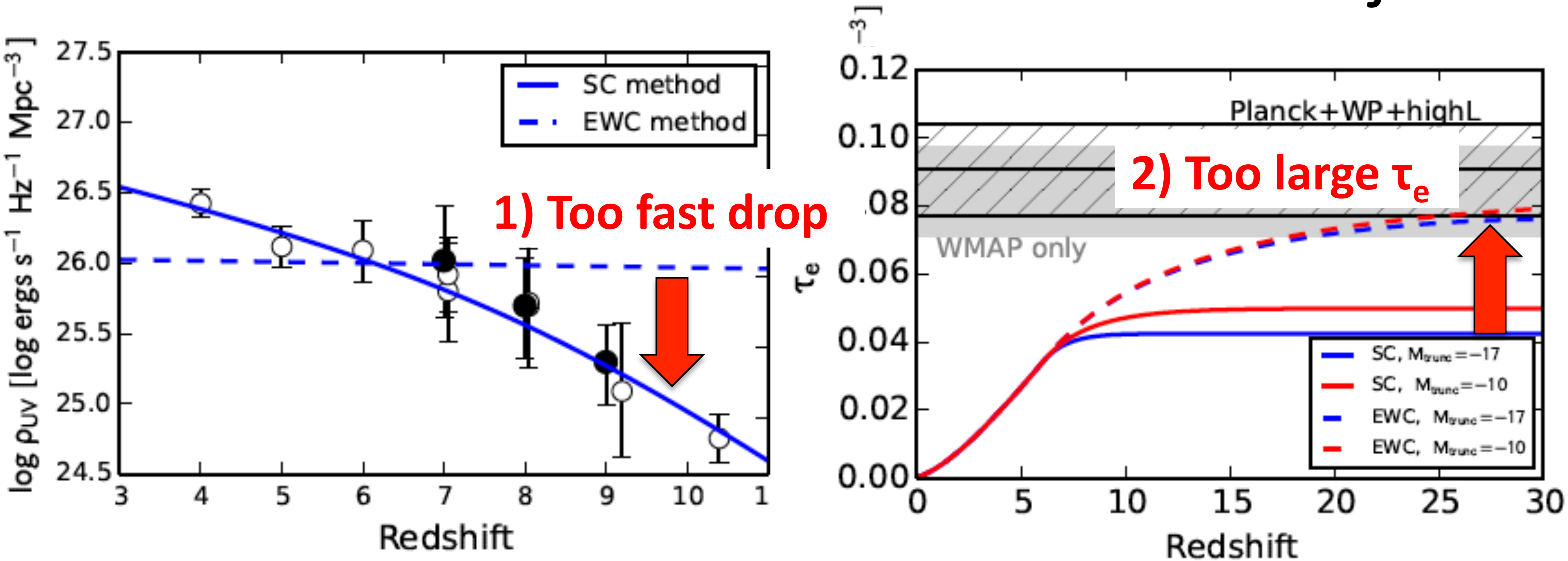
Can Star-Forming Galaxies at z~7-10 be Major Sources of Reionization? --- Hubble Frontier Fields to the WISH Project



Ishigaki,RK, MO et al. (2014)

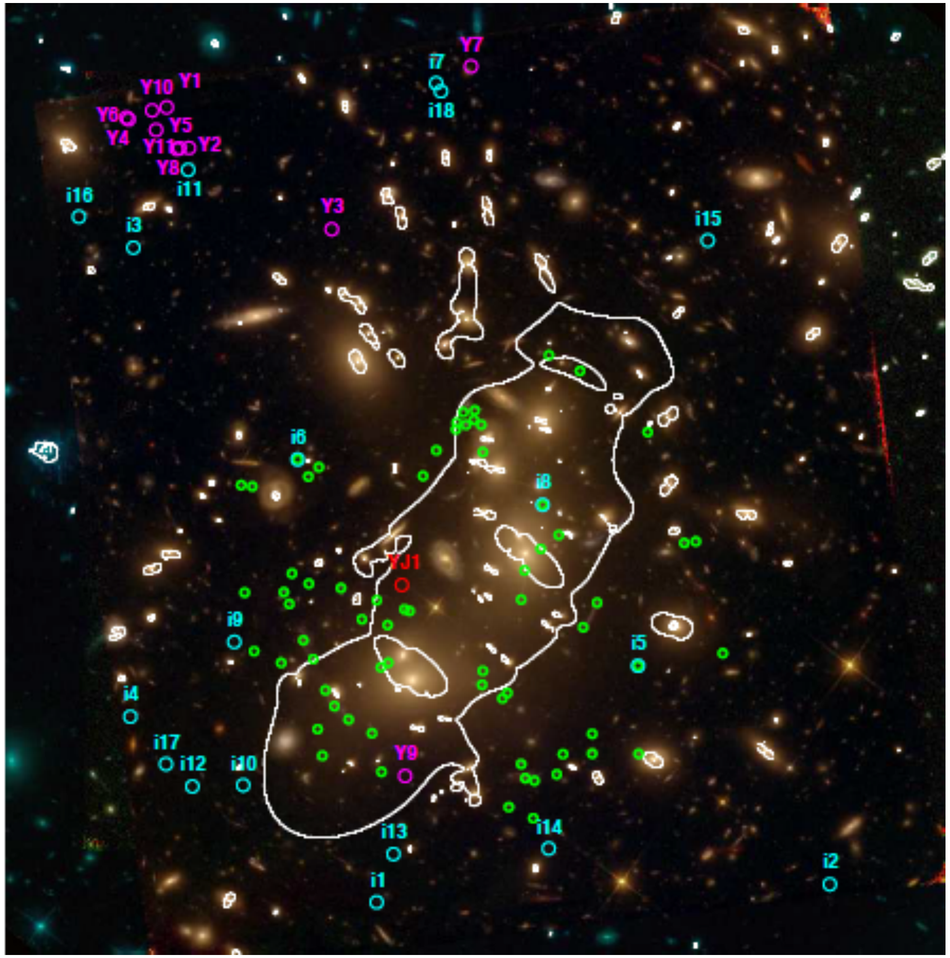
Masami Ouchi

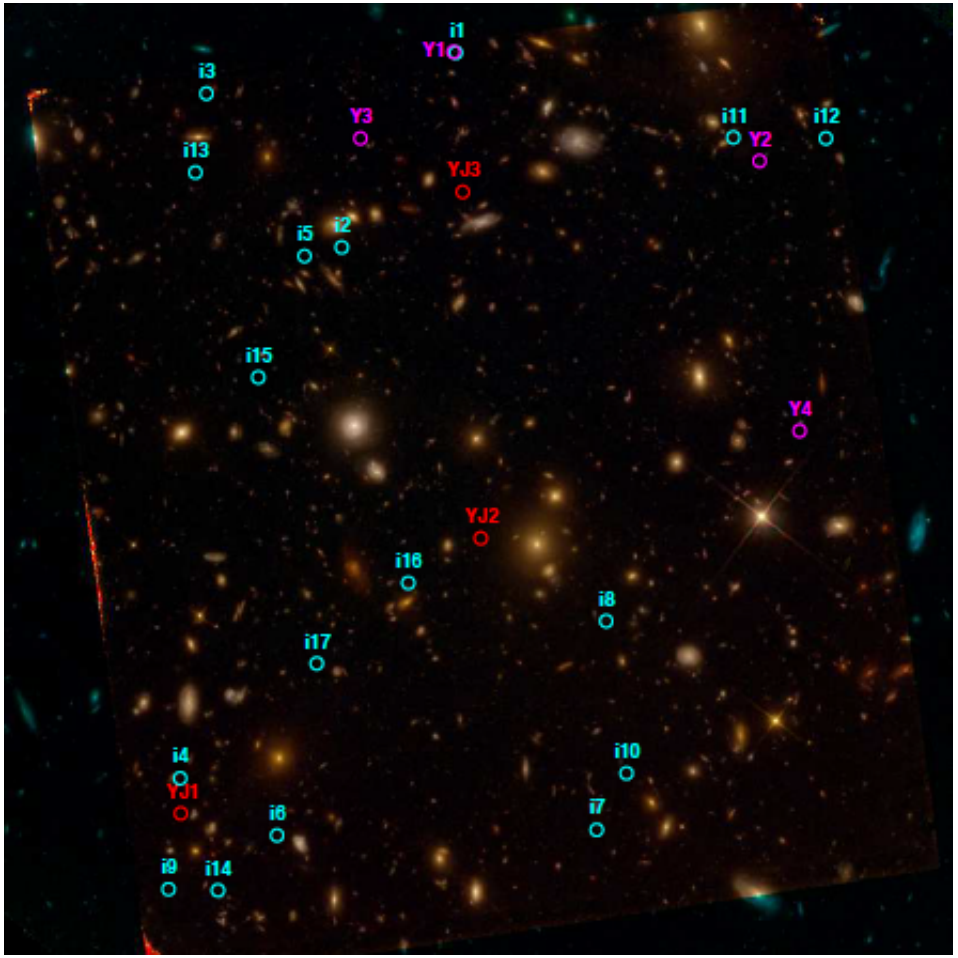
The University of Tokyo

Outline

- Sources of reionization from the first HFF full-depth data set
- Reionization history of $Q_{HII}(z)$ from Subaru Lya Surveys

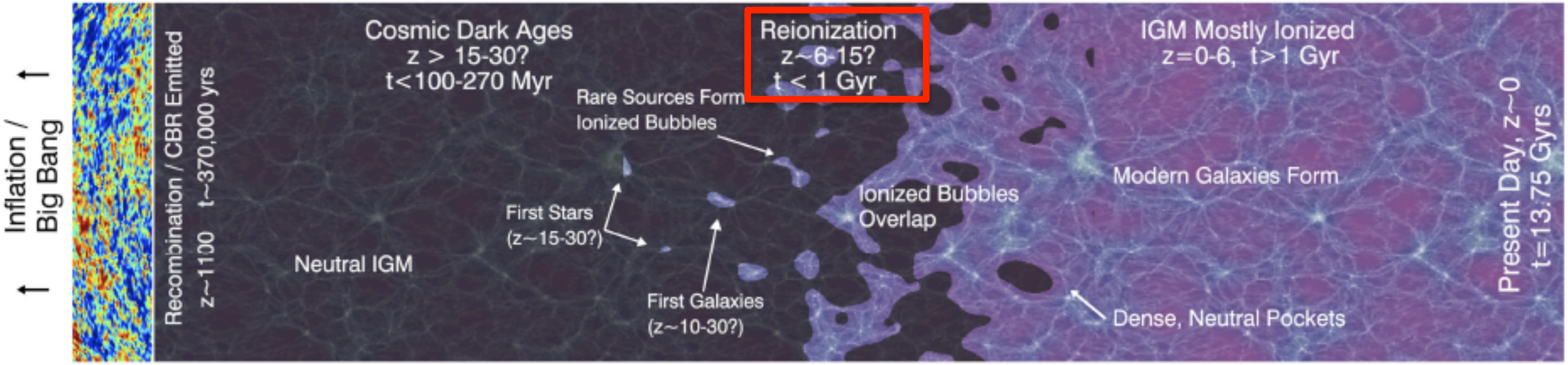
With the expectations for future WISH observations





Ishigaki,RK, MO et al. (2014)

WISH Science Goal: Reionization



Robertson et al. (2010)

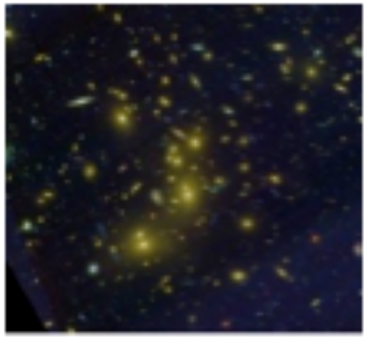
1) Sources of reionization

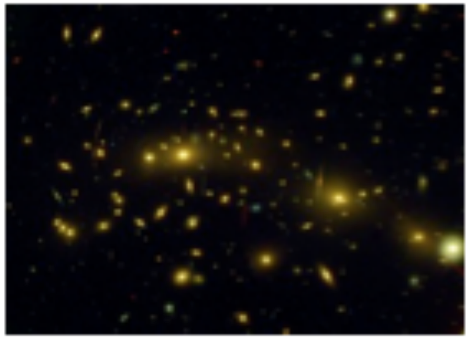
- Not QSO, but massive starts in galaxies (Bolton & Haehnelt 2007)
- SFRD (massive star dens.) decrease; Can reion. be explained?
- Not observed bright galaxies, but faint galaxies below observational limits (e.g. Yan+03, Ouchi+04, Stark+07)
- Galaxies can be reionization sources, if one includes faint galaxies (M_{UV}~-10) with high f_{esc} (>20%) (e.g. Ouchi+09,Robertson+13)

But, not sure if such faint galaxies w a high f_{esc} exists.→ HFF

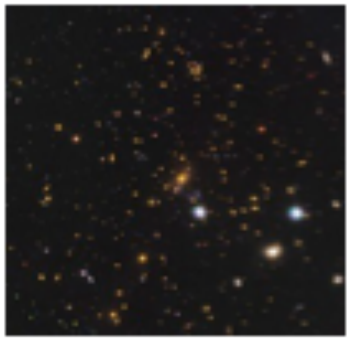
HFF Abell2744 and Parallel

- First HFF cluster/parallel completed in July 2014 (140+ orbits; PI J. Lotz)
- 1/6 data of planned HFF→ Pathfinder study for full HFF data and WISH studies (for complementary bright-end galaxy LF; M*→α)


Abell 2744


MACS J0416.1-2403


MACS J0717.5+3745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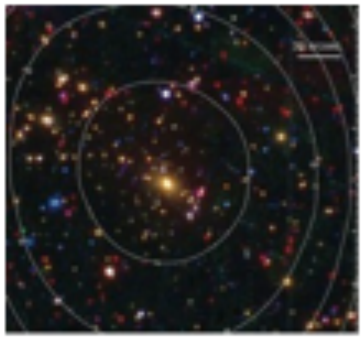
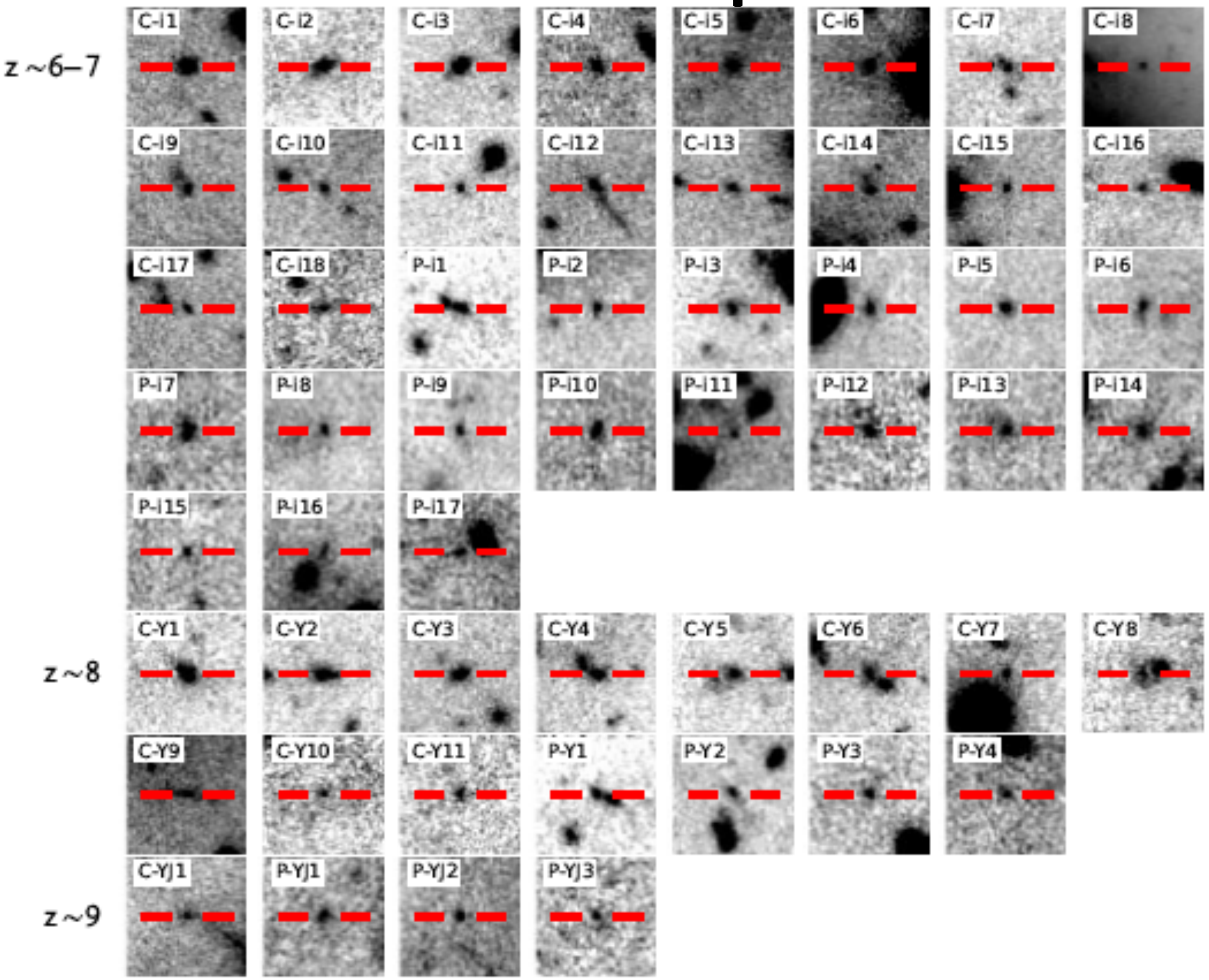
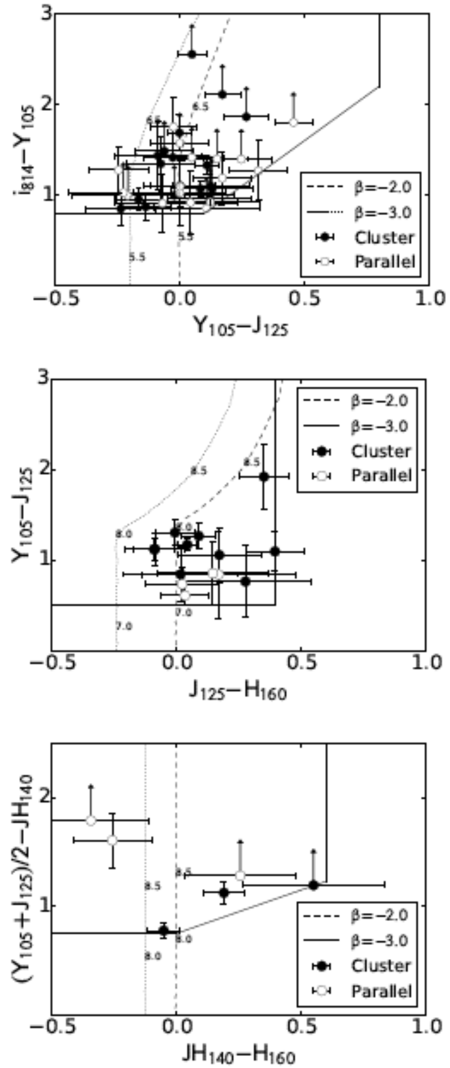

Abell S1063


Abell 370

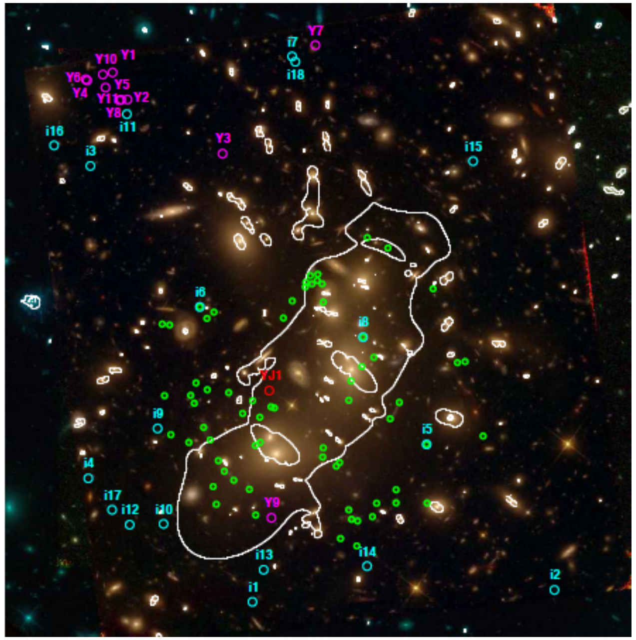
HFF Dropouts at z~5-10



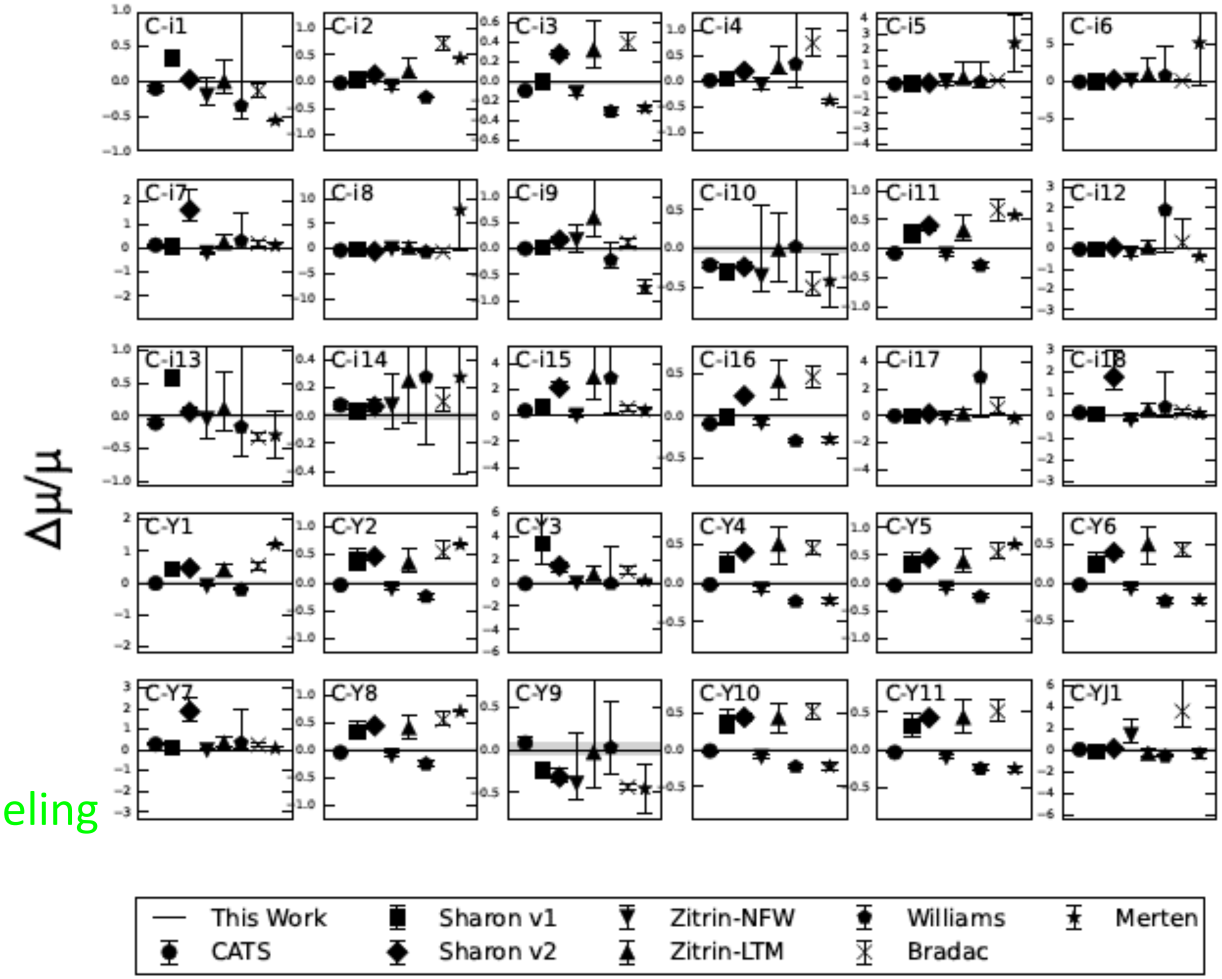


- Similar to Atek+13,Coe+14,Oesch+14,Zheng +14,Laporte+14,Zitrin+14
- Consistent with Atek+14 and Oesch+14 that use the complete Abell2744 data set.

Lens Models



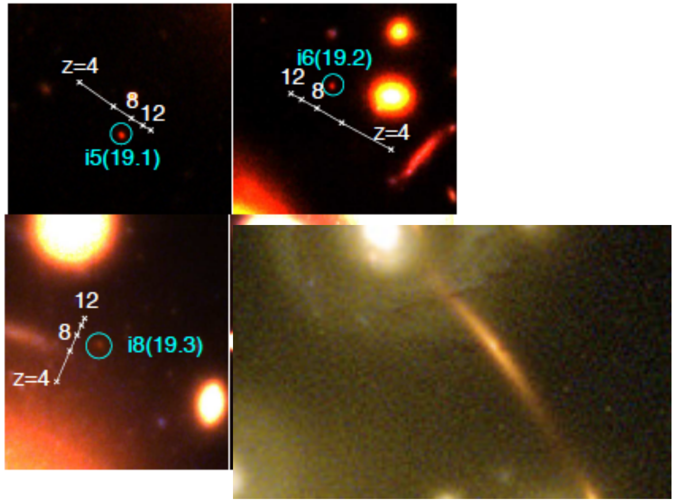
Green=multiple images for modeling



- Parametric mass model of GLAFIC software (Oguri+10) w all available multiple images in the literature.
- Comparisons with all of the available models → Consistent

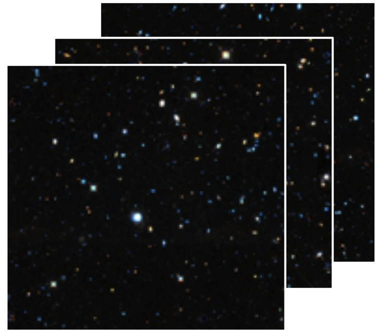
Fully Accounting for Lensing Effects

Mock observations (in the image plane)



Cluster (Lensing)

Simulation images for (L*, Φ*,α)



- Not only a simple magnification (μ), but also the other lensing effects,
  - Source distortion
  - Multiplication of images
  - Selection volume distorted by shear etc..

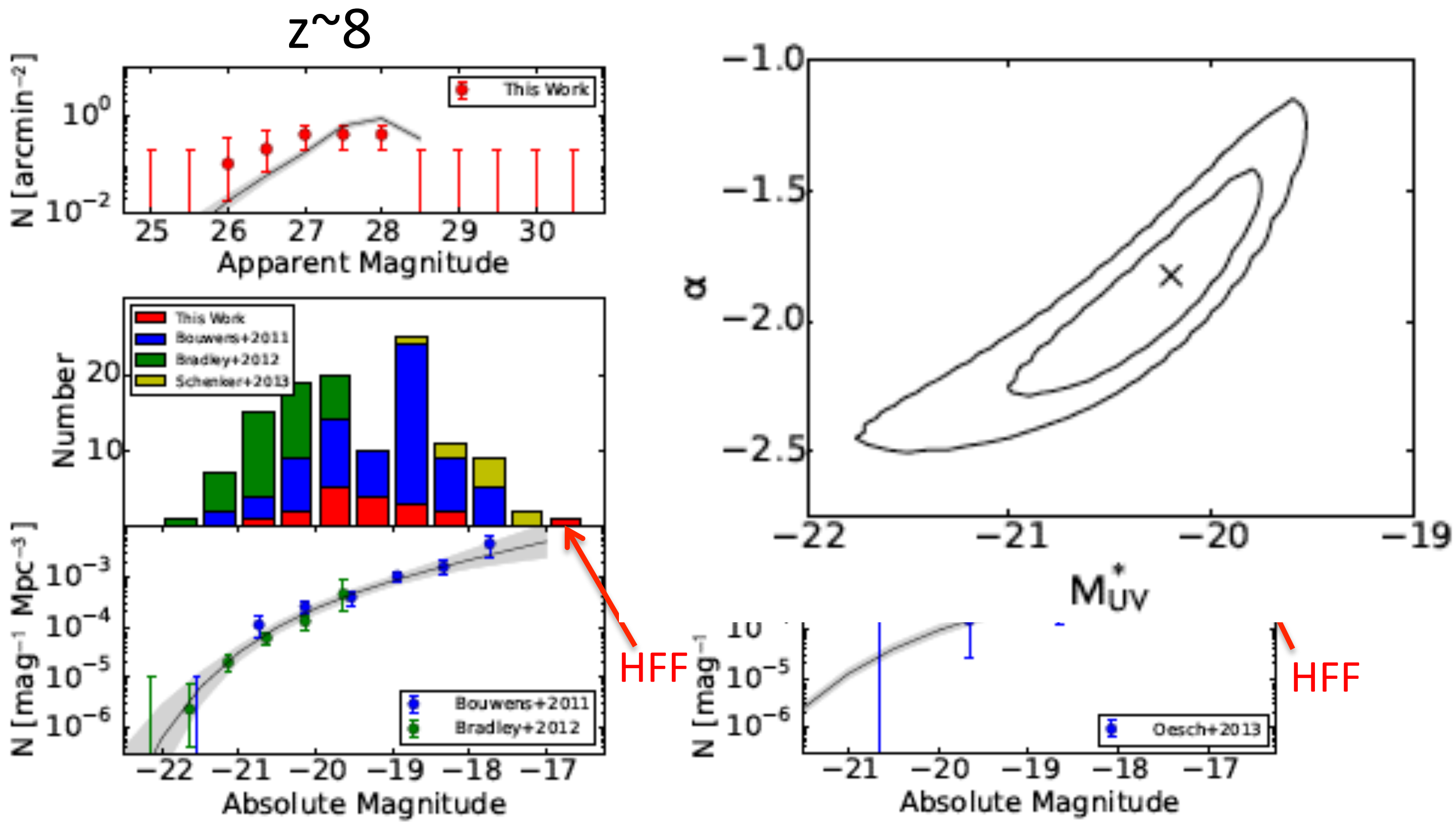
- Carefully evaluating the combination of observational incompleteness and the lensing effects by intensive Monte-Carlo simulations (in the image plane).

Luminosity Functions (LFs)

N(m)
[image plane]

$\mathbf{N_{obj}}$

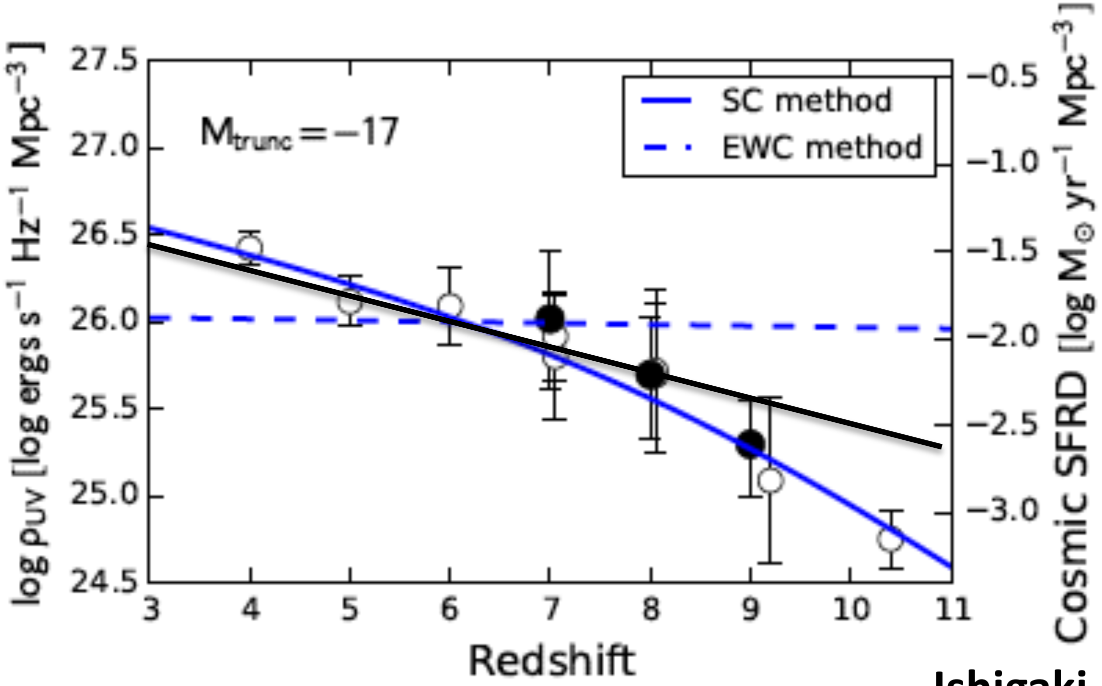
LFs



Ishigaki,RK, MO et al. (2014)

- Down to -17 mag at z~5-10. (mostly μ~1-2, but only a few w μ~10; small high-μ volume distorted by shear).
- Better constraints on a LF slope. α=-2.
- Notable improvements in z~9 LF.

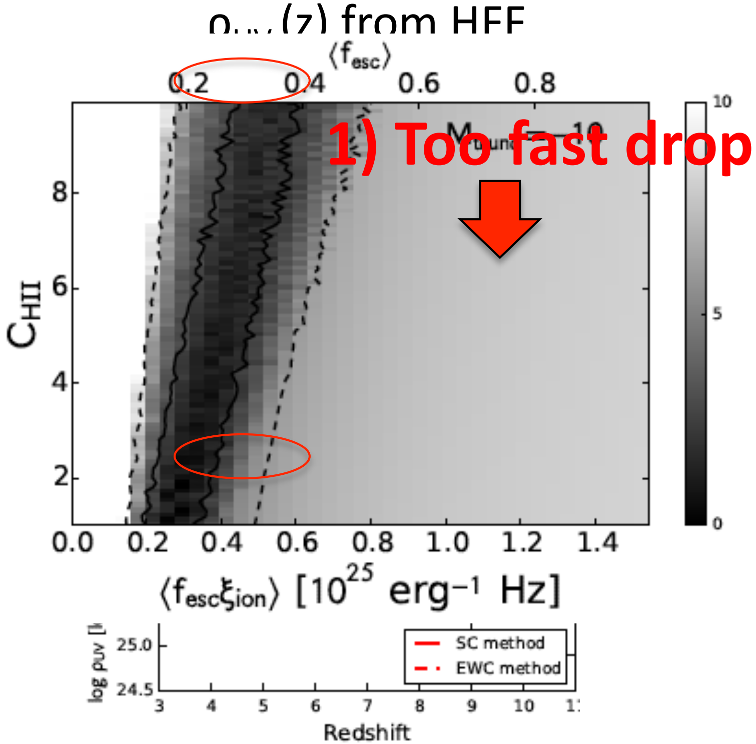
Evolution of ρ_{UV} (SFRD)

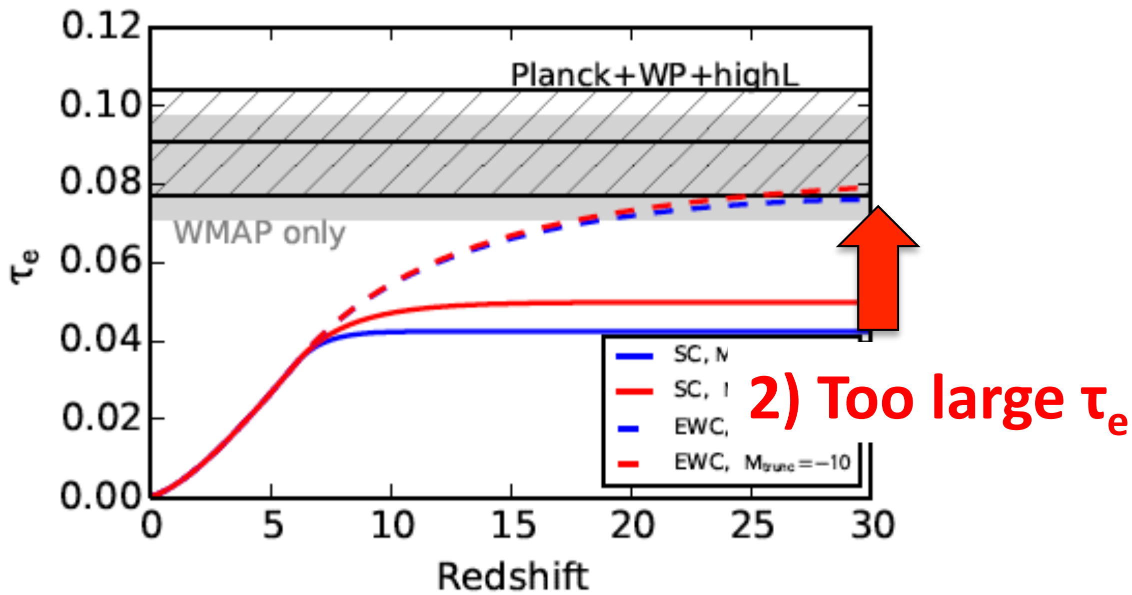


Ishigaki, RK,MO et al. (2014)

- Supporting the rapid decrease of ρ_{UV}, i.e. SFRD, at z>8 (Oesch+13,Bouwens+14)
- Strengthen the evidence of the rapid decrease of ρ_{UV} at z>8

HFF Detailed Constraints on Coscmic Reionization models





Ishigaki,RK,MO et al. (2014)

- Given the $\rho_{UV}(z)$ rapid drop, can you explain reionization?
- Another constraint. Thomson scattering τ_e from CMB observations.
  - .f_{esc} , ξ_{ion} ,and C_{HII} are unknown. (should be determined by observations; e.g. Iwata,Inoue+09). Free parameters of (f_{esc} ξ_{ion} ,C_{HII}).Ionized H frac Q_{HII}

→τ_e does not agree with WMAP+Planck results

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

Origin of Discrepancy---
Too rapid ρ_{UV} (z) decrease and too large τ_e.

There are three possibilities

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

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

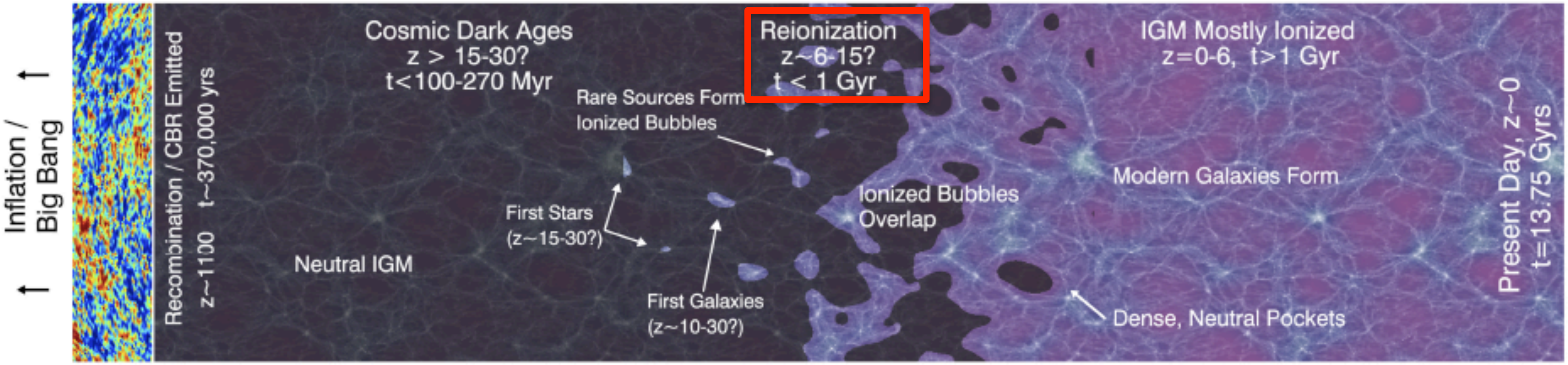
2) Evolving free paramemter

Average parameters, f_{esc} ξ_{ion}, increase. In other words, more efficient ionization production by popIII w a given SFRD.

3) Additional sources of reionization?

– Large contribution such from X-ray binaries/faint AGNs

WISH Science Goal: Reionization



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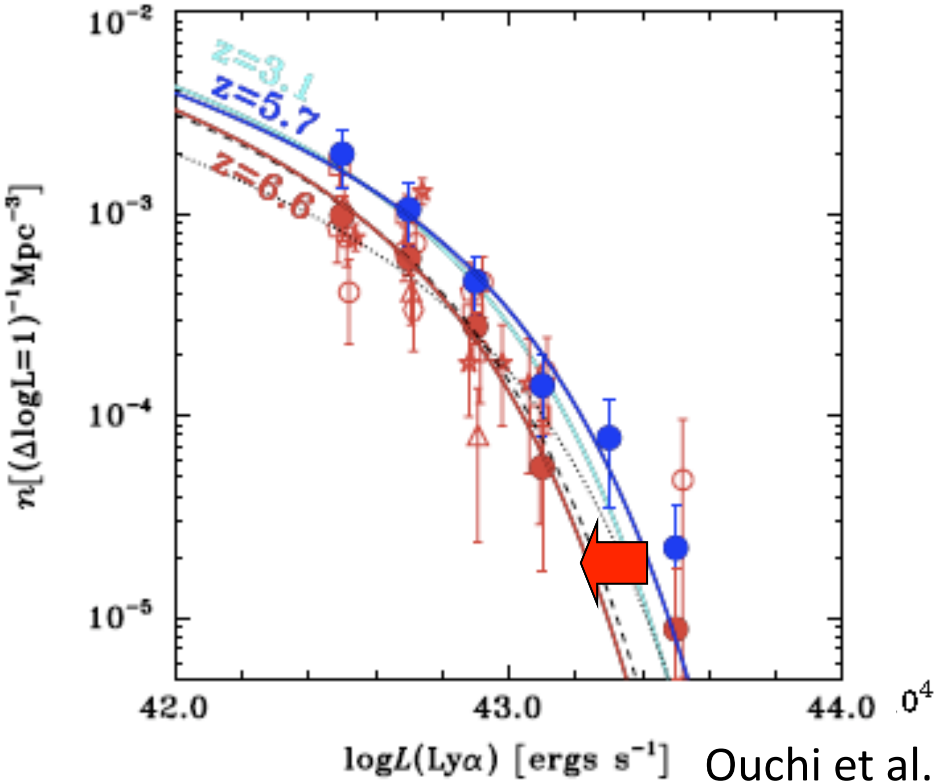
But, not sure if such faint galaxies w high f_{esc} exists.→ HFF

2) Cosmic reionization history

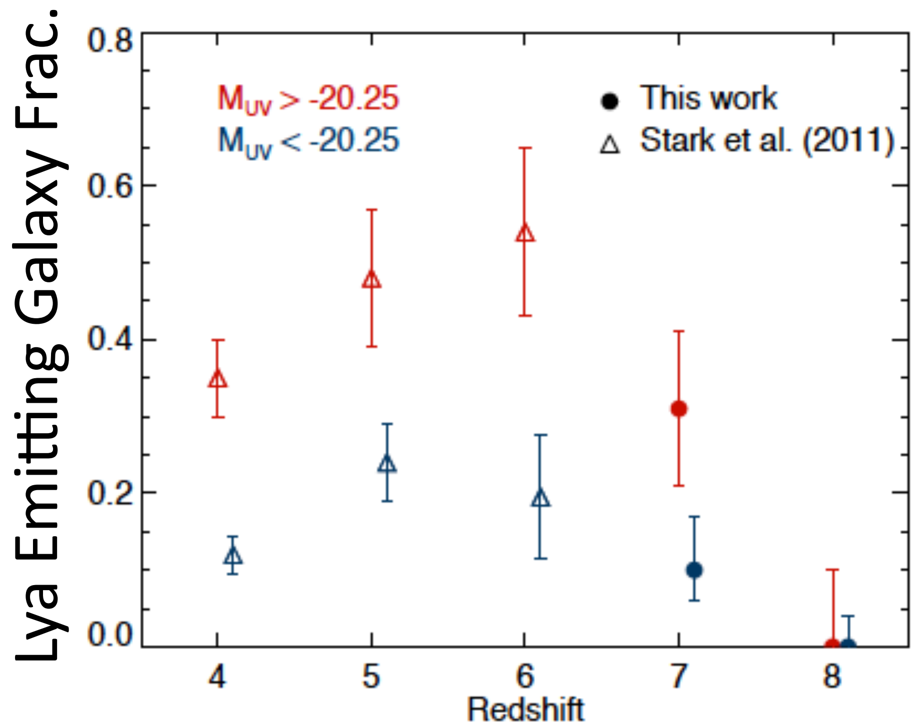
- Ionized hydrogen frac (Q_{HII}) as a function of redshift

Another Key Issue of Reionization
Reionization History

Lya Luminosity Function (Lya LF)



Ouchi et al. (2010)

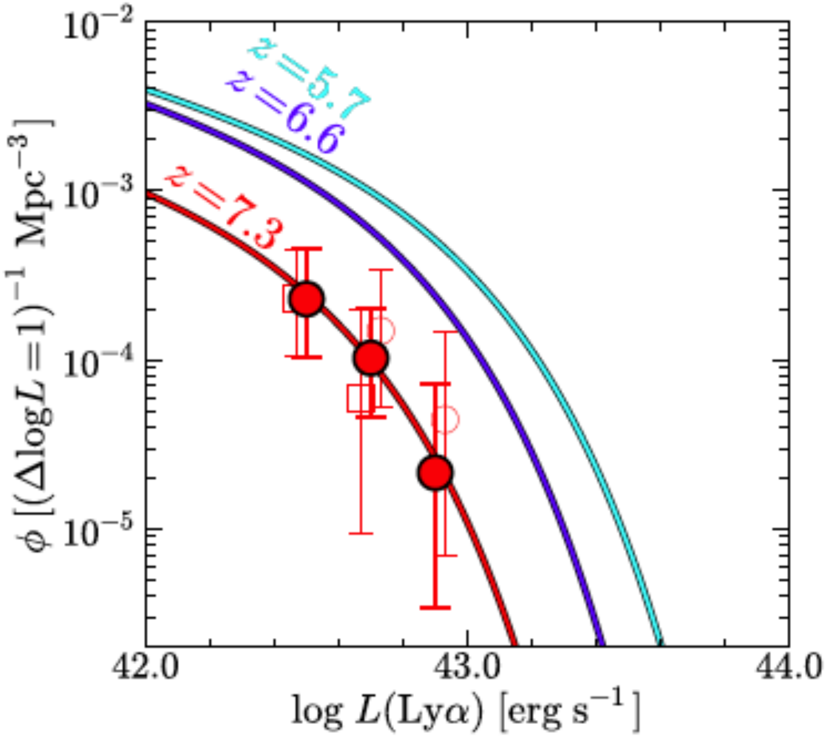


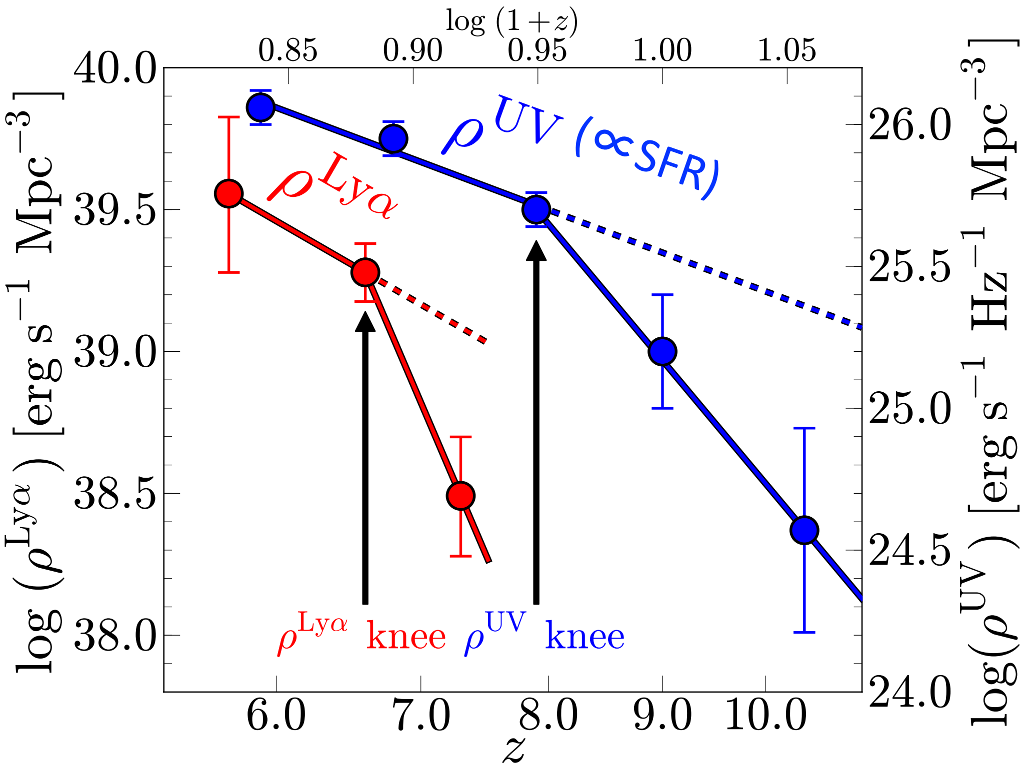
Schenker et al. (2014)

- Lya line/UV continuum is absorbed by Lya damping wing of HI in IGM. Reionization probe.
- Galaxy Lya luminosity function (LF) decreases faster than UV LF decrease from z=5.7 to 6.6 (e.g. Kashikawa+06,11, Ouchi+10).
- Dropping the fraction of Lya emitting to all galaxies (e.g. Pentericci+11,14, Ono+12, Schenker+12,14).
- Strong damping wing abs in QSO and GRB spectra (Mortlock+11, Totani+14)

Accelerated Evolution of Lya Luminosity at z>~7

Lya Luminosity Function (Lya LF)

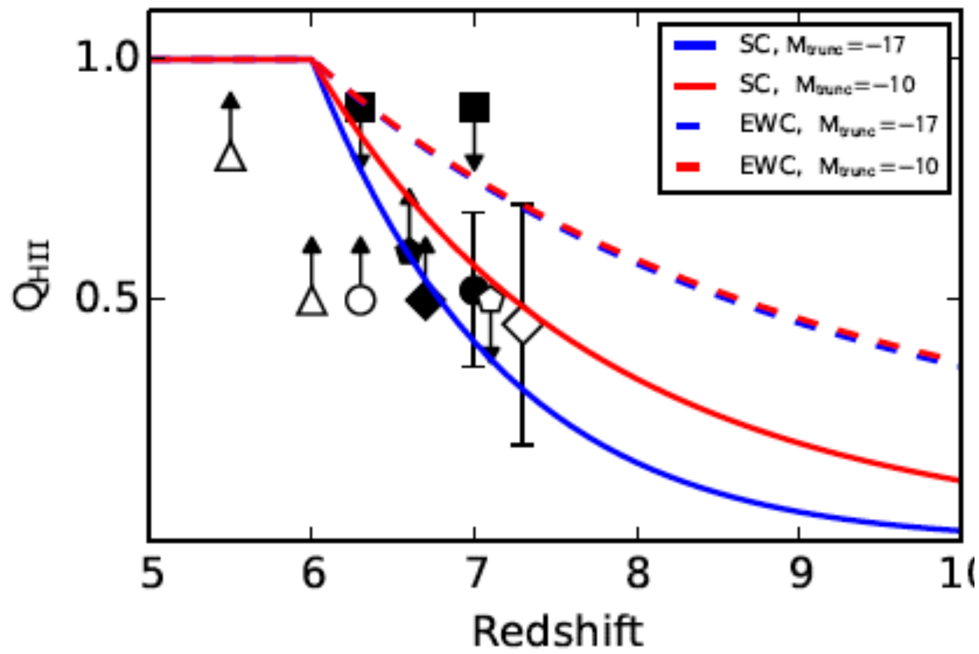


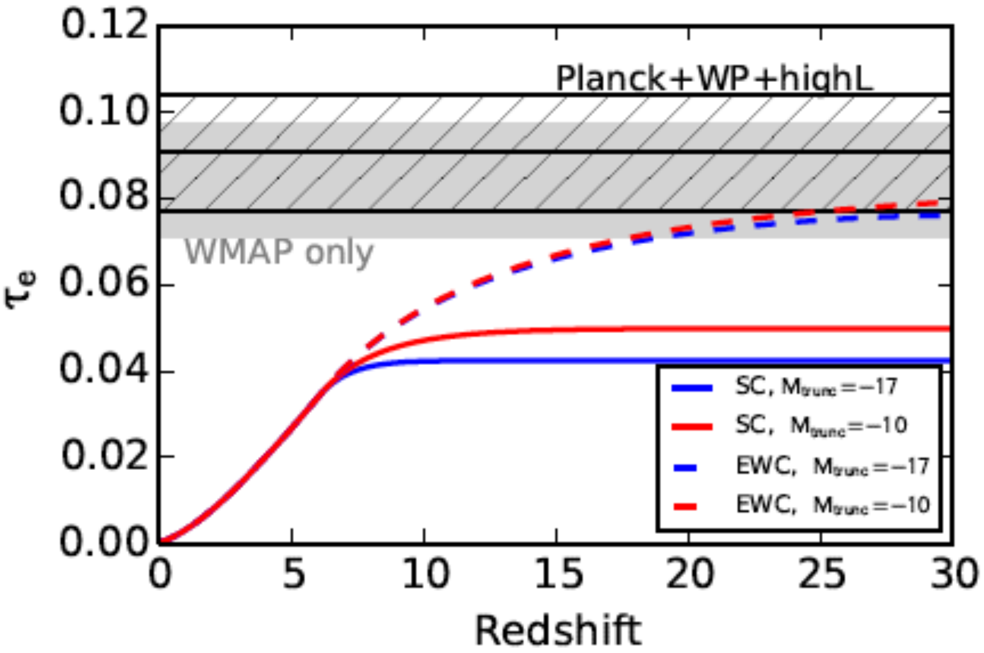


Konno, MO et al. (2014)

- Ultra-deep Lya emitter (LAE) survey for ~0.5 deg^2 with Subaru (106 hour integ.; cf. Shibuya+12)
- Decreasing Lya LFs (and ρ_{Lya}) from z=6.6 even to 7.3. Moreover,
  the Lya LF (and ρ_{Lya}) is accelerated at z>~7.
- No accelerated evol. of UV LFs(ρ_{UV}) at z~7, but only at z>8 (Oesch+13,Bouwens+14).
- If it is really caused by cosmic reionization, the evolution of Q_{HII} is rapid at z~7.

Q_{HII} Estimates Compared w HFF Results

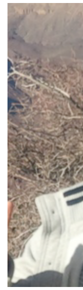


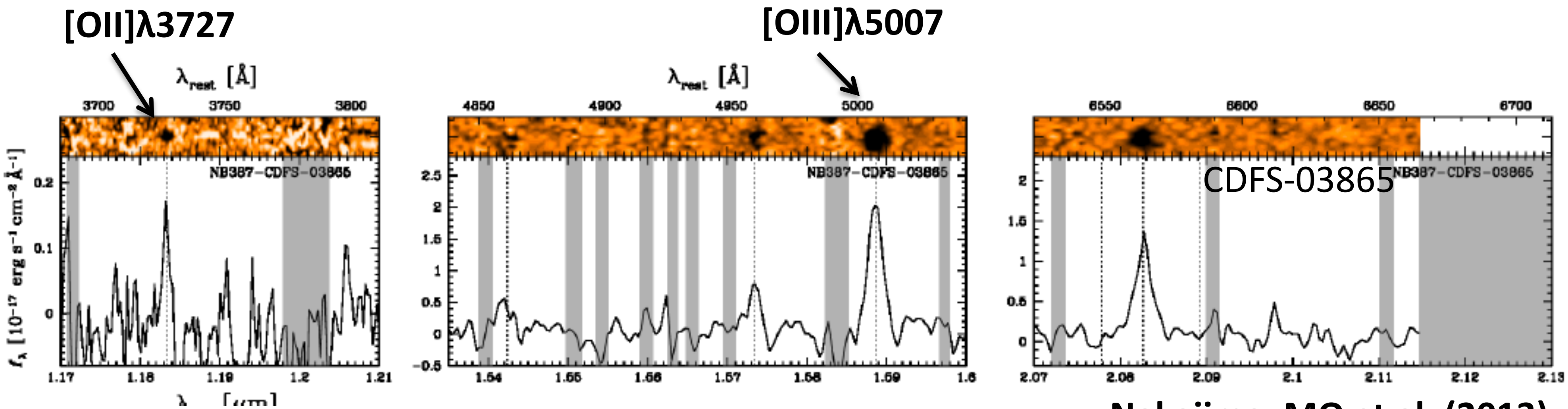


- Q_{HII} estimates from the accelerated Lya evolution.
  - Prefer moderately low Q_{HII} at z~7. Late reionization??
- But, again, tension w high τ_e from CMB…
  - Extended reionization history. The 3 possibilities→WISH
  - Or any problems in CMB τ_e measure/interpretation??→ Planck

Short Comments on WISH Spec (for Denis/Akio's talks)

Importance of 2-5μm Spectroscopy





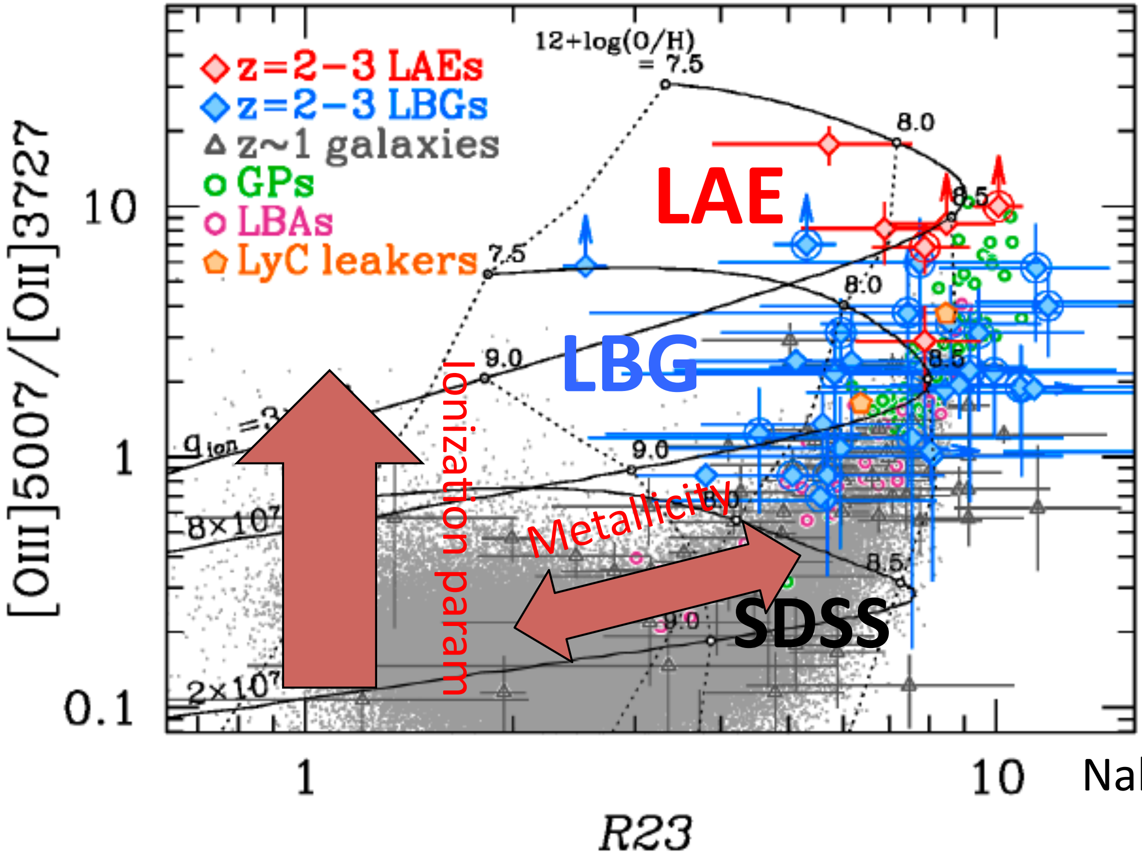
Nakajima, MO et al. (2013)

- Deep NIR Spectra of Keck, Subaru, Magellan for z~2 galaxies.
- Very large f[OIII]/f[OII]~10. (cf. Local galaxies <~1)
- No AGN (from the BPT diagram)

- Extinction? Extinction corrected by Balmer decrement.

→ what does it mean?

High Ionization Parameter at z~2-3

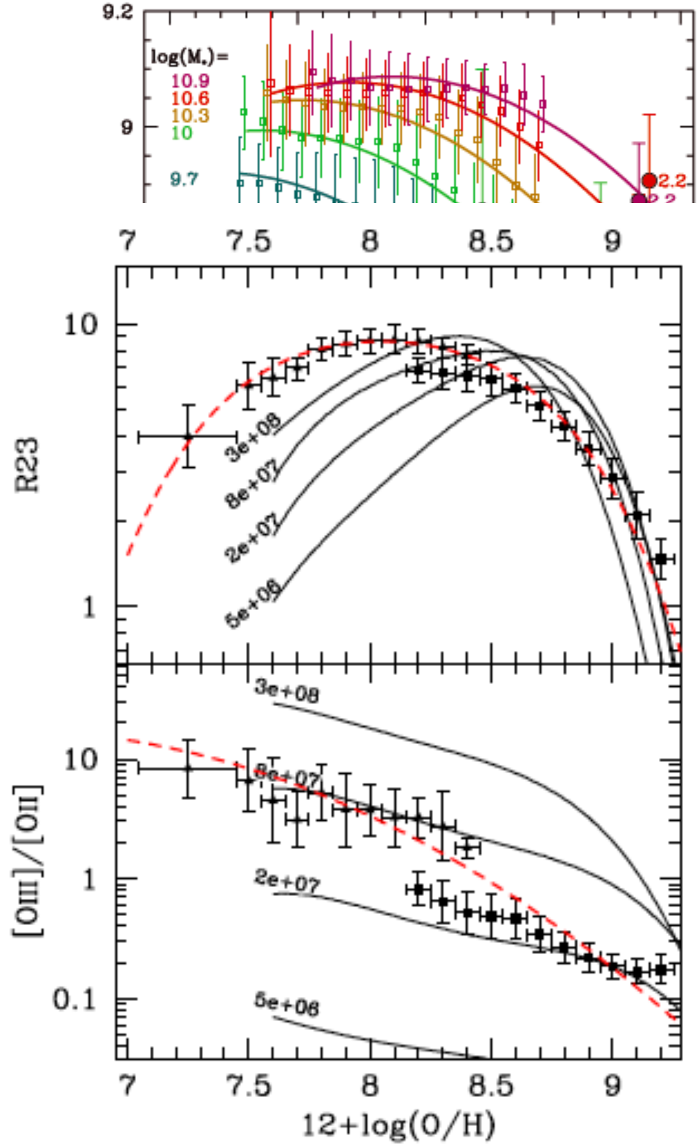


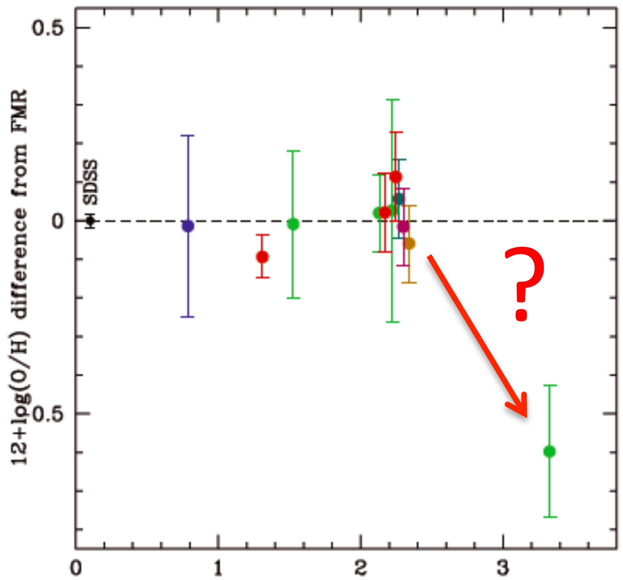
Nakajima & MO (2014)

- f[OIII]/f[OII] ratios of z~2-3 LBGs/LAEs is ~x10-100 higher than those of SDSS galaxies
  - NII/Ha index for resolving the degeneracy for z<2.5 galaxies.
  - High ionization parameter, Log(q_{ion} /cm s^{-1})~ 8-9 (Nakajima,MO+13,Nakajima&MO+13;See also Kewley+13)
  - Same metallicity, but higher ionization parameter

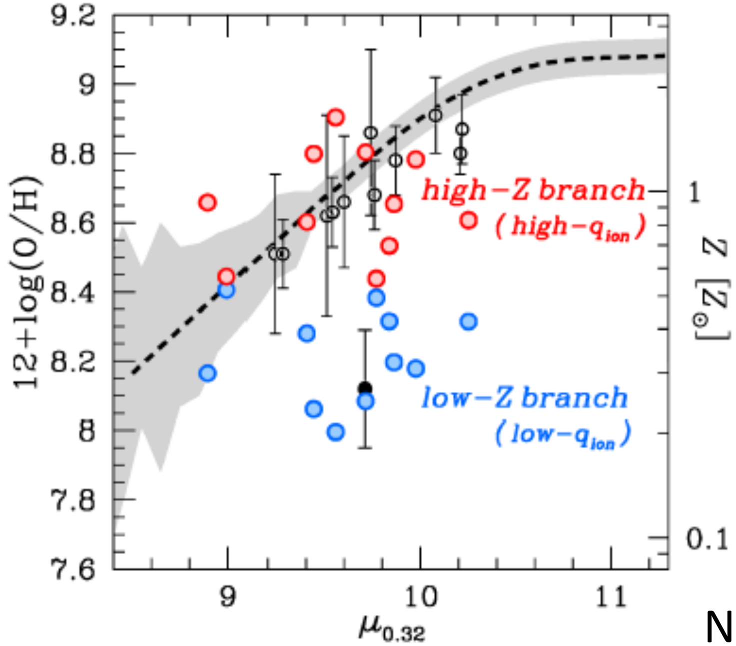
- Average ionization parameter increases towards high-z.
  - Very efficient ionizing photon production, due to young stellar population w a given hydrogen mass.
    Consistent with the decreasing $\tau_{depletion}$ towards high-z (Saintonge et al. 2013).

SFR-MZ Evolution and Ionization Parameter





Mannucci et al. (2010)



Nakajima & MO (2014)

- Need NII/Ha for z>3 to resolve the degeneracy→WISH Spec!

Summary

- Hubble Frontier Fields Results: First detailed HFF constraints on Reionization
  - Careful estimates of lensing effects w the image plane technique
  - Constraints on faint galaxy pop. LF slope. α=-2. Notable improvements in z~9 LF.
  - Supporting the rapid decrease of of ρ_{UV}, i.e. SFRD, at z>8 (Oesch+13,Bouwens +14)
  - Too rapid ρ_{UV} (z) decrease and too large τ_e. Why?
    - Moderate ρ_{UV} (z) decrease at z>11→ WISH imaging
    - Evolving free parameter: efficient ionization production
    - Additional sources of reionization? E.g. X-ray binaries/faint AGNs→ WISH-Spec

- Q_{HII} estimates from Subaru Lya Surveys
  - Accelerated evolution of Lya LF and ρ_{Lya}
  - Prefer moderately low Q_{HII} at z~7. Late reionization? But tension w high τ_e from CMB… Extended reionization. → WISH imaging

- Brief comments supporting the WISH-Spec efforts for SFR-MZ evolution test

WISH observations will significantly contribute to resolving these issues.