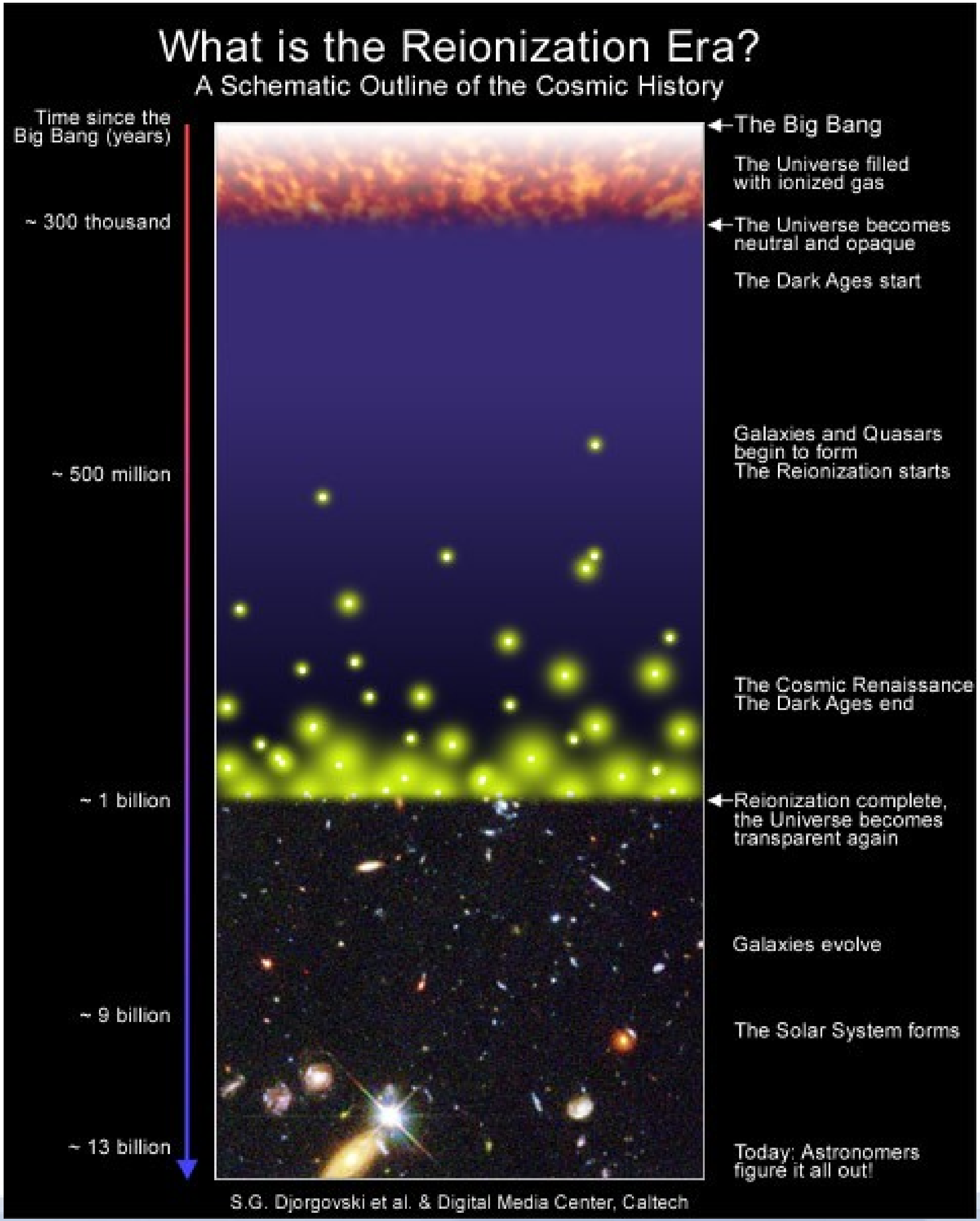
# Lyman Alpha Emitters and Reionization

Simone Ferraro (Princeton)
03 - 26 - 2013

# Outline

- Introduction to reionization
- Experimental probes
- Lyman Alpha emitters
- Luminosity function
- Clustering
- Line profiles
- Constraints on reionization
- Conclusions

# Reionization



# Reionization

- Absence of Gunn-Peterson trough in spectra and CMB E-mode polarization show that the universe is fully ionized at low redshift.
- Optical depth from CMB.
- For step reionization (unrealistic), $z_{reion}$ = 11.1 +/- 1.1
- Patchy reionization: Topology depends on what is producing reionization. Stars? Primordial black holes? Dark Matter annihilation?
- Stars (or in general any soft UV source) produce 'swiss cheese' reionization. Photon MFP is short (kiloparsecs) and ionization fronts are sharp.
- Primordial Black Holes (X-rays) give a 'meatball' topology: voids ionize earlier.

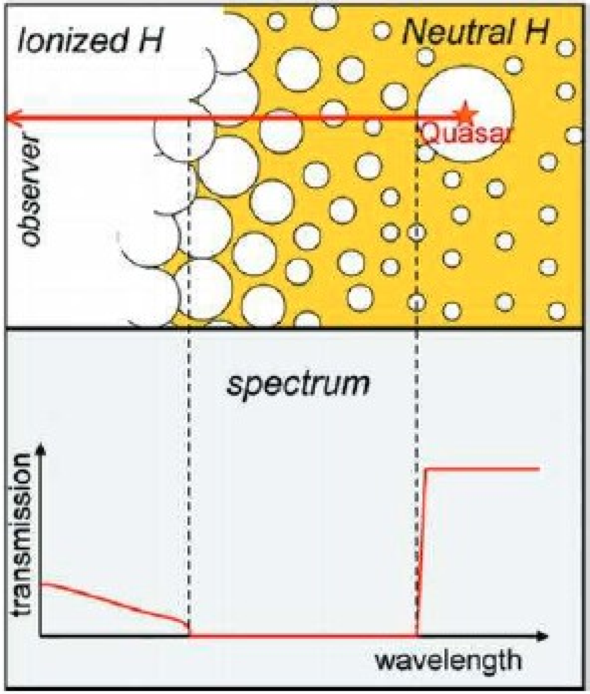
# Probing reionization

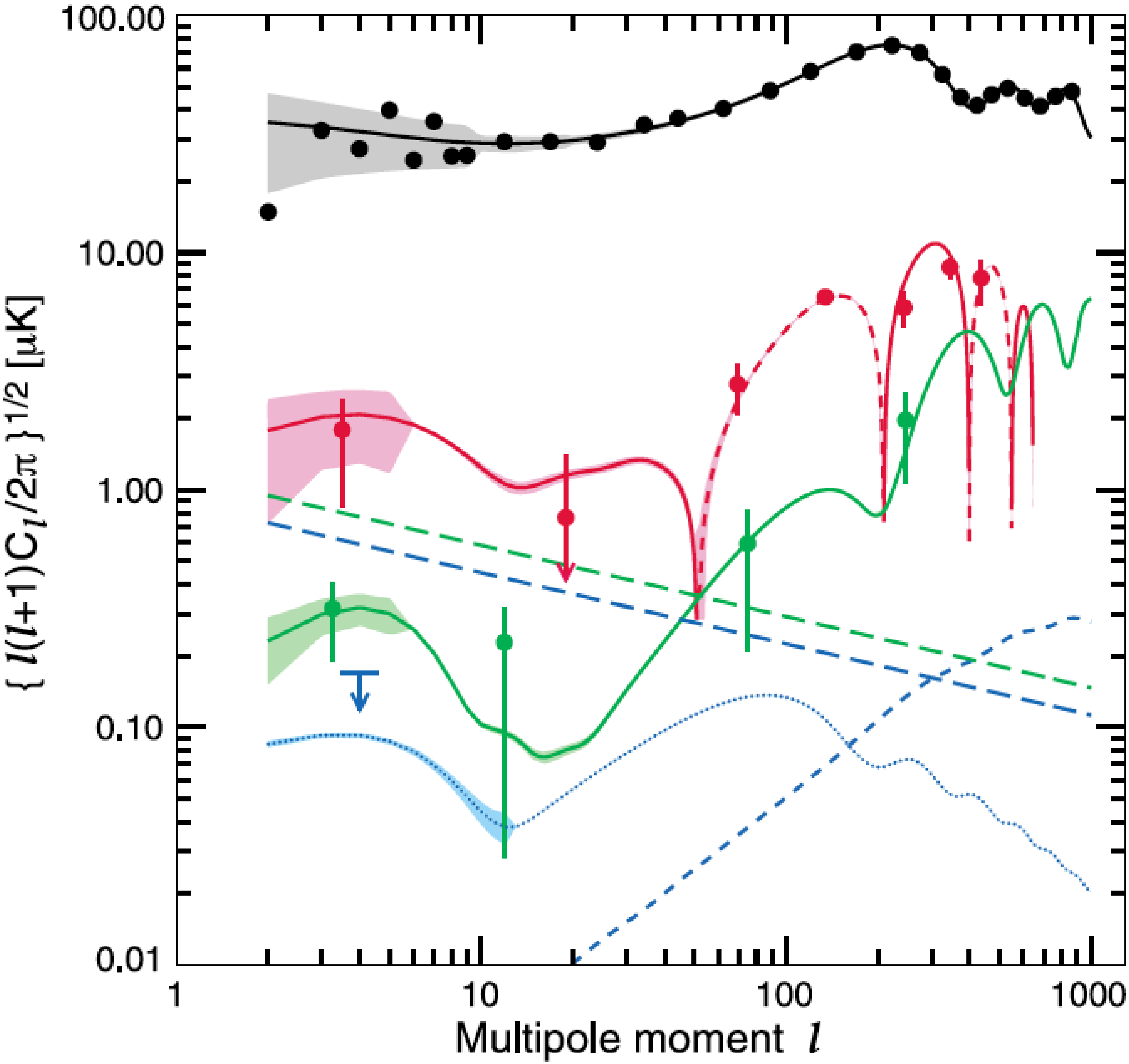
- Quasar spectra (Gunn-Peterson)

  but... $$\tau_s = \frac{\pi e^2 f_\alpha \lambda_\alpha n_{\mathrm{H\,I}}(z_s)}{m_e c H(z_s)} \approx 6.45 \times 10^5 x_{\mathrm{H\,I}} \left(\frac{\Omega_b h}{0.03}\right) \left(\frac{\Omega_m}{0.3}\right)^{-1/2} \left(\frac{1+z_s}{10}\right)^{3/2}$$

  Insensitive to order unity fluctuations in $x_e$!
- GRB
- CMB
- 21cm
- Ly Alpha emitters
- Have to satisfy constrain for Thomson scattering:

  $\tau$ = 0.09 +/- 0.01 (WMAP + Planck)




100.00
10.00
1.00
0.10
0.01
1
10
100
1000
Multipole moment $l$
$\{ l(l+1)C_l/2\pi \}^{1/2}$ [μK]

WMAP 3

# Ly Alpha Emitters

- High-z galaxies with large fraction of flux in Ly Alpha.
- Relatively dust-free
- Selected with narrow-band techniques
- KEY POINT: Ly Alpha transmission is decreased if neighborhood of emitter is neutral!
- Live in relatively low mass halos (~ $10^{10}$ – $10^{11}$ $M_{sun}$)

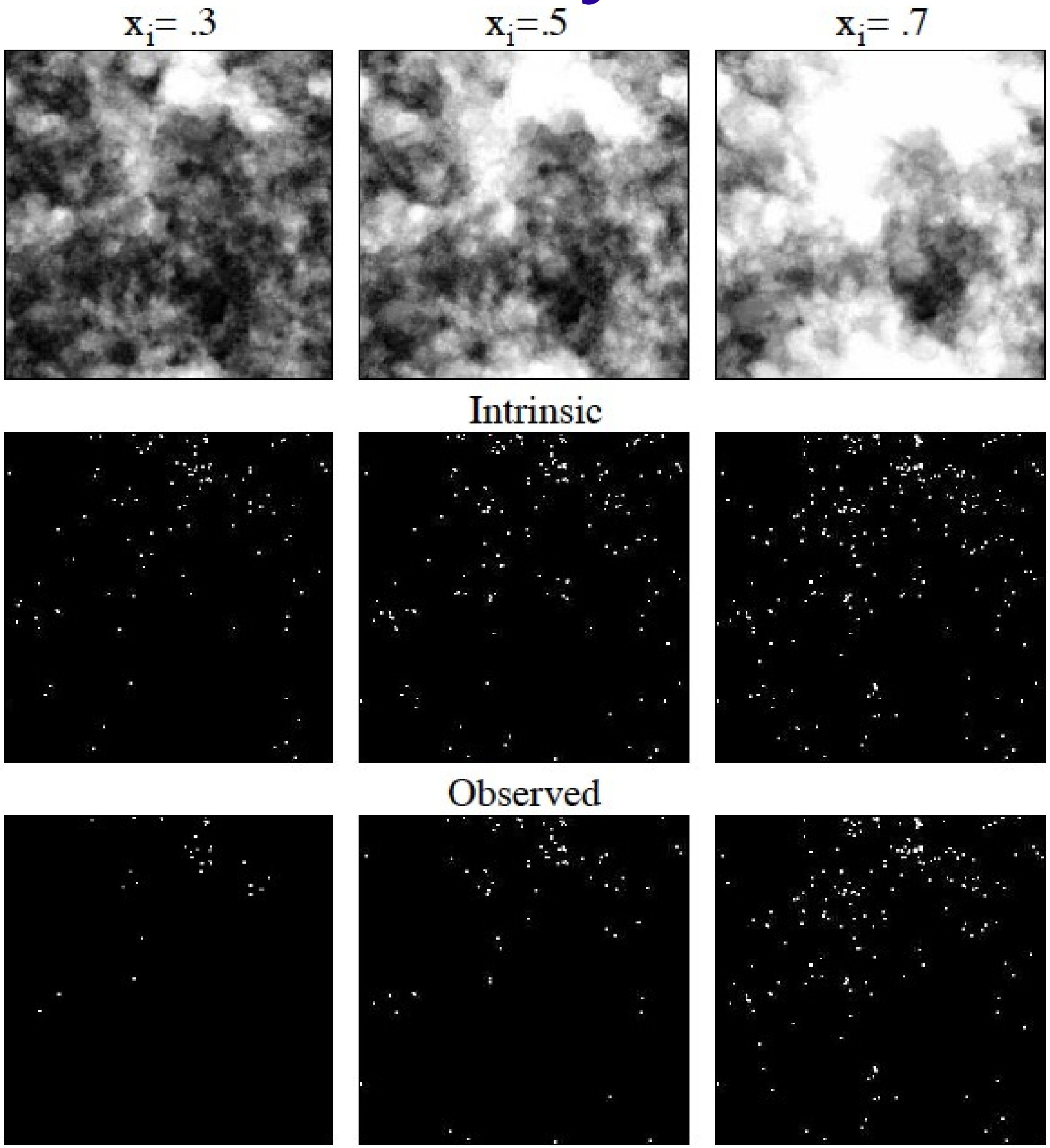
# LAE as a probe of reionization

- Likely that LAE will provide the first direct evidence of when reionization occured, provided that $z_{reion} < 8$ or so.
- Three methods to probe reionization with LAE:
- - Luminosity function

  - Clustering

  - Line profile

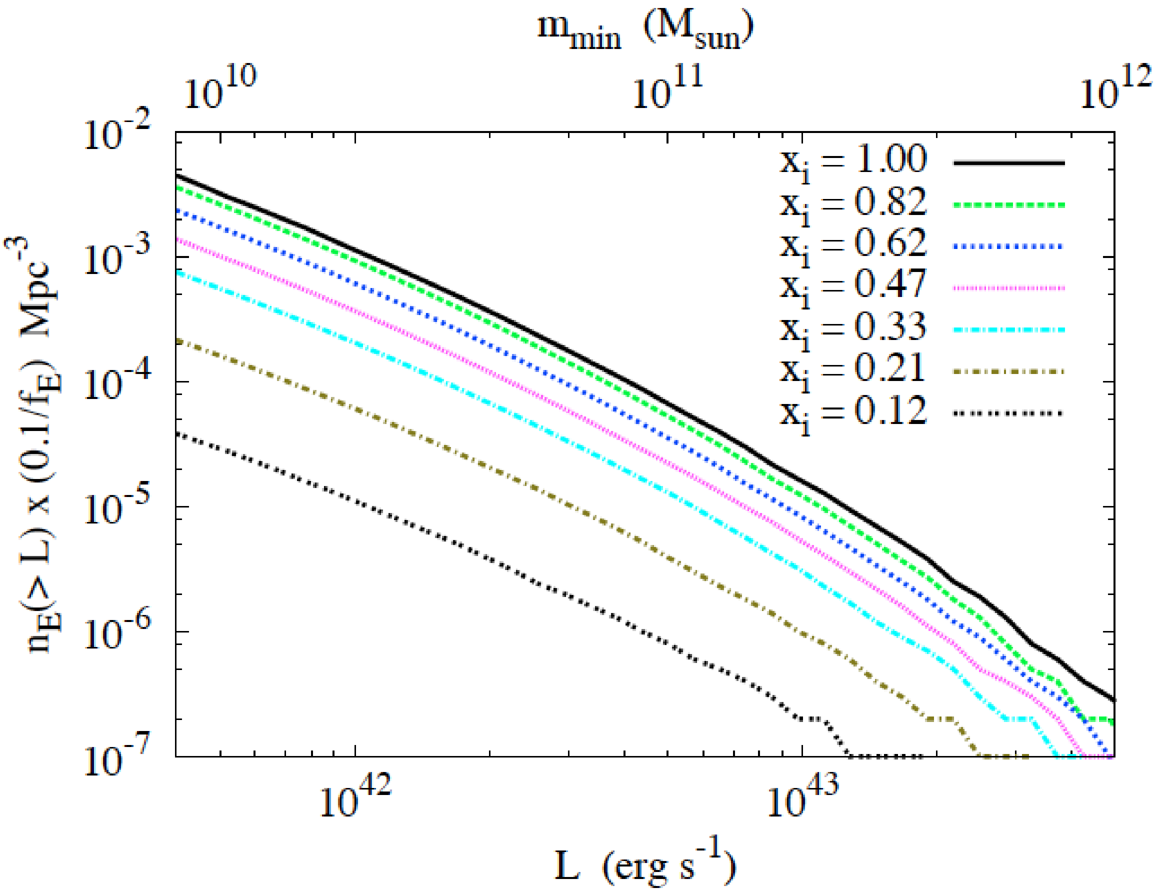
# Luminosity function




McQuinn et al (2007)

# Luminosity function

- As reionization proceeds, larger HII regions form allowing more LAE to be seen
- From simulations (McQuinn et al, 2007).




$n_E$ with

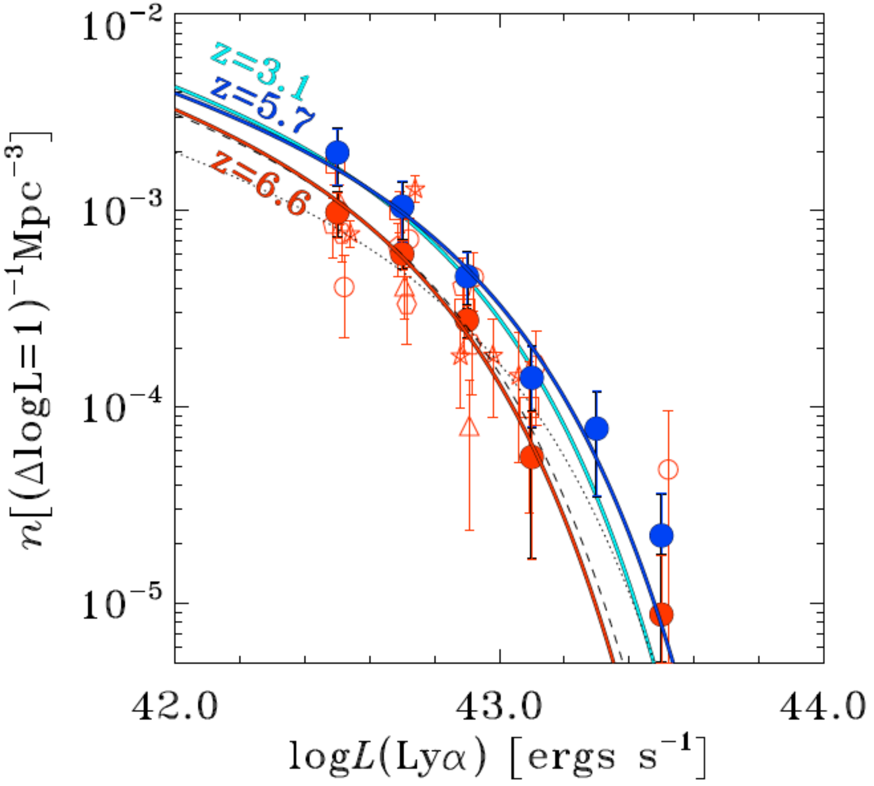
$$m \ \exp(-\tau_\alpha(\nu_0)) > m_{\rm min}$$

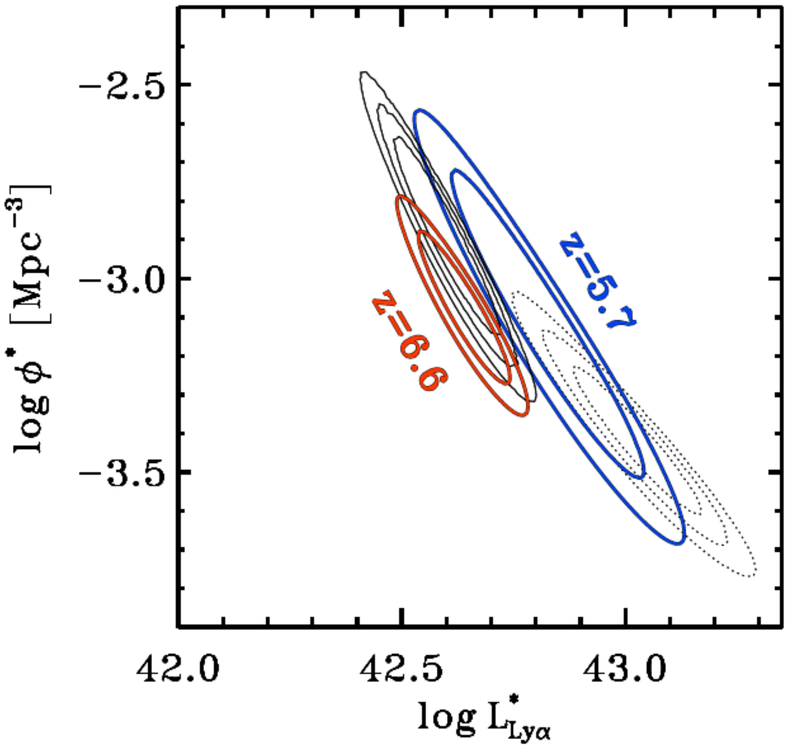
- Pioneering observations by Malhotra & Rhoads find no evidence of evolution of LF between z = 6.5 and 5.7

# Luminosity function - observation

- 207 LAE at z = 6.6 from the SXDS sample (Ouchi et al. 2010) on Subaru, vs sample at z = 5.7
- Fit with Schechter function

$$\phi(L)dL = \phi^*(L/L^*)^\alpha \exp(-L/L^*)d(L/L^*)$$



# LF Implications

- Find an evolution of LF from z = 6.6 to 5.7 at 90% CL
- Pure luminosity evolution preferred to number density evolution, with L* decreasing by ~ 30%
- Could be due to:

  - Change in duty cycle

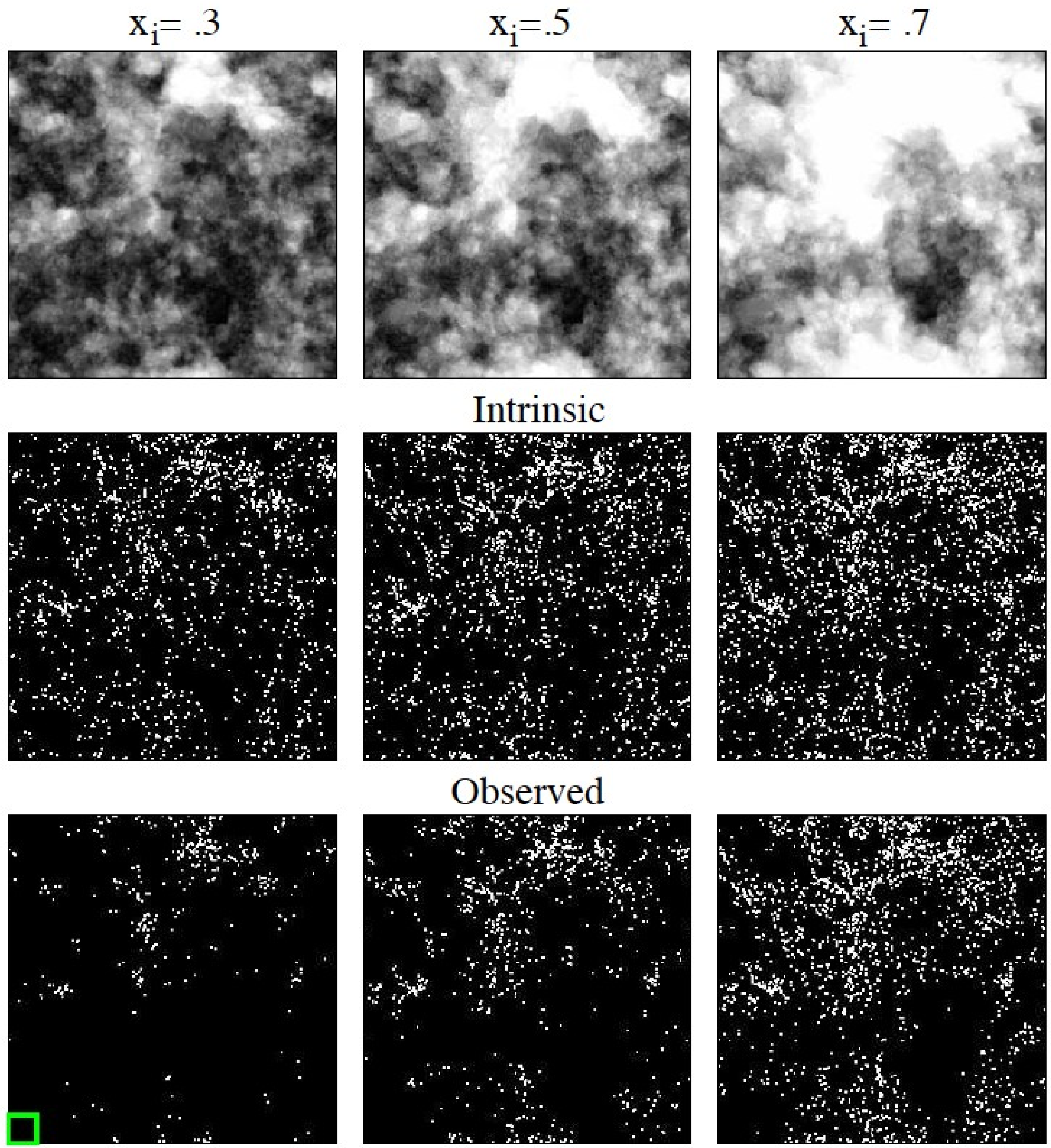
  - Increasing halo mass

  - Reionization
- Effects are often degenerate. Ouchi et al (2010), claim that these measurements constrain (at z = 6.6)

$$x_{\mathrm{H_I}} \lesssim 0.2 \pm 0.2.$$

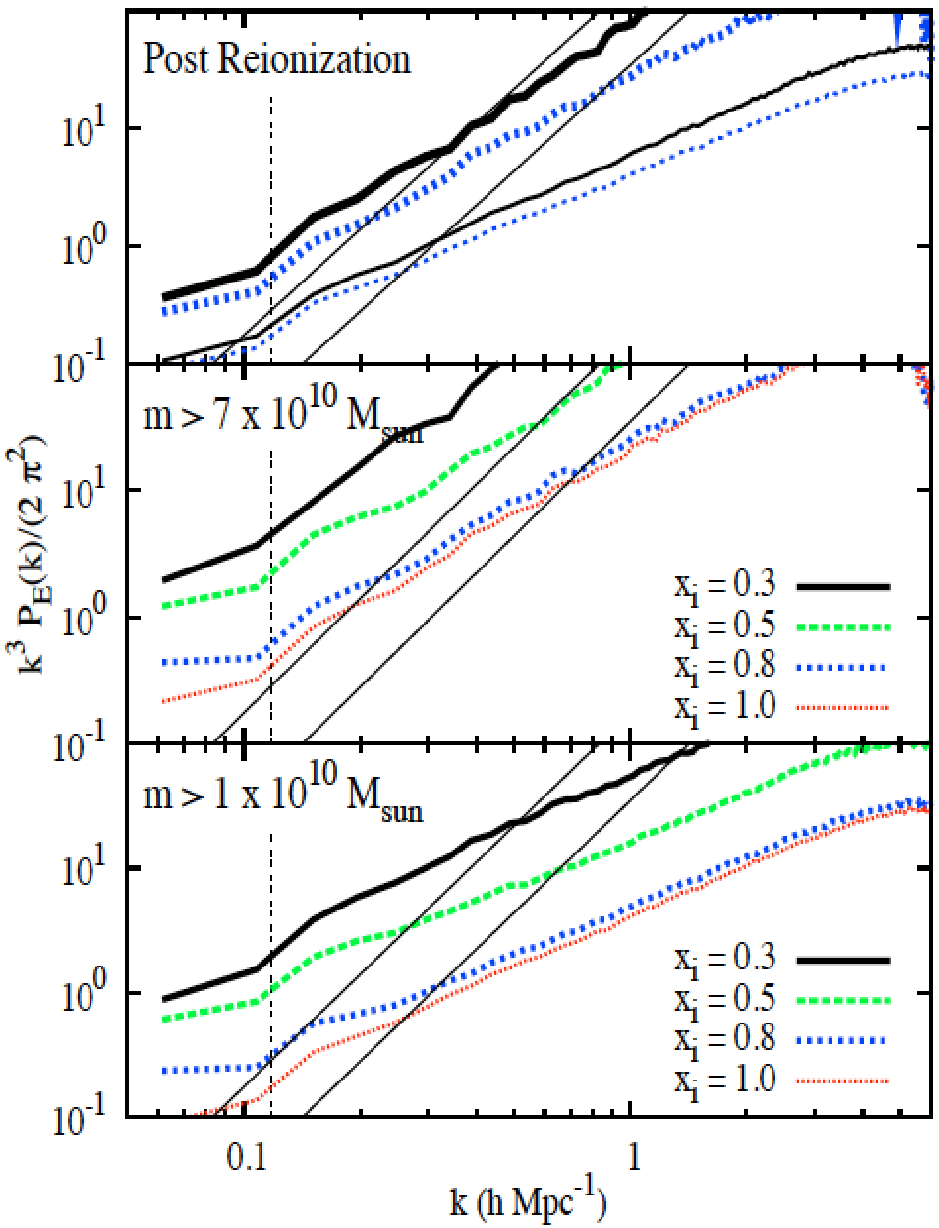
- Can we place more robust constraints?

# Clustering



# Clustering

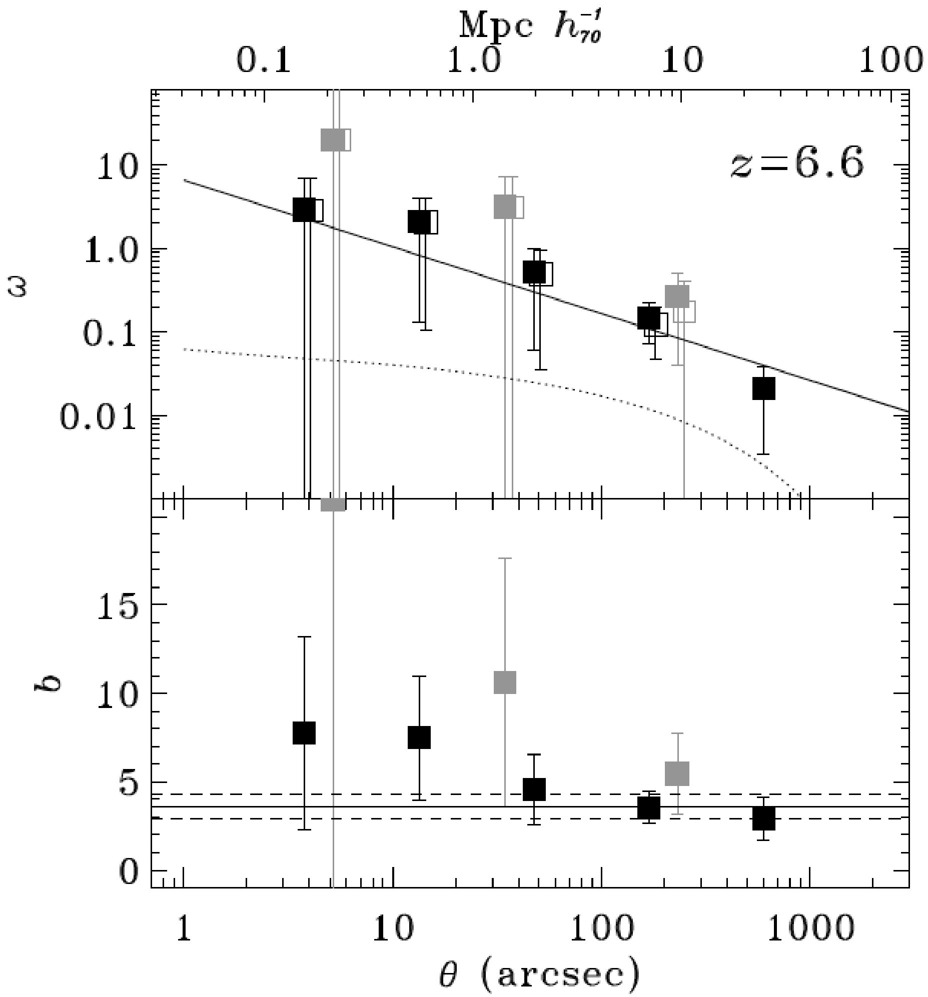
- When the mean ionization fraction is low, the amplitude of the clustering of observed sources is boosted, because the observed LAE reside in rare HII regions.
- Measuring the evolution of the clustering amplitude is very powerful and can't be mimicked by astrophysical processes.
- Can cross-correlate with H-alpha surveys for added certainty




McQuinn et al (2007) – from simulations

# Clustering observations

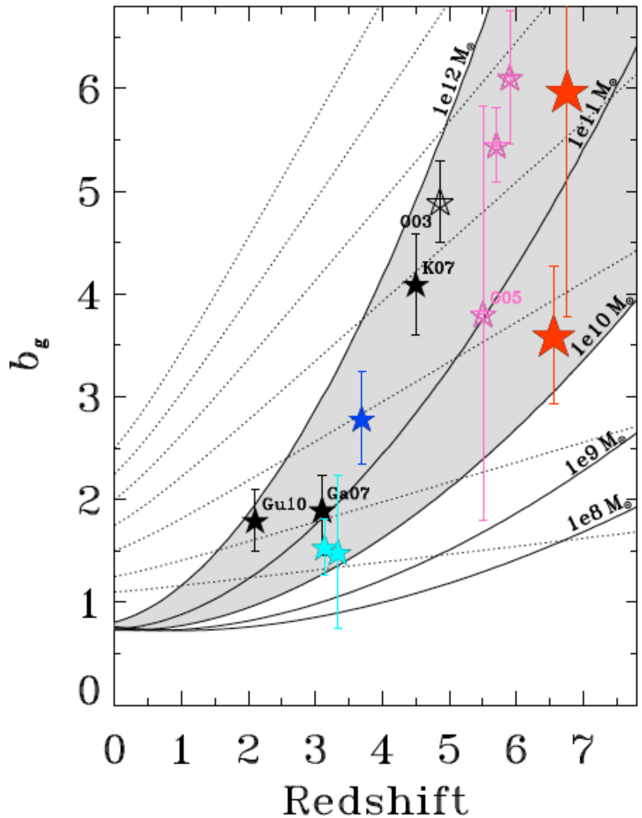
- Detect clustering in auto-correlation:




Ouchi et al 2010

# Clustering observations

- Dark matter halo mass function also changing. Infer bias and compare with semi-analytic prediction for the evolution (eg Sheth & Tormen):

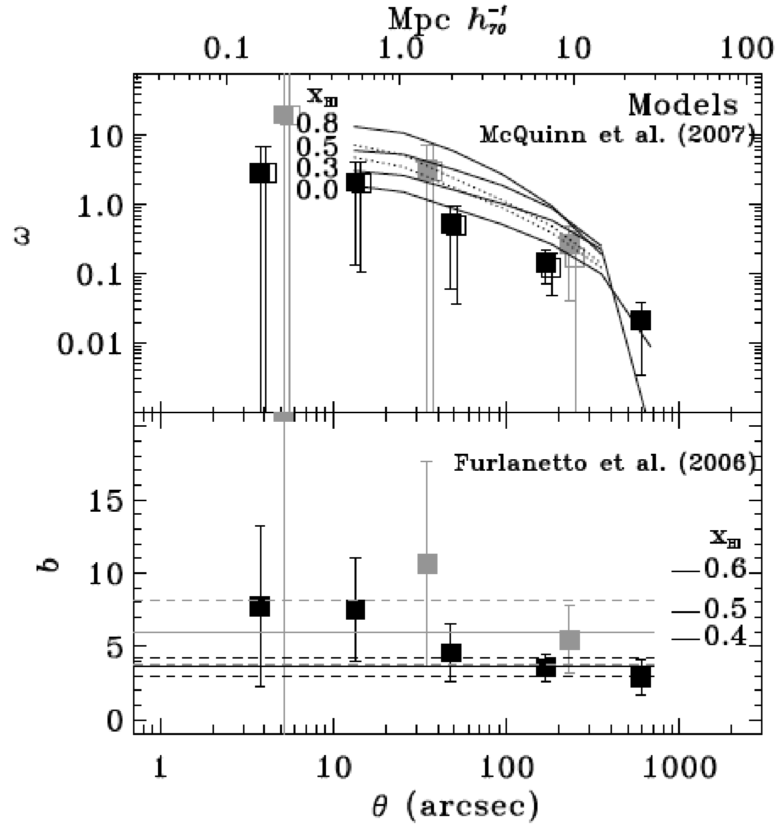



Ouchi et al 2010

# Clustering implications

- Compare to simulations by McQuinn et al. Or Furlanetto et al.
- Making some assumptions can get the weak constrain

$$x_{\rm HI} \lesssim 0.5 \text{ at } z = 6.6$$

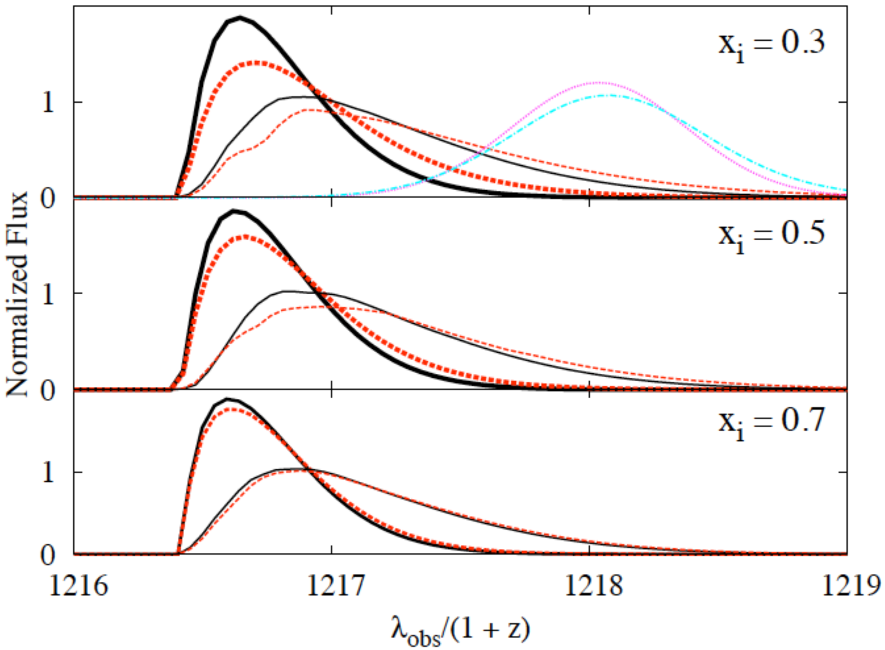



Ouchi et al 2010

# Line Profiles

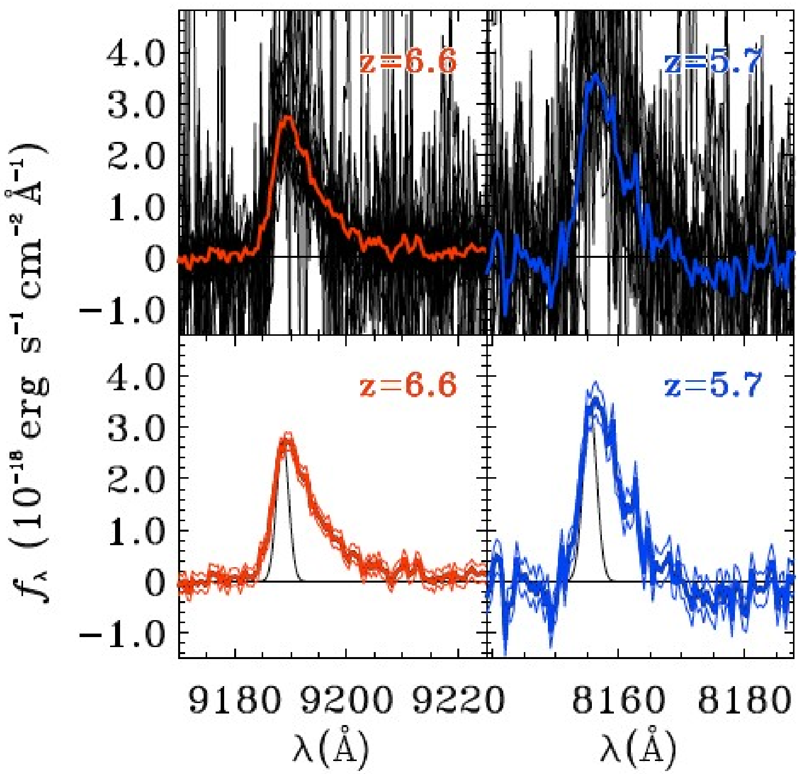
- A partially or fully neutral universe will preferentially absorb blueward of the Ly-Alpha transition (due to cosmological redshift).
- Also broadening of the line
- Predict 7-10% change in FWHM between a LAE in a very neutral medium vs very ionized.
- Need high quality spectra

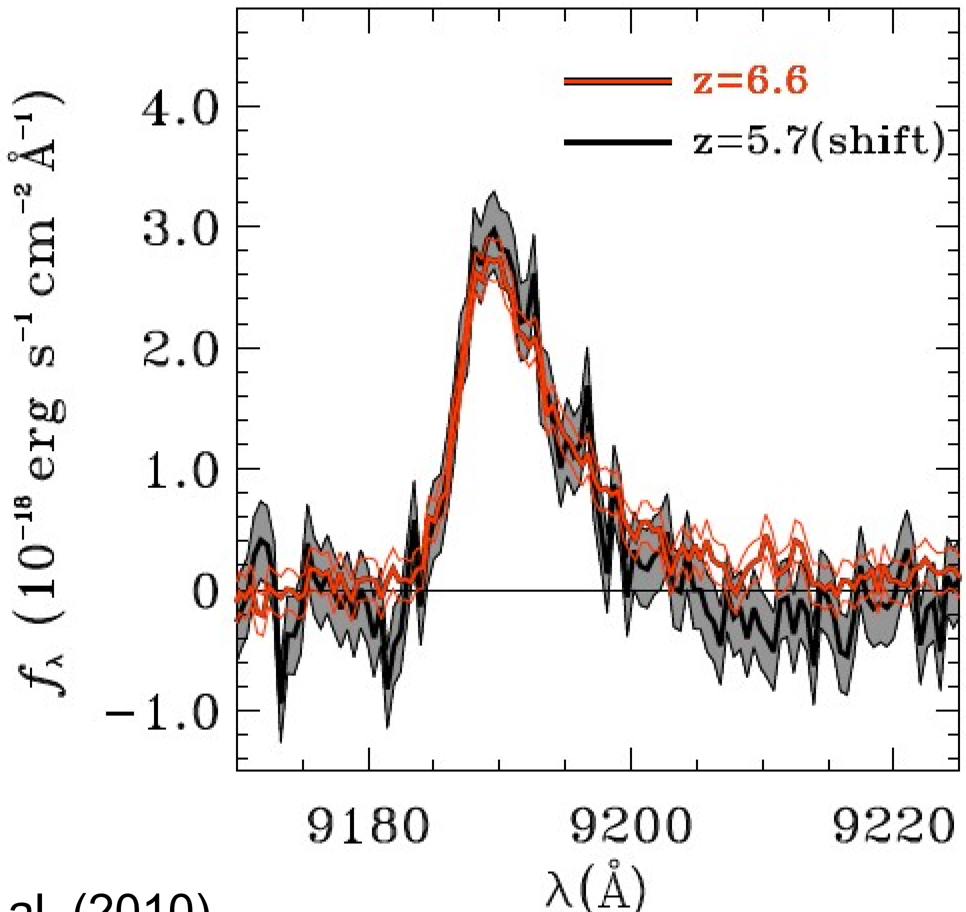
McQuinn et al. (2007)



# Line Profiles - observations

- Stack 19 spectra at z = 6.6 and 11 at z = 5.7
- No evidence of broadening, but error bars larger than the expected difference...

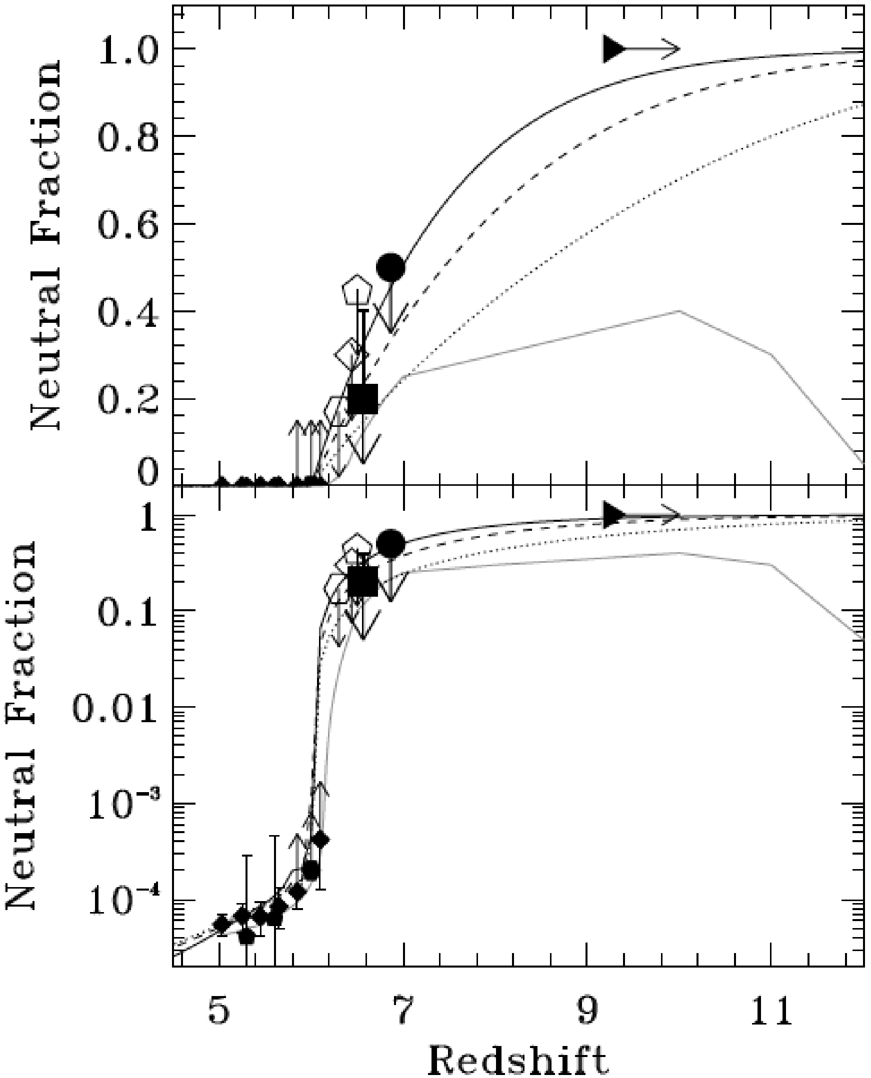



Ouchi et al. (2010)

# Summing up...

- Rule out neutral universe at z = 6.6
- Different studies seem to agree.
- Reionization only by large halos ruled out.
- Double reionization?
- In case of instantaneous reionization z ~ 11.1 +/- 1.1 (Planck + WMAP Pol)




Ouchi et al. (2010)

# Conclusions

- LAE very promising probe of reionization.
- Clustering will probably be the most robust probe (but so far barely detectable above Poisson noise). No large change in amplitude detected.
- LF increases by ~30% from $z = 6.6$ to 5.5
- Luminosity evolution preferred to number evolution.
- Asymmetric line profile but no evolution detected.
- Most of reionization happens at $z > 7$ (consistent with CMB, GRB and QSO constraints).

# References


- M. McQuinn et al. (2007): arXiv:0704.2239
- M. Ouchi et al. (2010): arXiv:1007.2961
- S. Malhotra & J. Rhoads (2004): astro-ph/0407408
- D. Stark et al. (2010): arXiv:1009.5471