Sources of Uncertainty in Modelling 21cm Fluctuations

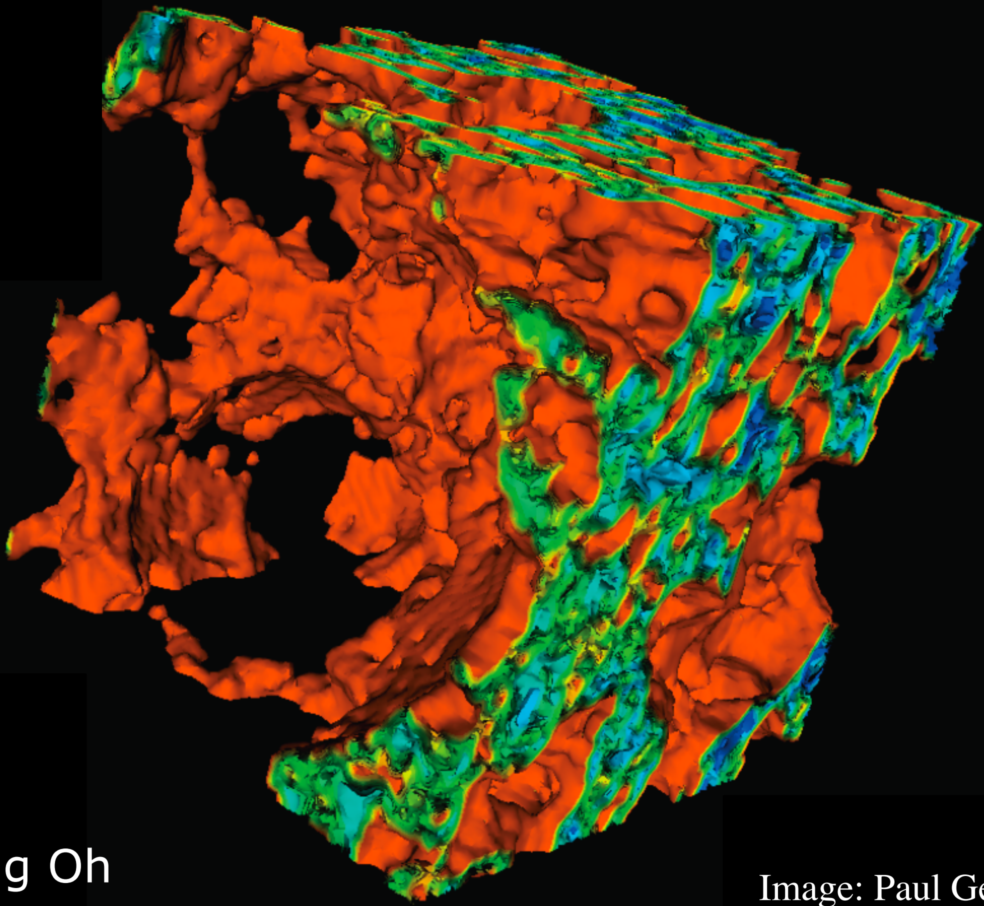

Image: Paul Geil

Stuart Wyithe

Jonathan Pritchard, Avi Loeb,

Paul Geil, Lila Warszawski, Peng Oh

Outline

- Current constraints on the reionization history
- Basic properties of the ionization structure
- Astrophysical uncertainties in models of the 21cm power-spectrum:

    a) Contribution to 21cm signal from galactic HI

    b) Contribution to reionization from quasars

    c) Contribution to reionization from X-rays

Astrophysical uncertainties lead to 21cm power-spectrum predictions that are systematically uncertain

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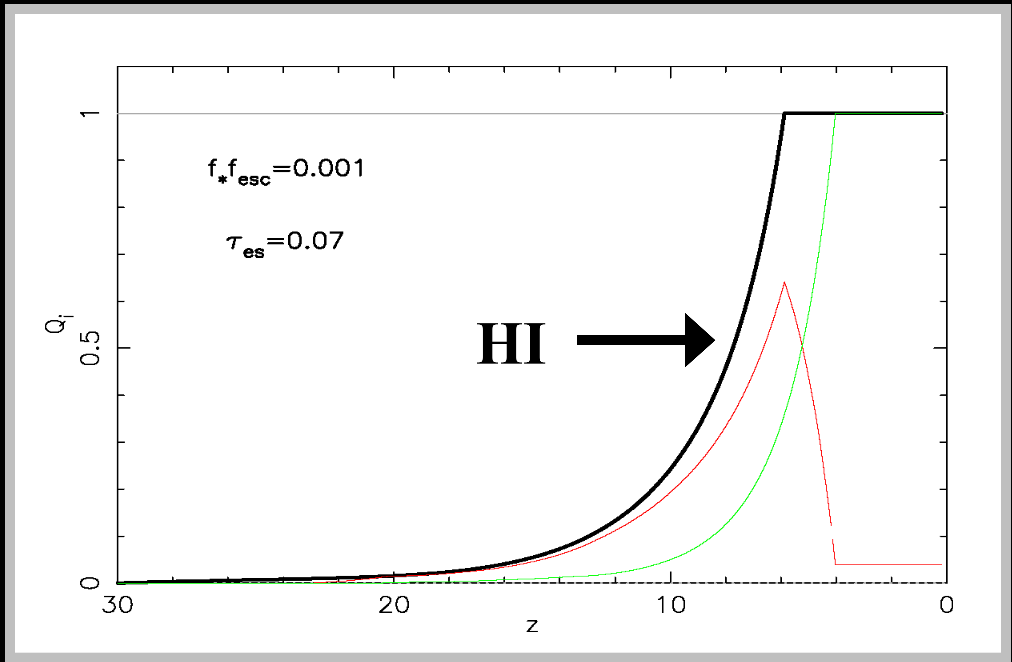
Analytic Models of Hydrogen Reionization

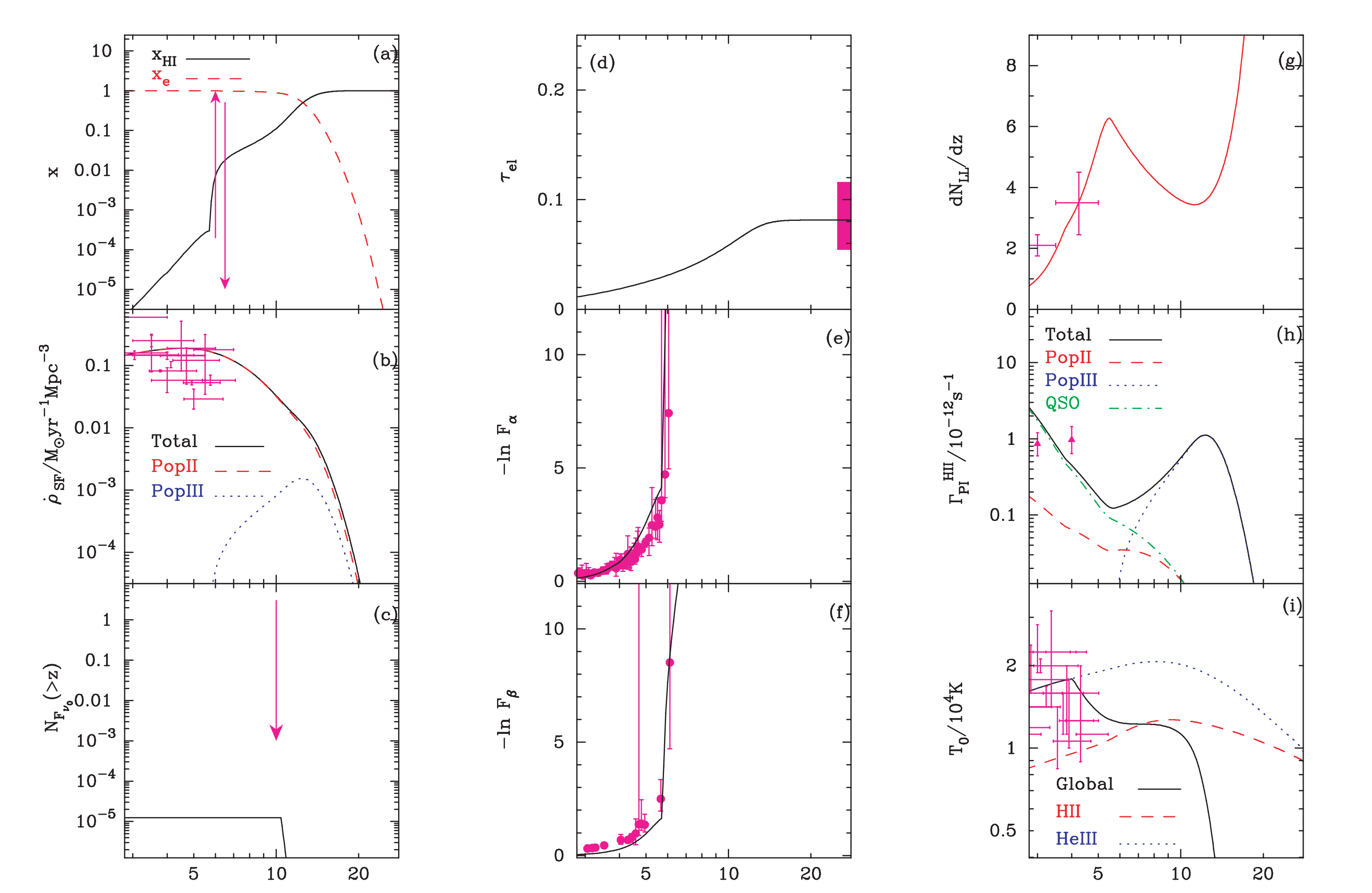


$$\frac{dQ_i}{dz} = \frac{1}{n_0}\frac{dn_\gamma}{dz} - \alpha_B \frac{C}{a^3} Q_i n_e \frac{dt}{dz}$$

$$\frac{dn_\gamma^{H^+}}{dz} = N_\gamma f_{esc} f_* \frac{dF_b}{dz} n_b$$

- Models based on F_{col}, with $f_{star}f_{esc}$ a free parameter
- Sensible values for star-formation efficiency, escape fraction etc can reionise H over a wide range of z

Self-consistent reionization modeling

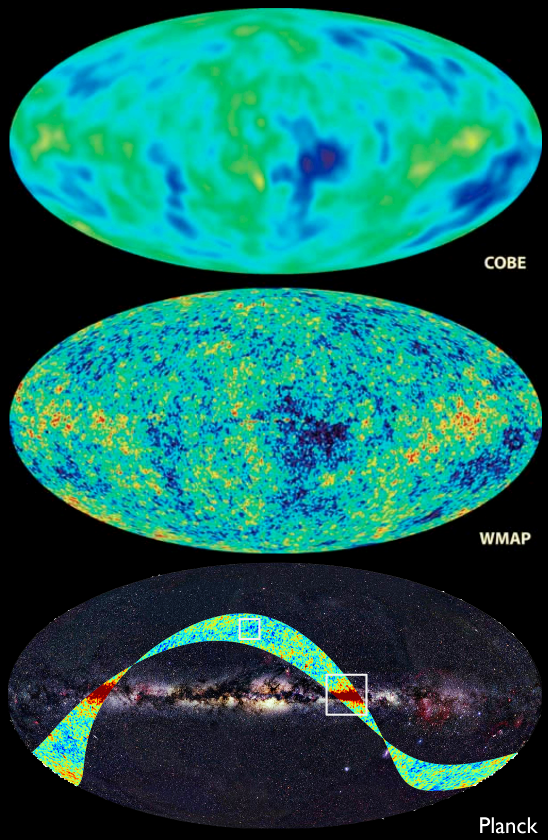


Throw all observations at detailed model and make predictions

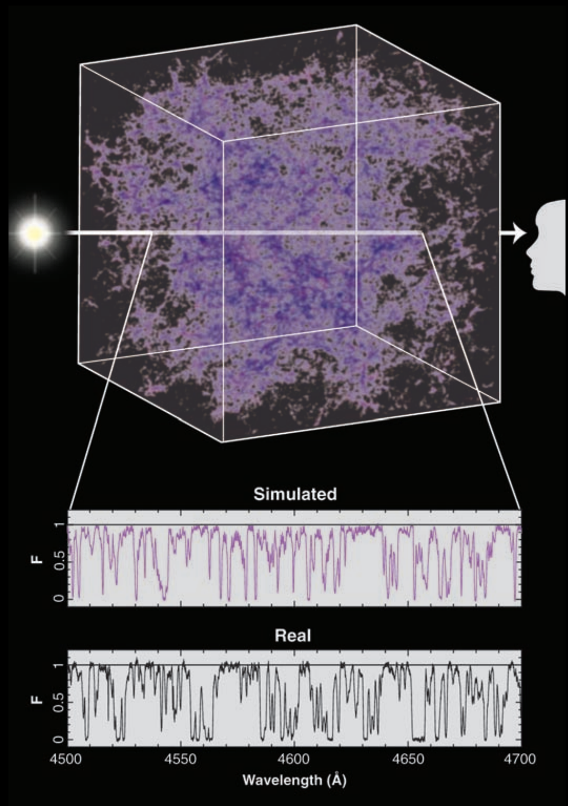
Choudhury & Ferrara 2008

Robust Observations

CMB



Lyman alpha forest

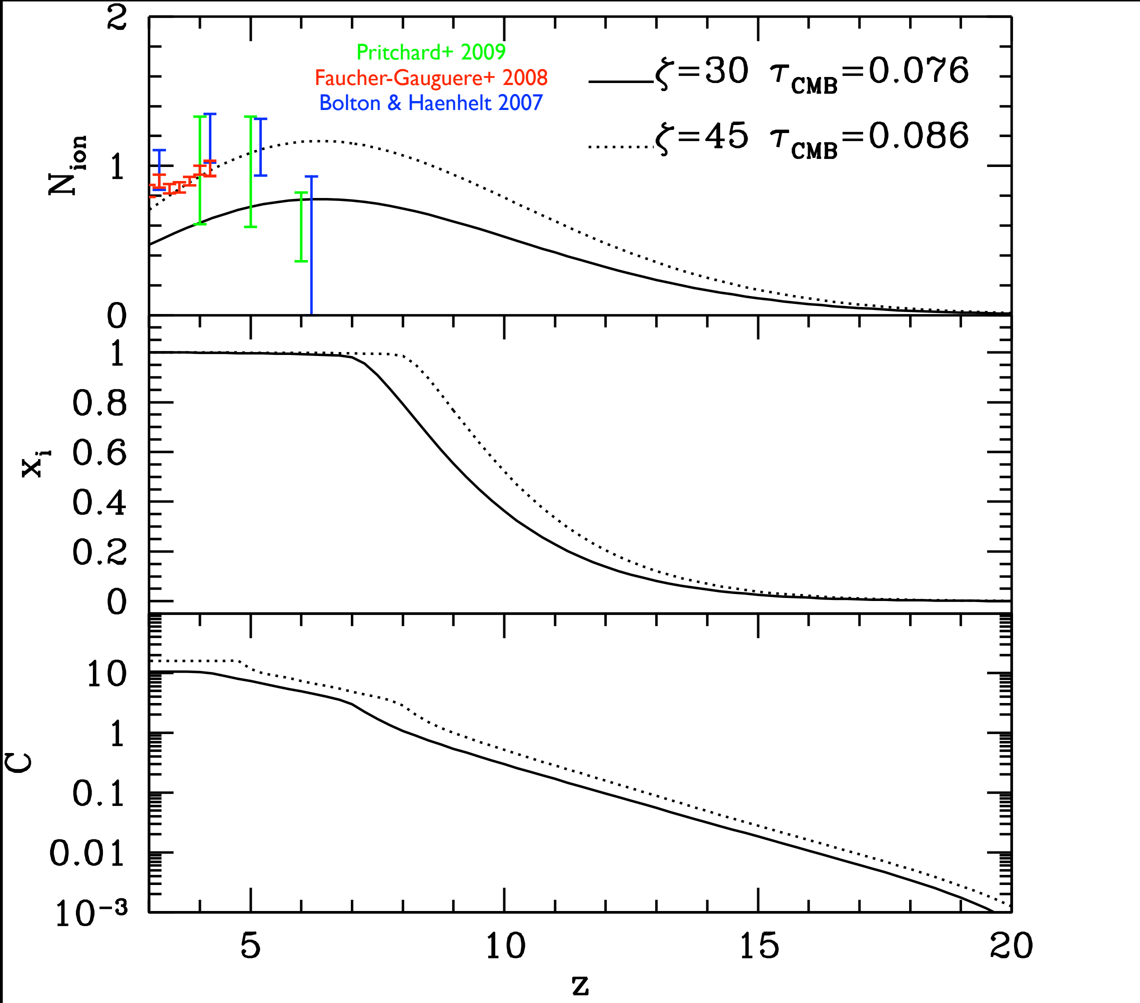


Here focus on CMB & Ly alpha forest
and stay agnostic about sources

Arbitrary Parameterised Model

Filling fraction of ionized regions

$$\frac{dQ_{HII}}{dt} = \frac{\dot{N}_{ion}}{n_H(0)} - Q_{HII} C_{HII} n_H(0)(1+z)^3 \alpha_A(T).$$



$$\dot{N}_{ion}(z) = \zeta(z) n_H(0) \frac{df_{coll}(z)}{dt},$$

Clumping set assuming IGM ionized up to density threshold set by HII region size

Miralde-Escude+ 2000

Furlanetto & Oh 2005

Parametrizations of Ndot

Need to explore different parametrizations of Ndot ...try two

via source emissivity

$$\dot{N}_{\rm ion}(z) = \zeta(z) n_H(0) \frac{{\rm d}f_{\rm coll}(z)}{{\rm d}t},$$

$$\zeta(z) = \zeta_0 + \frac{(\zeta_1 - \zeta_0)}{2}\left[\tanh\left(\frac{z - z_0}{\Delta z}\right) + 1\right]$$

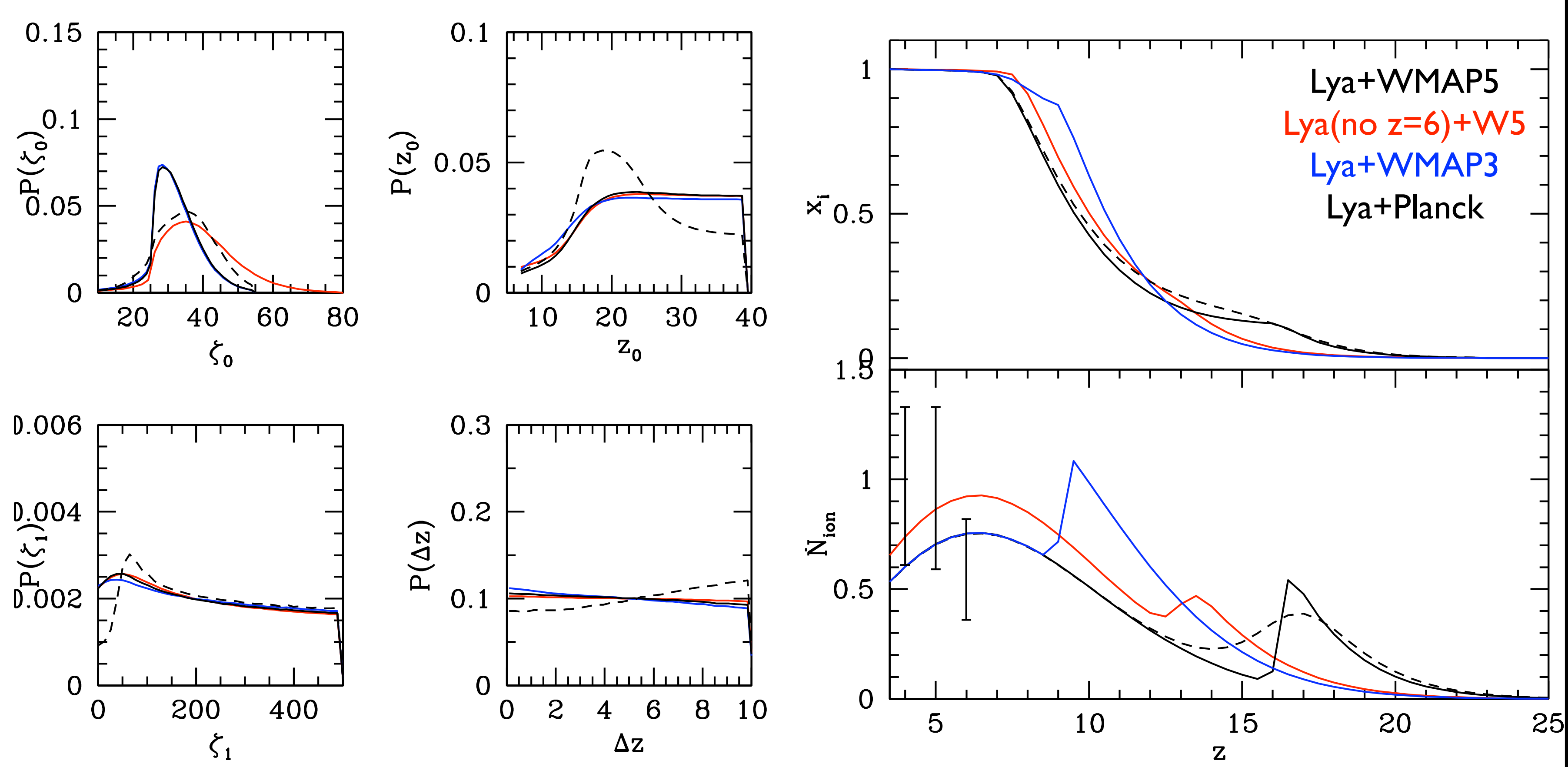
polynomial

$$\dot{N}_{\rm ion} = N_0 A_{\rm ion}[1 + N_1(z - z_0) + N_2(z - z_0)^2 + N_3(z - z_0)^3] \times \Theta(z - z_{\rm max}), \quad (5)$$

If very different parametrizations give same physical predictions may be robust

Step Model

$$\zeta(z) = \zeta_0 + \frac{(\zeta_1 - \zeta_0)}{2}\left[\tanh\left(\frac{z - z_0}{\Delta z}\right) + 1\right]$$

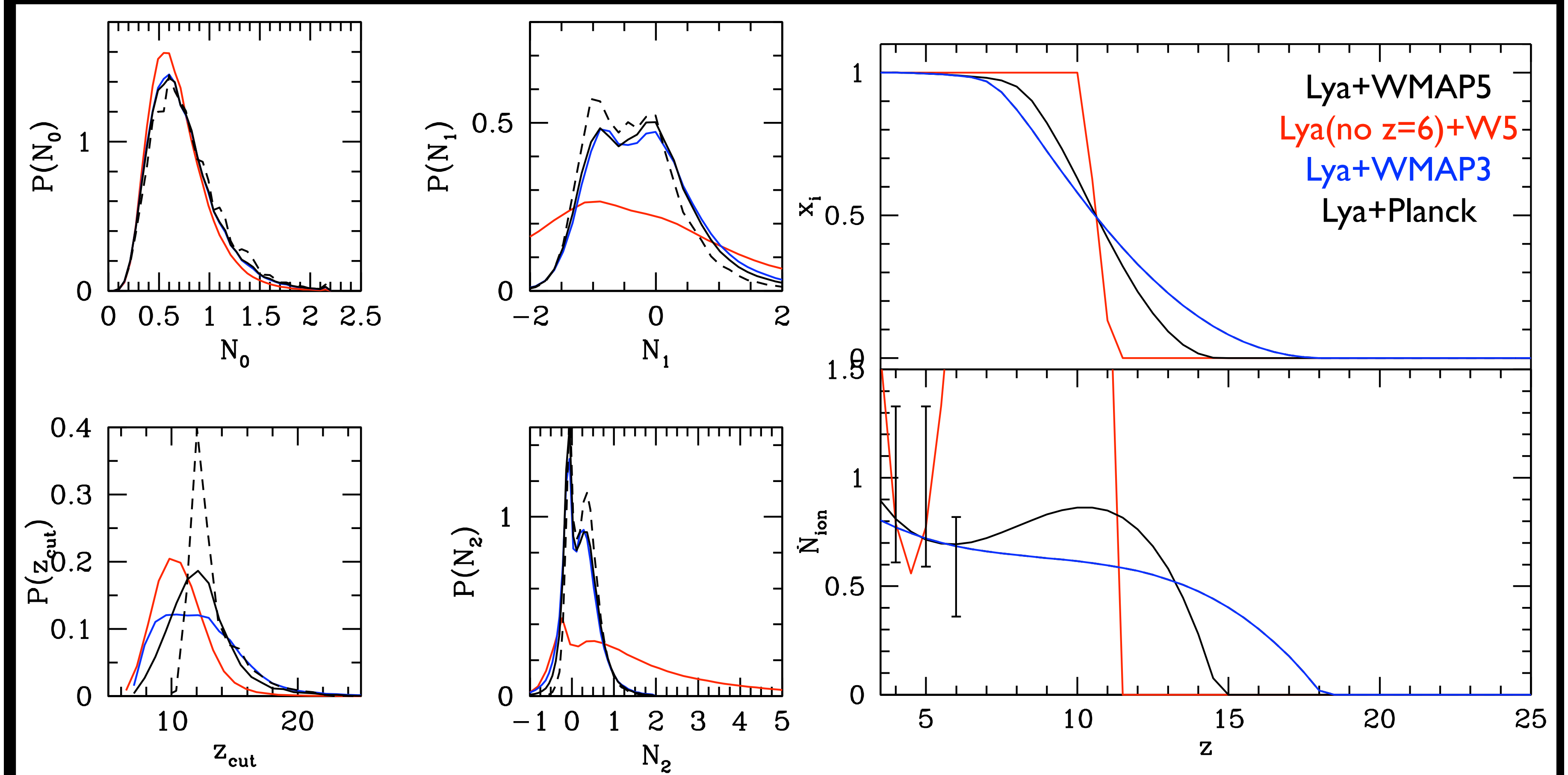


model parameters

best fitting history

Polynomial Model

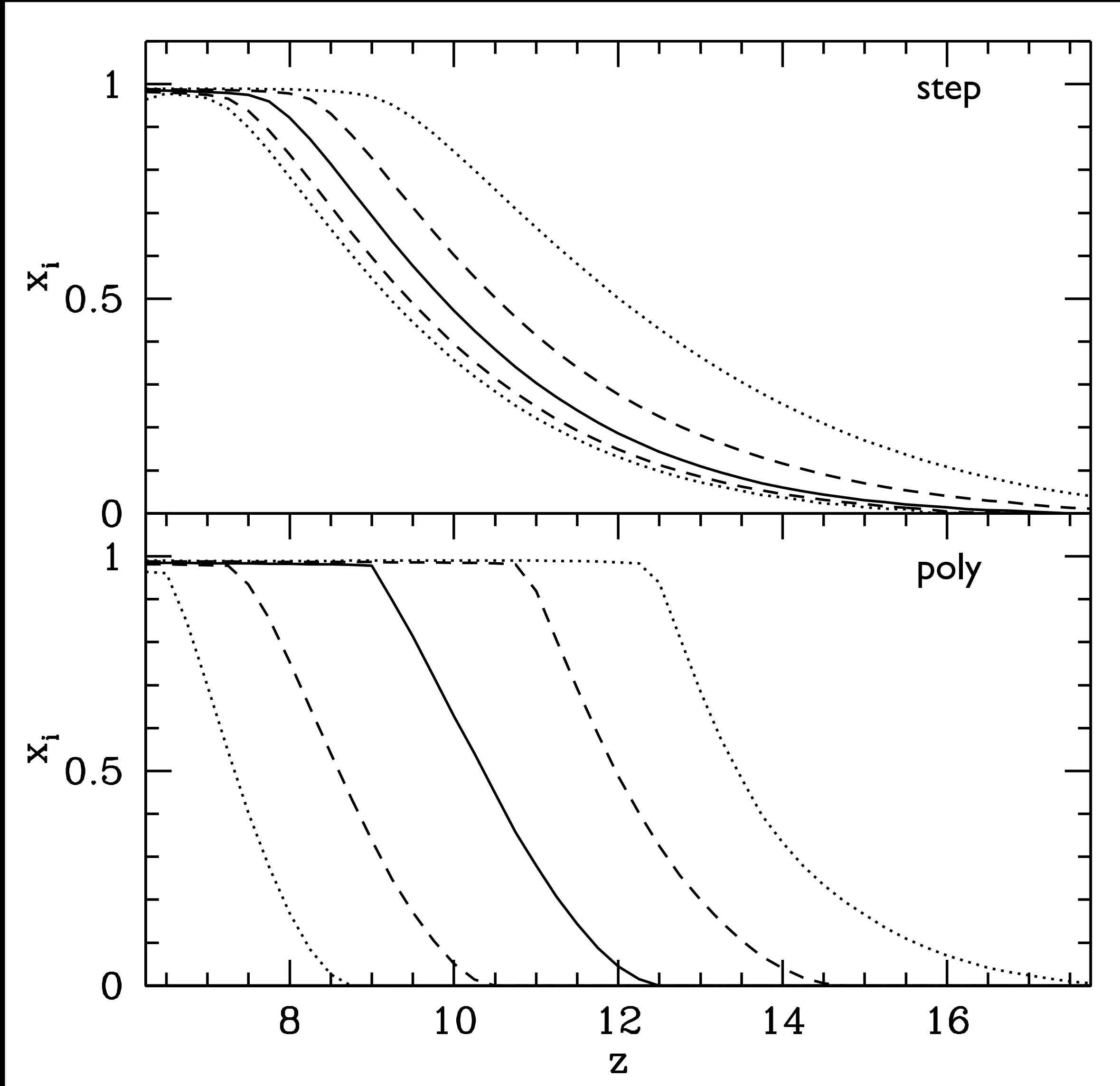
$$\dot{N}_{\rm ion} = N_0 A_{\rm ion}[1 + N_1(z - z_0) + N_2(z - z_0)^2 + N_3(z - z_0)^3] \times \Theta(z - z_{\rm max}), \quad (5)$$



model parameters

best fitting history

Ionization History

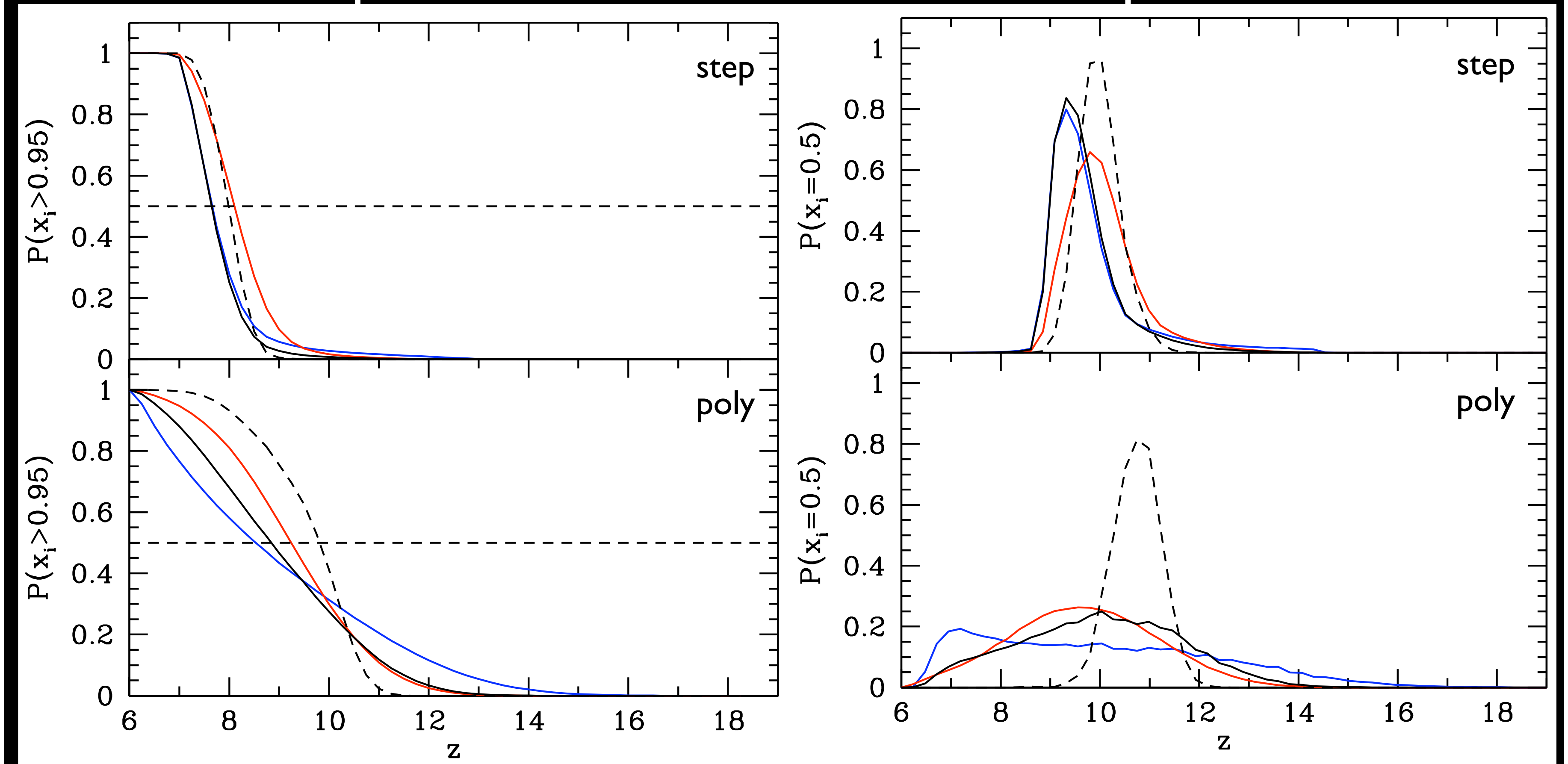


Contours from cumulative probability distribution (not 1 & 2 sigma errors and not best fit)

More restrictive parametrization gives tighter bounds on allowed histories

Milestones of Reionization

"end" point $x_i>0.95$ | midpoint $x_i=0.5$



Universe mostly ionized by z=8
Mid-point of reionization typically occurs around z=9-11
Polynomial more flexible, so larger spread in distribution

Lya+WMAP5
Lya(no z=6)+W5
Lya+WMAP3
Lya+Planck

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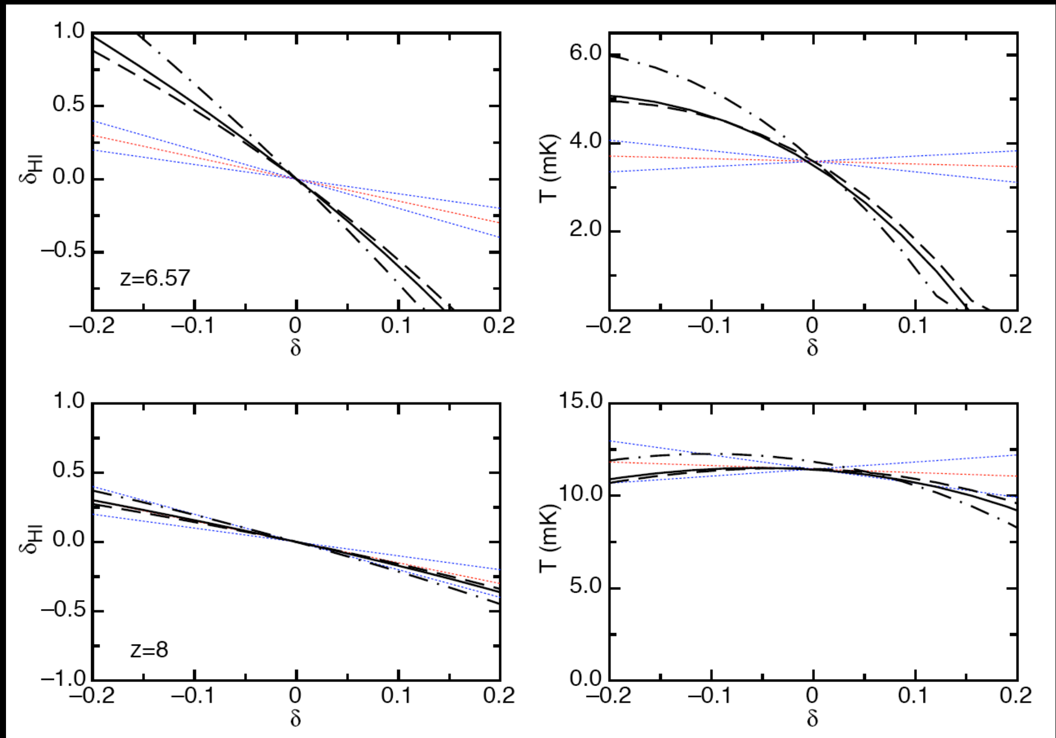
Galaxy Bias & Patchy Reionization



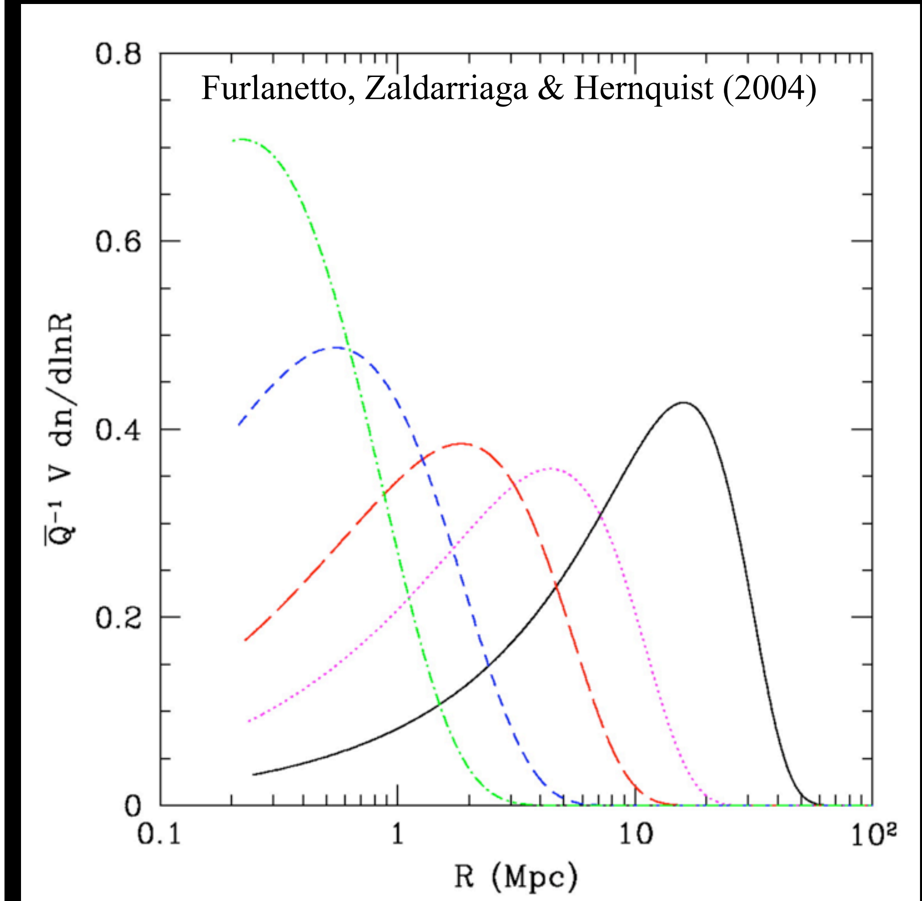
- - · - · - C=2
——— C=10
- - - - - C=20

Intensity not very sensitive to overdensity.

Standard Expression has δ=0 and R=∞.

$$\frac{dQ_{\delta,R}}{dt} = \frac{N_{\rm ion}}{0.76}\left[Q_{\delta,R}\frac{dF_{\rm col}(\delta,R,z,M_{\rm ion})}{dt} + (1-Q_{\delta,R})\frac{dF_{\rm col}(\delta,R,z,M_{\rm min})}{dt}\right] - \alpha_{\rm B} C n_{\rm H}^0\left(1+\delta\frac{D(z)}{D(z_{\rm obs})}\right)(1+z)^3\,Q_{\delta,R},$$

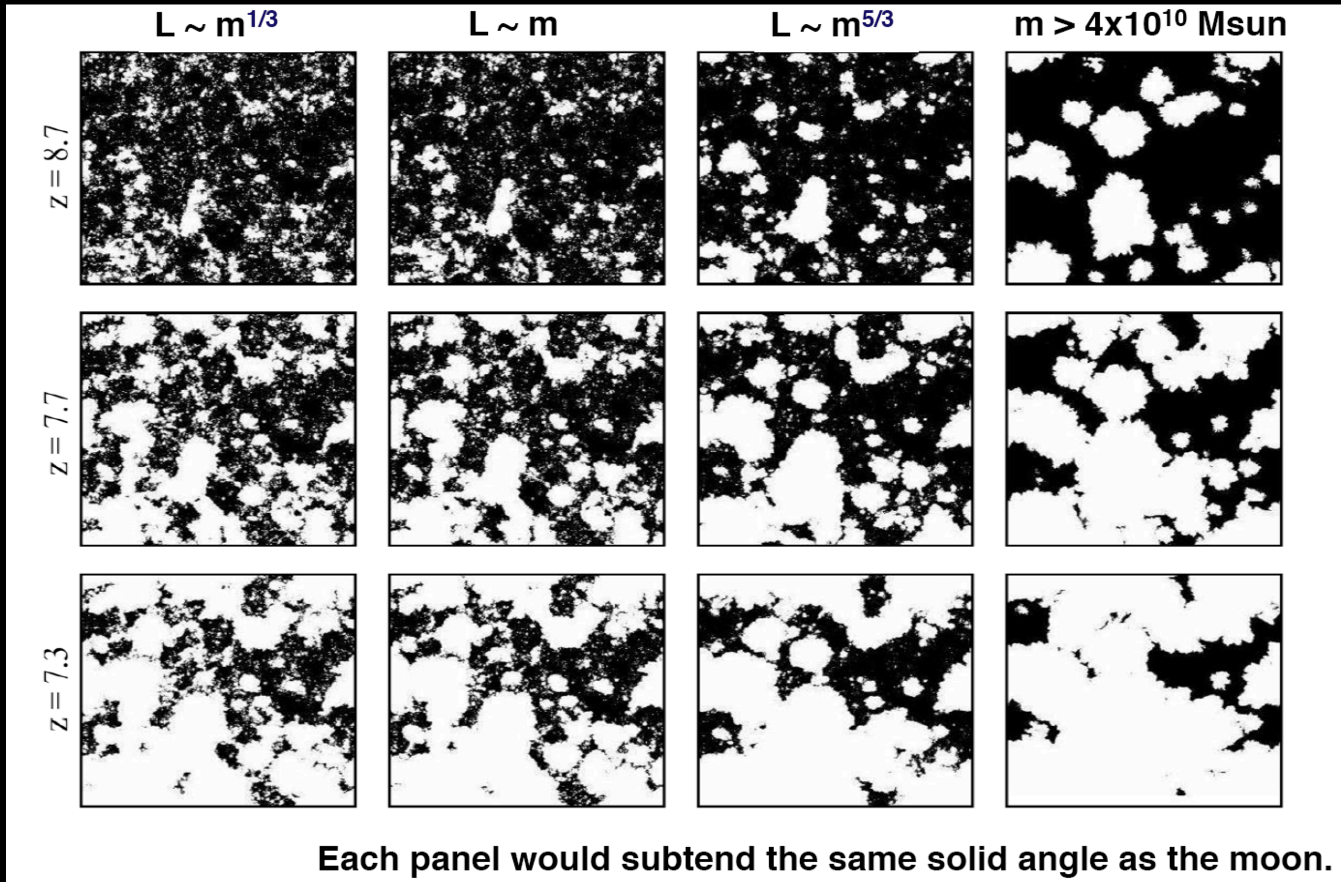
Characteristic Scale of HII Regions



- An HII region forms when a critical number of photons are produced per baryon of IGM
- Ansatz: Ionizing photons produced in proportion to collapsed fraction, so that formation of an HII region corresponds to crossing of a barrier in mass overdensity

- The mass function of HII regions can then be calculated in analogy with the excursion set formalism

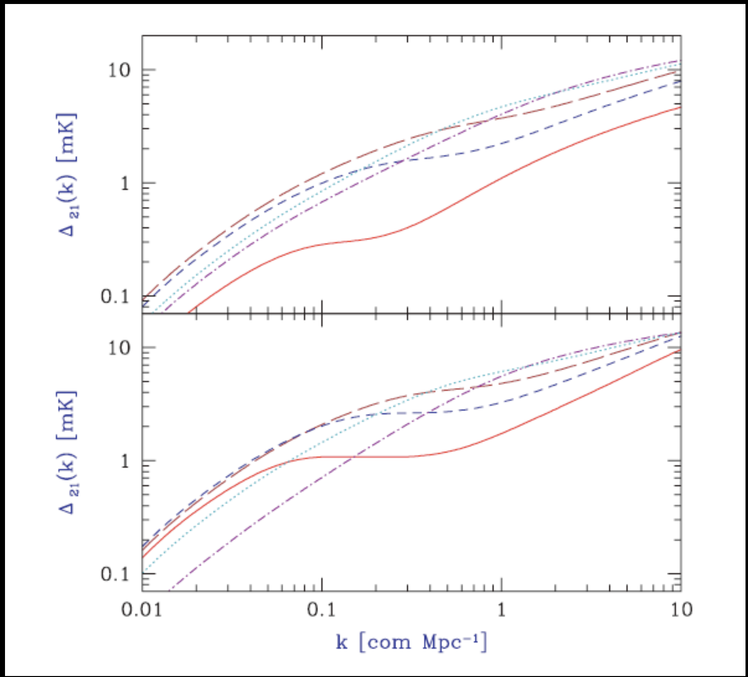
"Structure" of Hydrogen Reionization is Sensitive to the Source Population

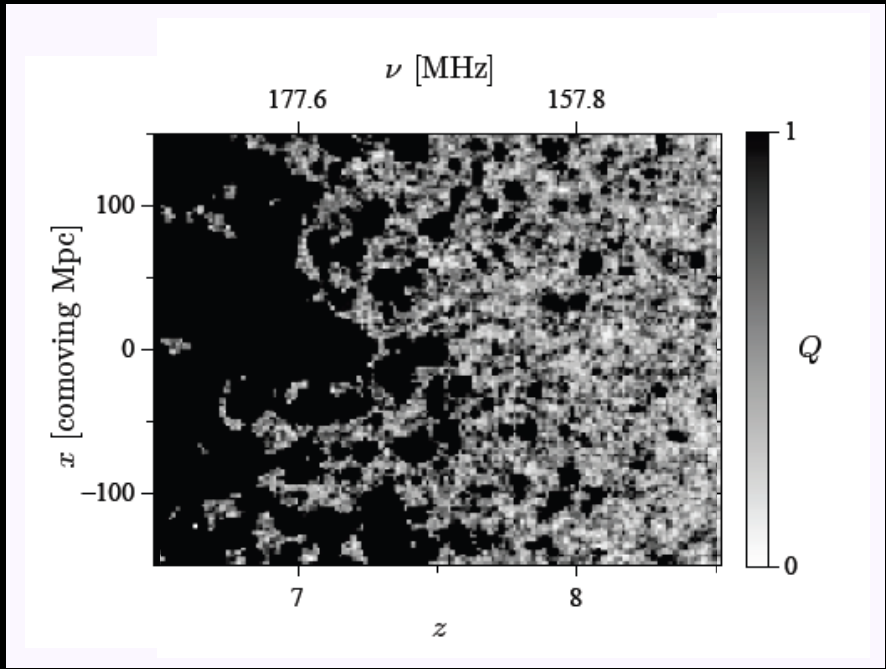


McQuinn et al. (2007)

- The structure of HII regions encodes information on population of galaxies responsible for reionization

“Structure” of Reionization is Encoded in the 21cm Intensity Power-Spectrum

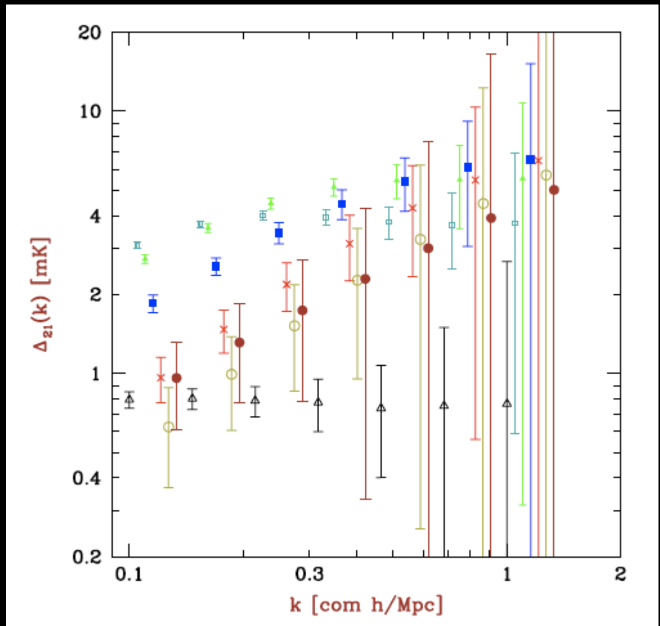


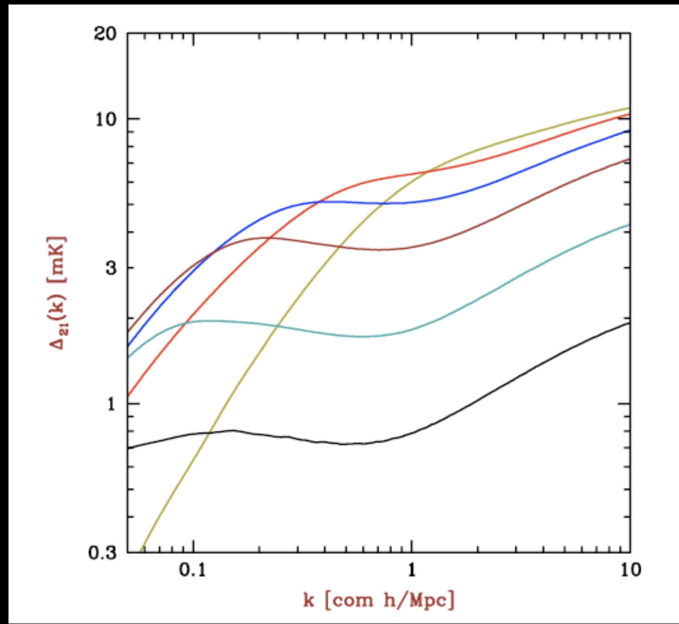


- Reionization should leave a distinct mark on the power-spectrum of spatial fluctuations in 21cm emission
- Galaxy evolution drives the evolution in the shape and amplitude of the 21cm power-spectrum

Barkana (2007)

Power Spectrum Constraints





- Compare observations with a multi-d grid of models
- Features of the 21cm PS could be connected to the galaxy population *if the modeling was astrophysically complete*
- Reionization models are not analagous to CMB fast!

Barkana (2008)

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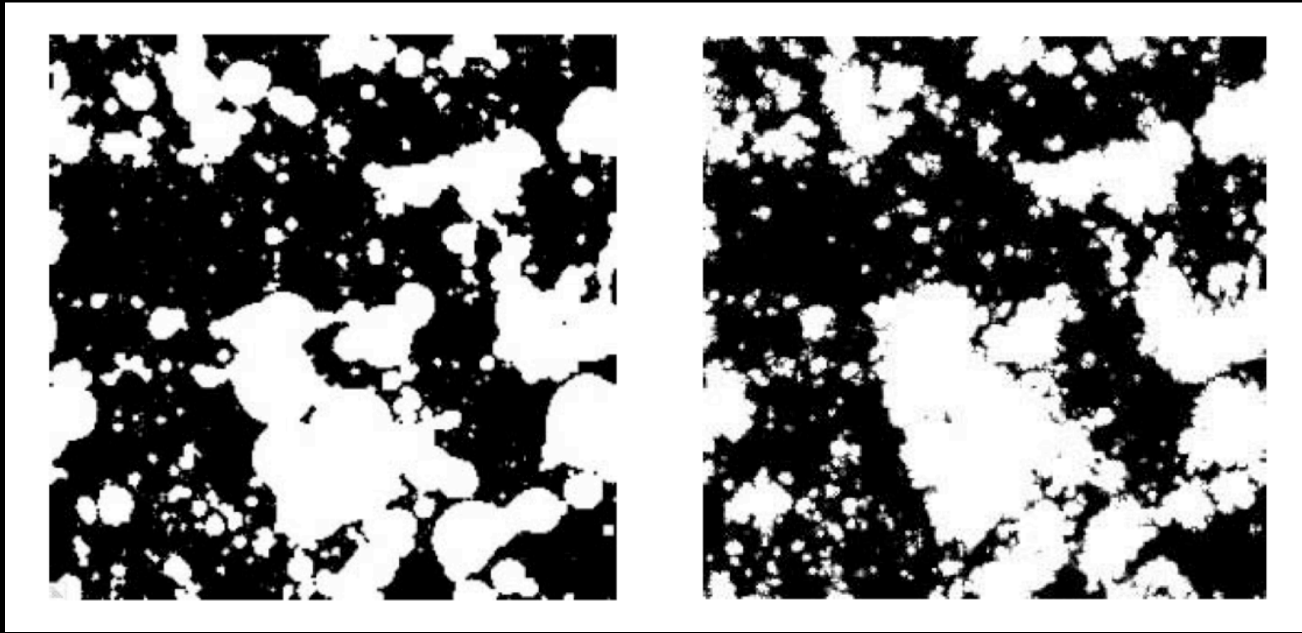
Some Astrophysical Uncertainties in Models of the Power-Spectrum

- Theoretical studies have concentrated on UV ionization and fluctuations from neutral IGM, or fluctuations in heating/spin-temperature owing to X-rays early in reionization
- There are at least 3 other obvious contributions
  - HI in galaxies (DLAs at high redshift)
  - A potential contribution to reionization from quasars
  - A potential contribution to reionization (as distinct from heating) from X-rays

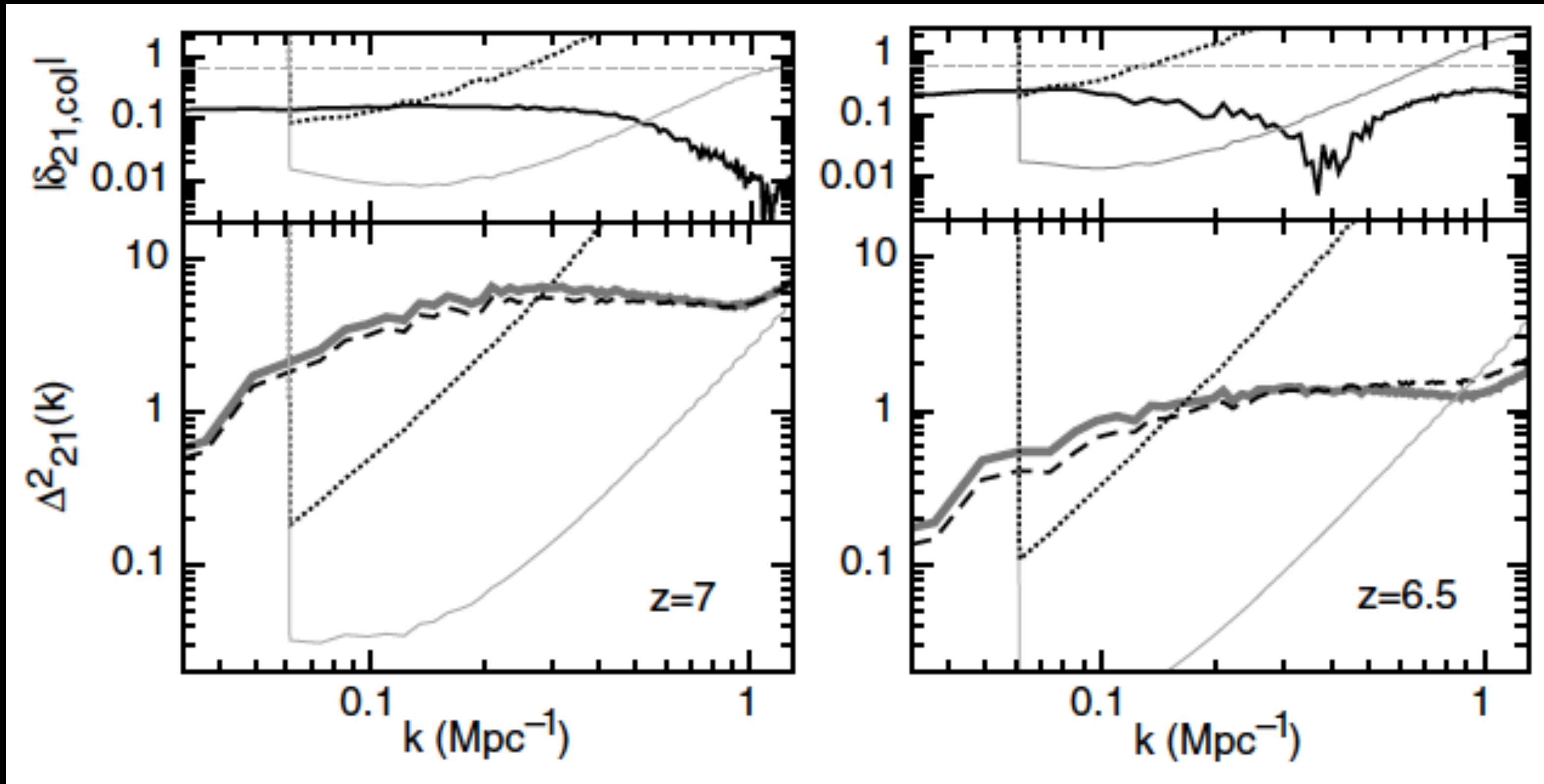
Semi-Numerical Models



- Application of Bubble model to a realization of the mass density field
- Good agreement of fluctuation statistics with those produced using RT simulations
- Can be used to study different effects
- Computationally efficient

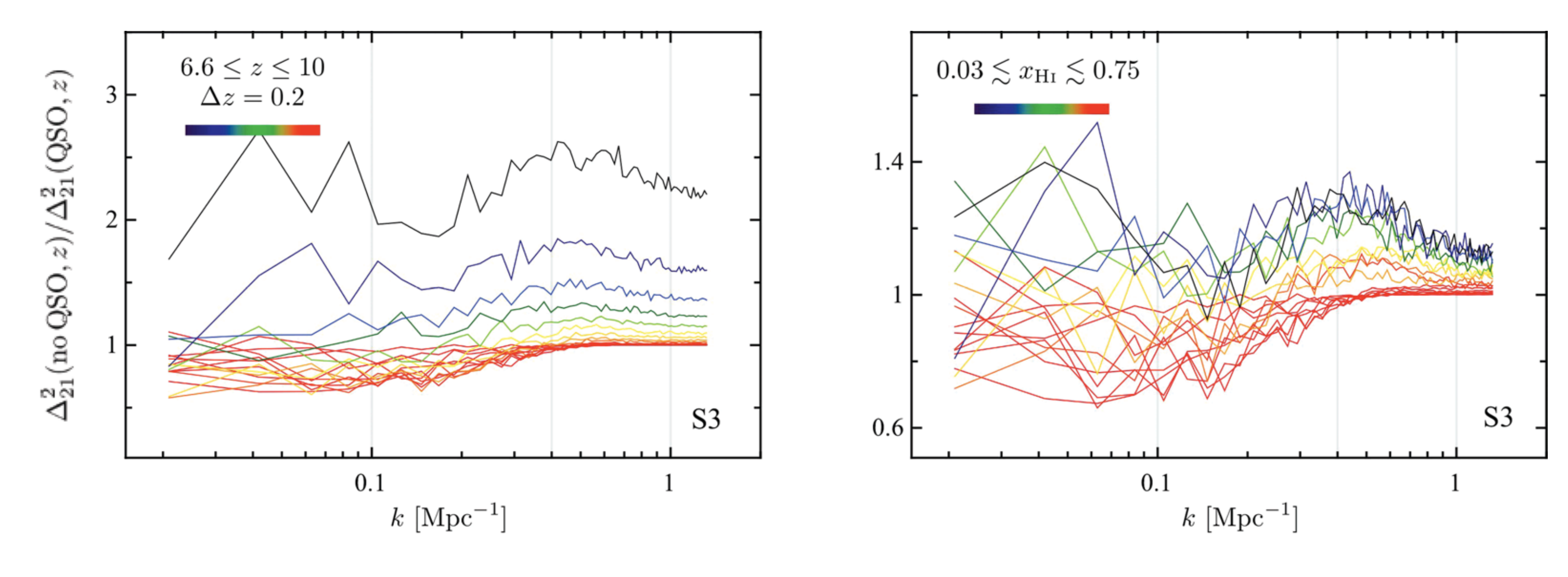
Mesinger & Furlanetto (2007)
also Zahn et al. (2007)

a)Effect of Galactic HI on the 21cm PS



- HI in galaxies can be significant by mass w.r.t the IGM towards the end of reionization (assume 2% by mass).
- Inclusion of galactic HI changes the PS amplitude by ~20%, and changes its shape on small scales

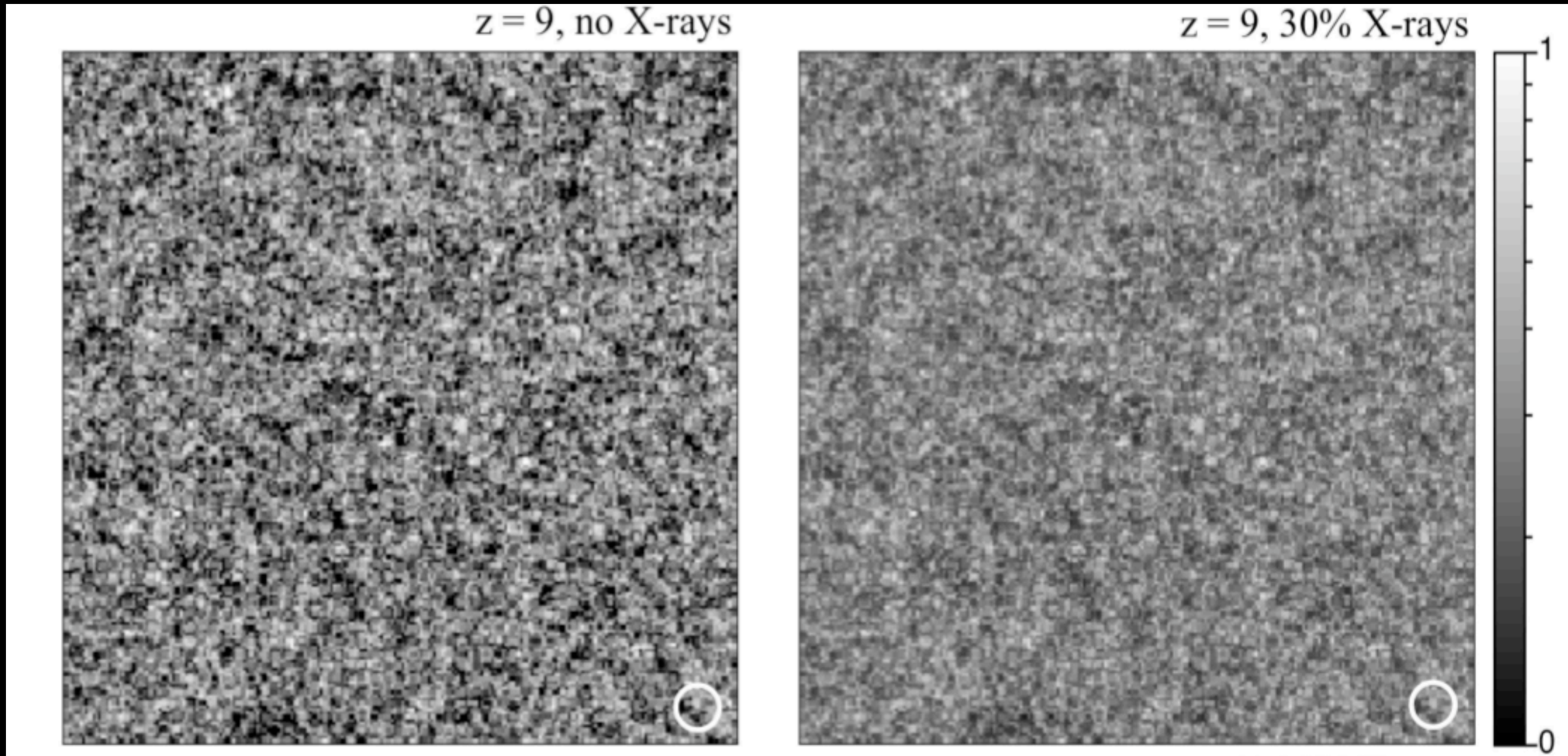
b) Effect of Quasars on the 21cm PS



- Assume a 10% contribution to reionization by overlap
- A quasar contribution increases the mean bias of ionizing sources and so changes the amplitude and shape of the 21cm power-spectrum

Geil & Wyithe (2009)

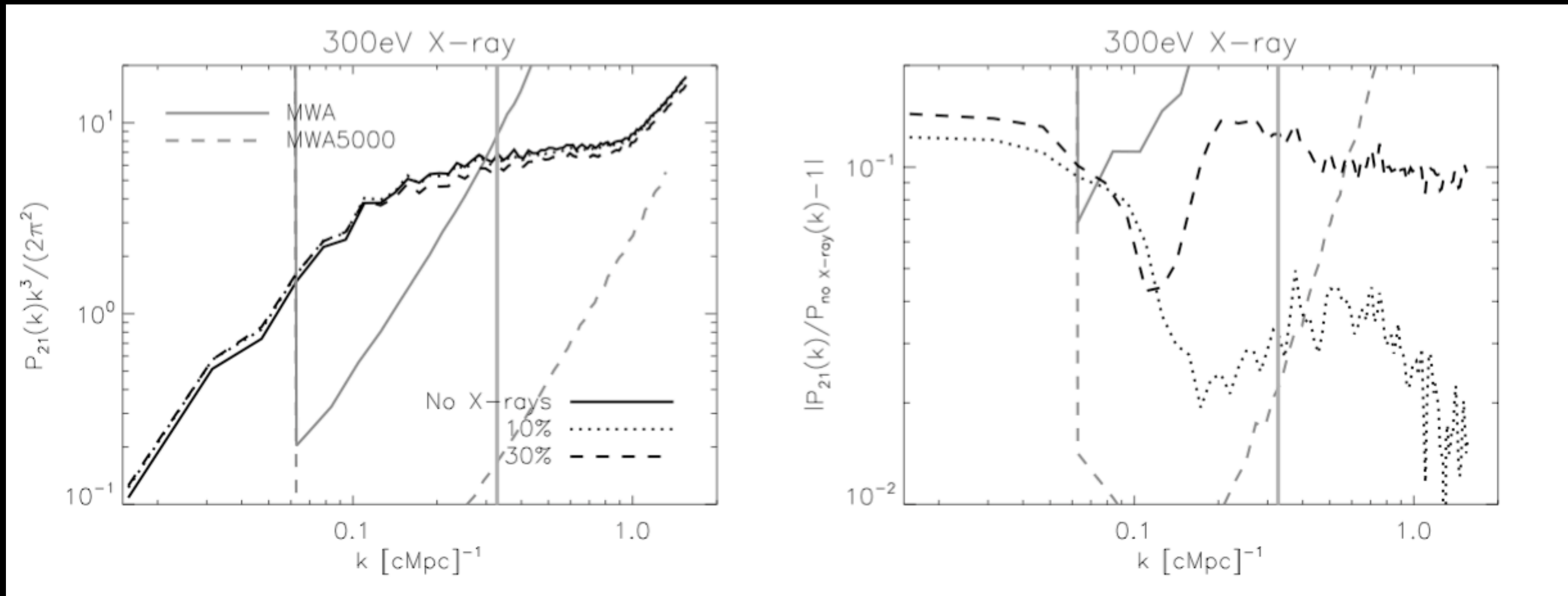
c) Effect of X-ray Ionization



- The X-ray contribution to the fraction of ionizations in the IGM during much of reionization could be 10s of %
- While UV photons have a short m.f.p. and so retain the clustering bias of their sources, the long X-ray m.f.p. de-correlates ionizations from over-densities

Warszawski et al. (2008)

c) Effect of X-ray Ionization



- The MWA will have sufficient sensitivity to detect the modification of the PS due to a 10–30 per cent contribution to reionization by X-rays, so long as the MFP falls within the range of scales over which the array is most sensitive (~0.1 Mpc^{-1}).

Warszawski et al. (2008)

Summary

- Despite the uncertainties it is interesting to perform an inference exercise on analytic models:

  - Reionization was likely complete by z=8

  ↘ - Mid point of reionization probably z=9-11

- Astrophysical uncertainties like the quasar and X-ray contributions to reionization, and the density of galactic HI modify the predicted power-spectrum at a level comparable to projected MWA uncertainties

- If the goal of 21cm studies is to unravel the astrophysics of the galaxies responsible for reionization from the shape and evolution of the PS, then modelling of the observations will need to include a range of effects in addition to ionization by UV photons from star-burst galaxies