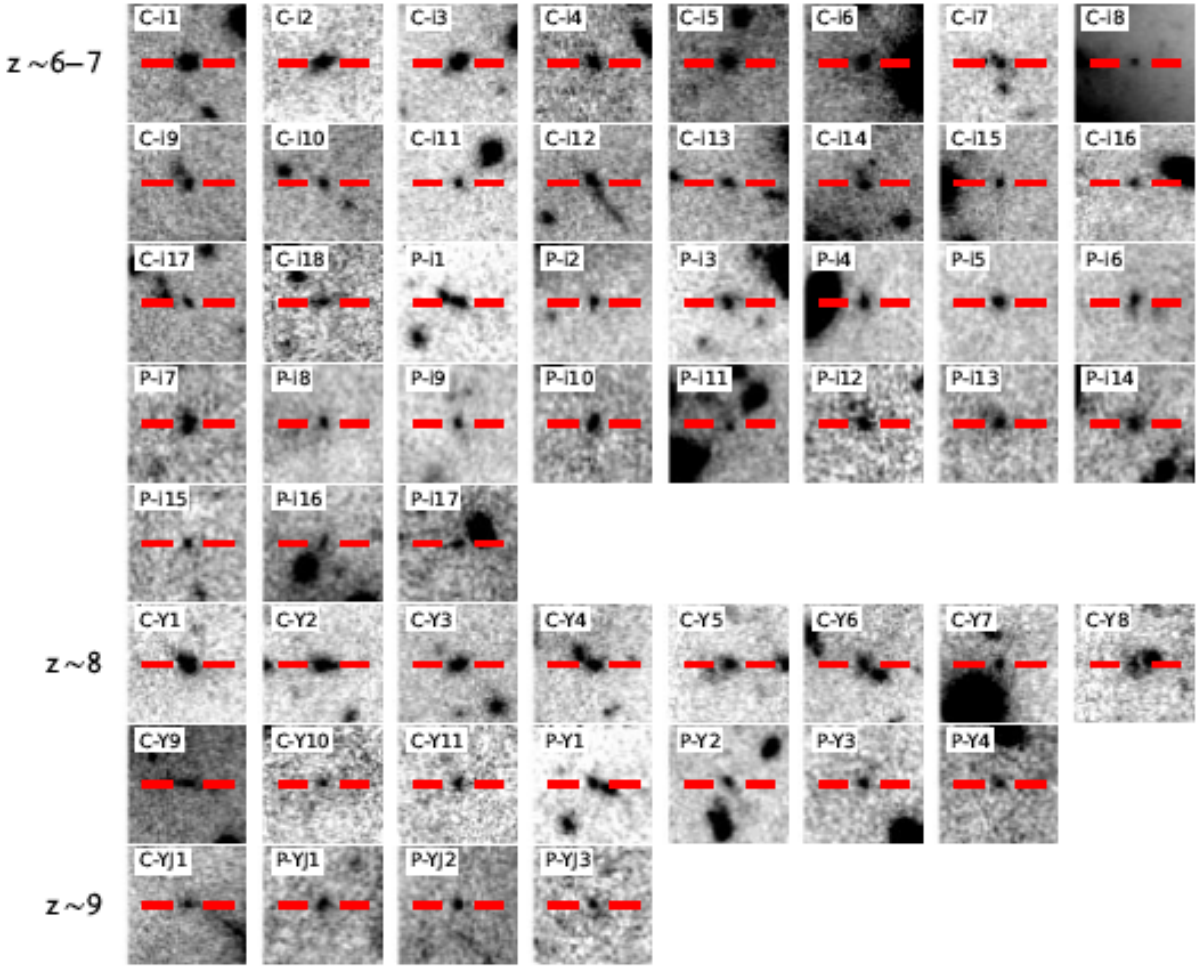
First complete cluster, Abell 2744 and its parallel fields data

Dropout Selection









Similar to Atek+14, Coe+14, Oesch+14, Zheng+14, Laporte+14, Zitrin+14

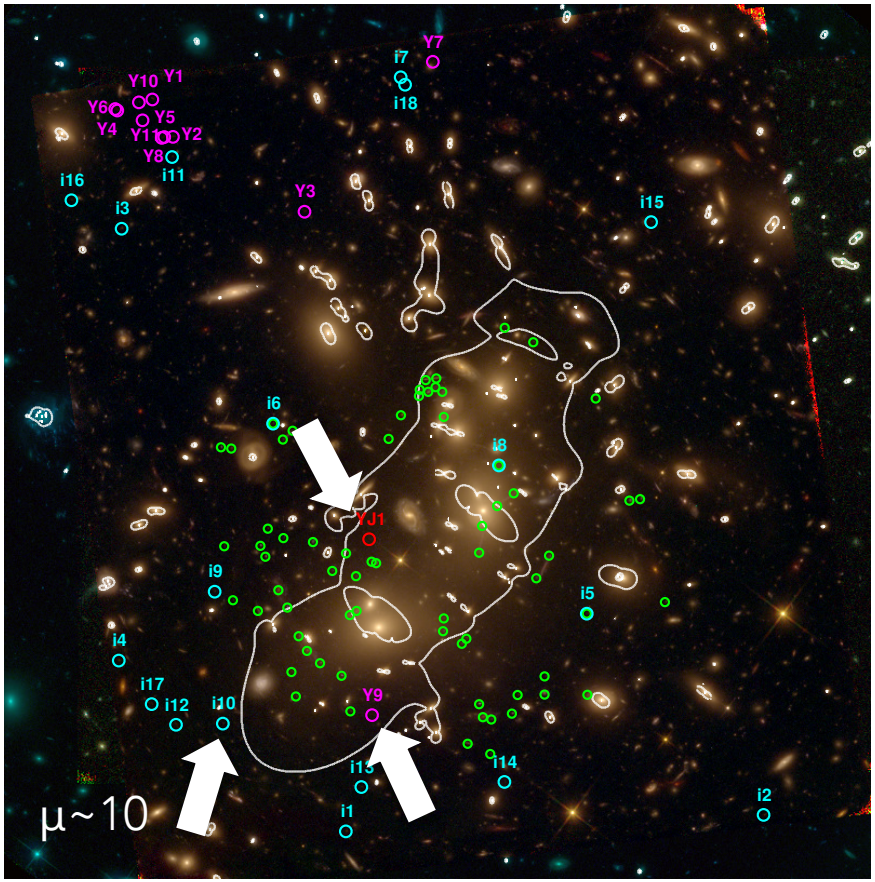
Abell 2744 and its parallel fields

Cyan z ~ 6-7 dropouts

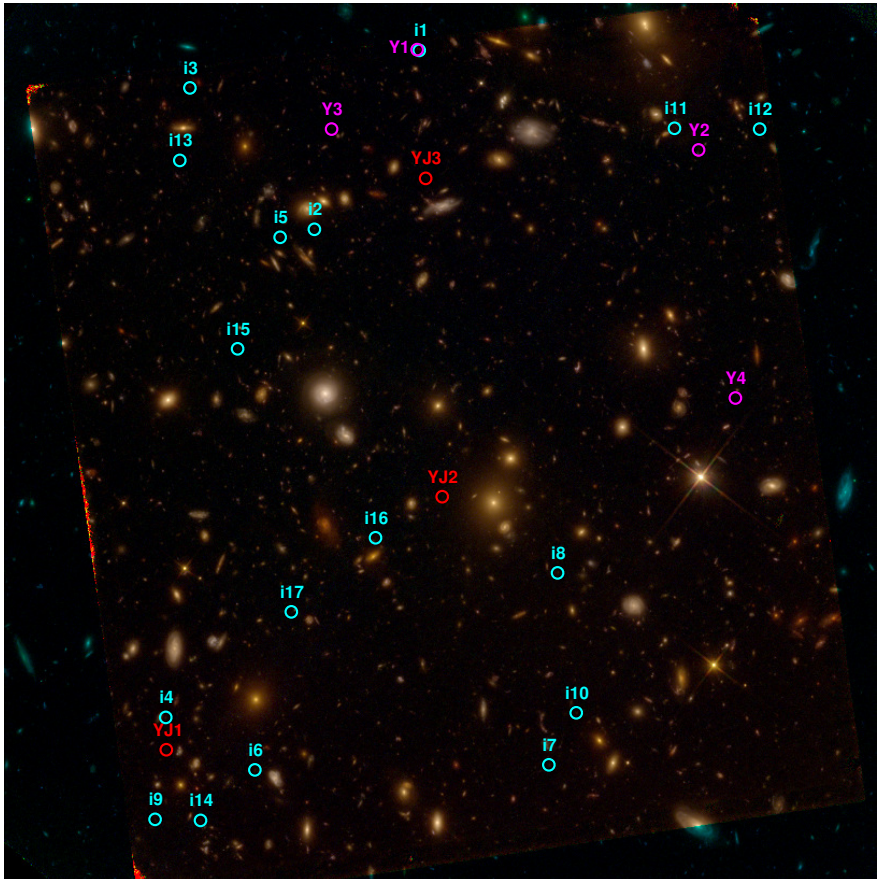
Magenta z ~ 8 dropouts

Red z ~ 9 dropouts

Green Multiple images for modeling



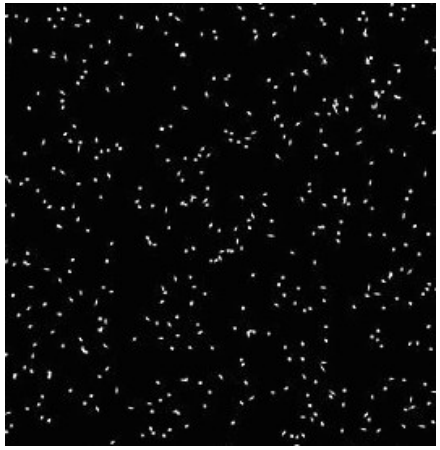
Abell 2744 Cluster field



Parallel field

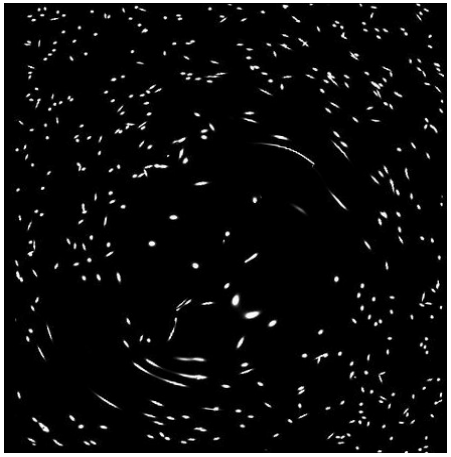
Monte Carlo Simulation

Simulation images for (M*, Φ*,α)



Lensing
(GLAFIC)

Lensed images



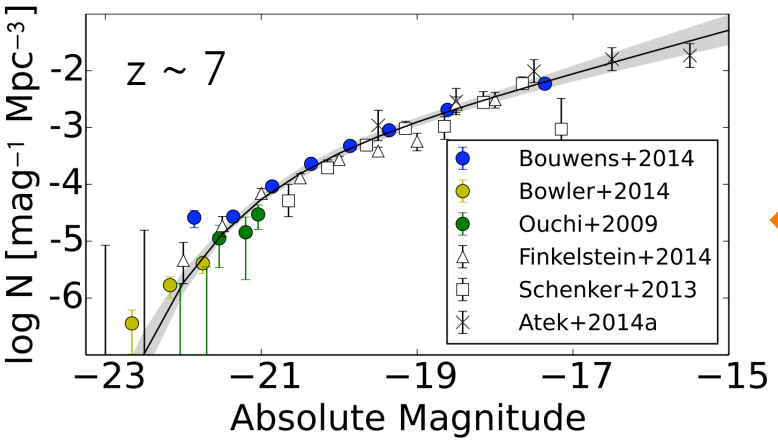
place them in the
real HFF image

Mock observations

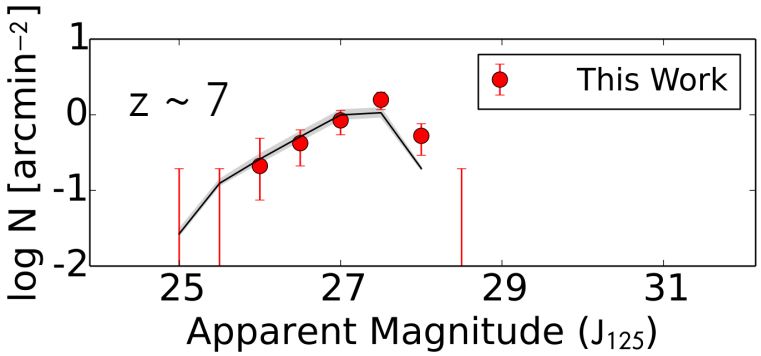
- Include not only a simple magnification, but also the other lensing effects,
  - Source distortion
  - Multiplication of images
  - Distortion of selection volume

Monte Carlo Simulation

Luminosity function
in the source plane



Observed number density
in the image plane



- Include not only a simple magnification, but also the other lensing effects,
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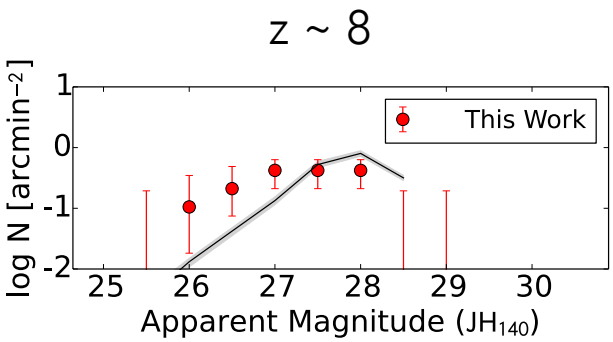
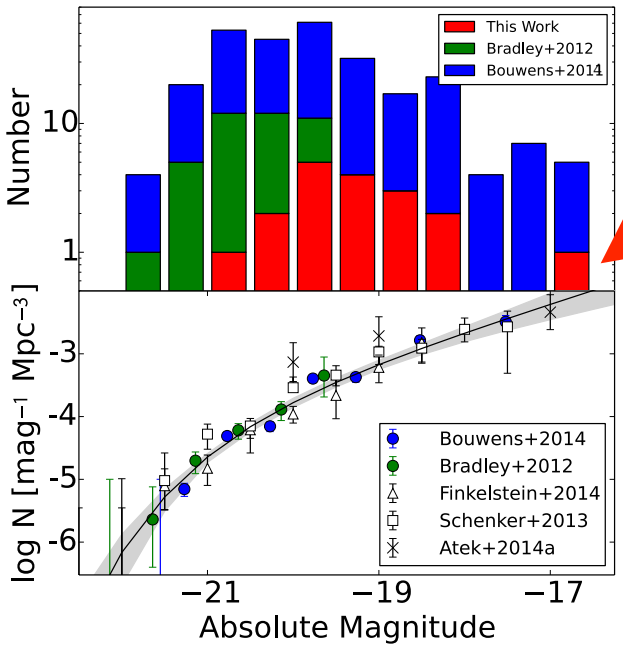
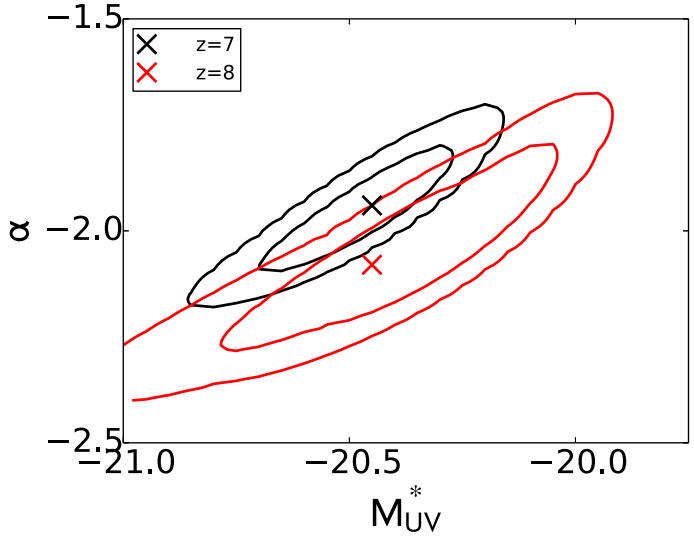
Luminosity Functions

Number density in the image plane





HFF



LF in the source plane

Down to -17 mag at z~5-10

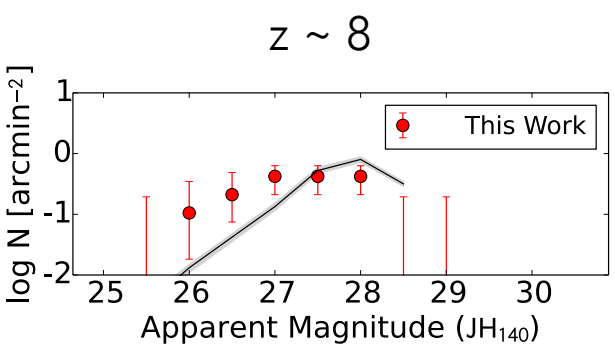
Faint end slope α ~ -2 (consistent with Atek+2014)

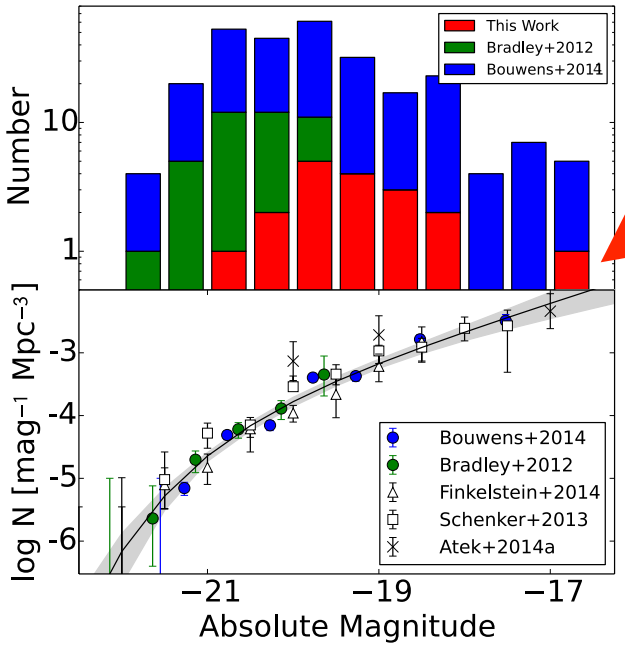
Notable improvements in z~9 LF

Luminosity Functions

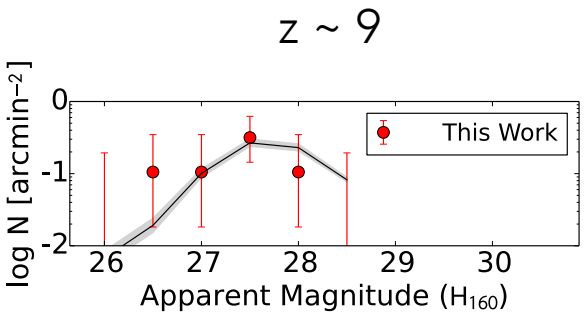
Number density in the image plane

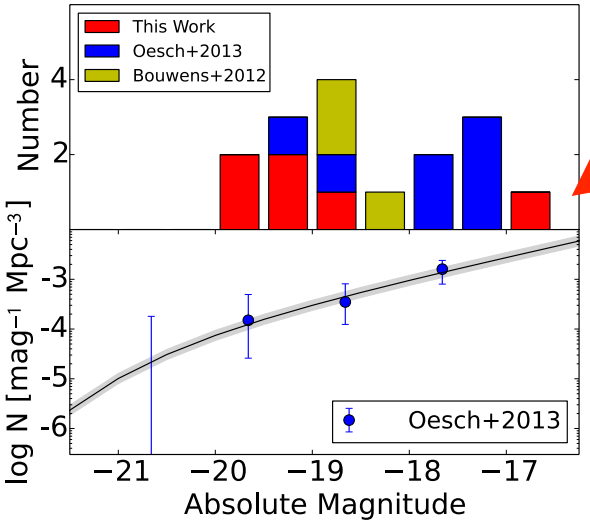
LF in the source plane





HFF





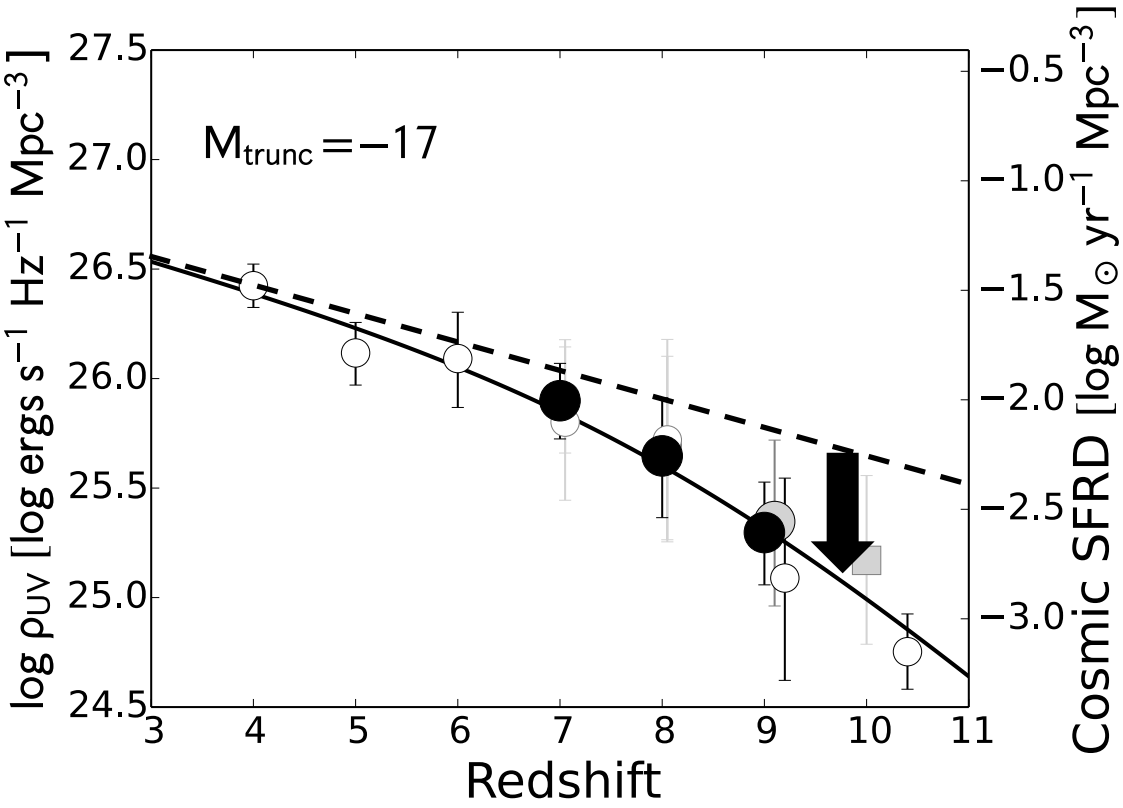
HFF

Down to -17 mag at z~5-10

Faint end slope α ~ -2
(consistent with Atek+2014)

Notable improvements in z~9 LF

UV luminosity Densities ρ_{UV}



- Support the rapid decrease of ρ_{UV} at z>8 (Oesch+13,Bouwens+14)
- Strengthen the evidence of the rapid decrease of ρ_{UV} at z>8

Contribution to Cosmic Reionization

Calculate Thomson scattering optical depth τ_e from ρ_{UV}

Free parameters: escape fraction f_{esc}, clumping factor C_{HII}, conversion factor ξ_{ion}

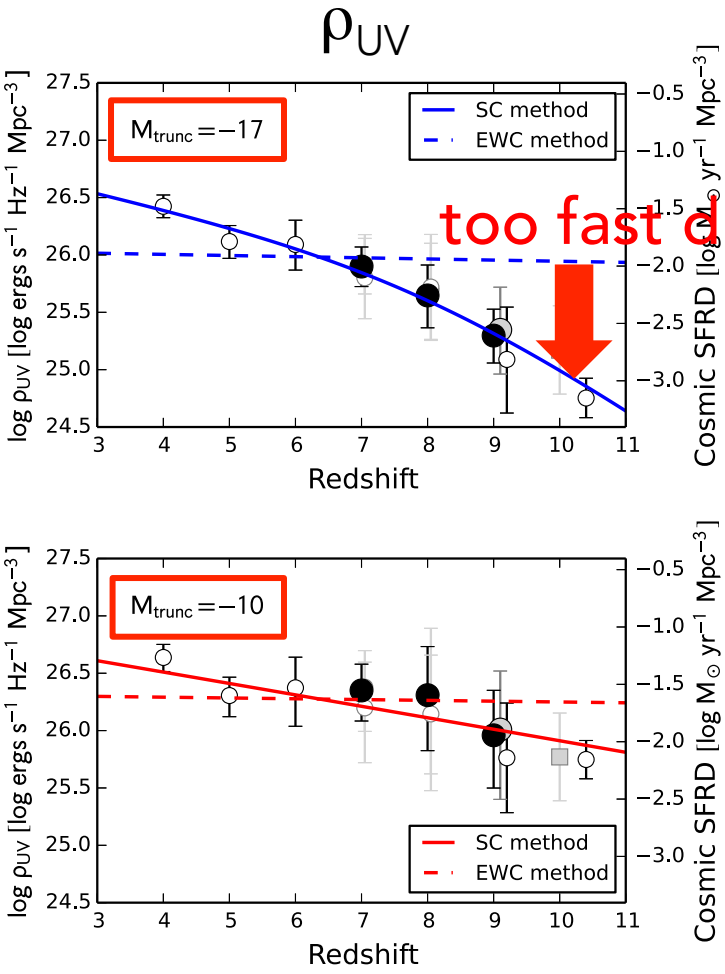
$$\dot{Q}_{\rm H\,II} = \frac{\dot{n}_{\rm ion}}{\langle n_{\rm H}\rangle} - \frac{Q_{\rm H\,II}}{t_{\rm rec}},$$

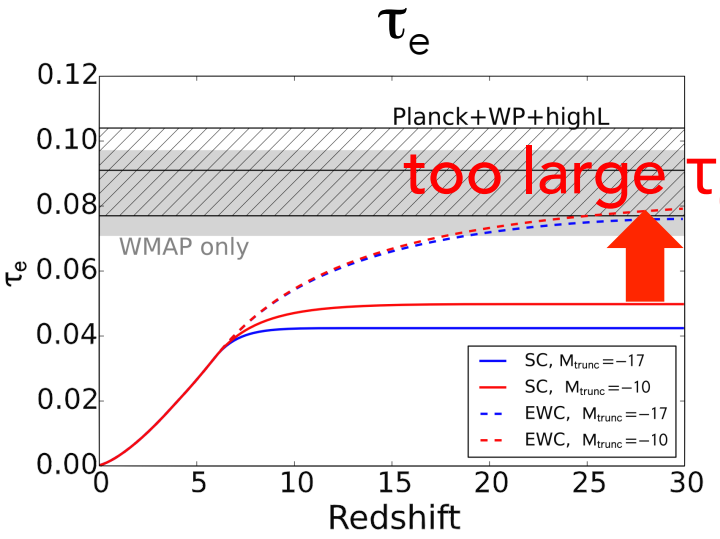
$$\dot{n}_{\rm ion} = f_{\rm esc}\,\xi_{\rm ion}\,\rho_{\rm UV}$$

$$t_{\rm rec} = \frac{1}{C_{\rm H\,II}\,\alpha_{\rm B}(T)(1 + Y_{\rm p}/4X_{\rm p})\langle n_{\rm H}\rangle(1+z)^3}$$

$$\tau_{\rm e} = \int_0^\infty {\rm d}z \frac{c(1+z)^2}{H(z)} Q_{\rm H\,II}(z)\,\sigma_{\rm T}\,\bar{n}_{\rm H}\,(1+\eta Y/4X)$$

Contribution to Cosmic Reionization





τ_e does not agree with WMAP+Planck results

Decrease of ρ_{UV} (z) is too fast to produce the large τ_e

Origin of Discrepancy

(Too rapid ρ_{UV} (z) decrease and too large τ_e)

Three possibilities:

1) Moderate ρ_{UV} (z) decrease at z>11

Partial reionization at z~15 largely helps to increase τ_e,
due to the high baryon density at the early epoch

2) Evolving free paramemter

f_{esc} and/or ξ_{ion} increase towards higher redshift. In other words, more efficient ionization production by popIII with a given SFRD.

3) Additional sources of reionization

Large contribution such from X-ray binaries/faint AGNs

Summary

- Detect ~50 dropout galaxies at z~5-10 in the Abell 2744 cluster field and parallel field
- 3 dropouts are magnified with μ~10, reaching the intrinsic luminosities M_{UV} ~ -17
- Derive UV luminosity functions carefully evaluating the lensing effects: magnification, distortion and multiplication of images.
- Strengthen the evidence of the rapid decrease of ρ_{UV} at $z > 8$
- Cannot reproduce both ρ_{UV} decrease and the large τ_e