Detecting the Rise and Fall of 21cm Fluctuations

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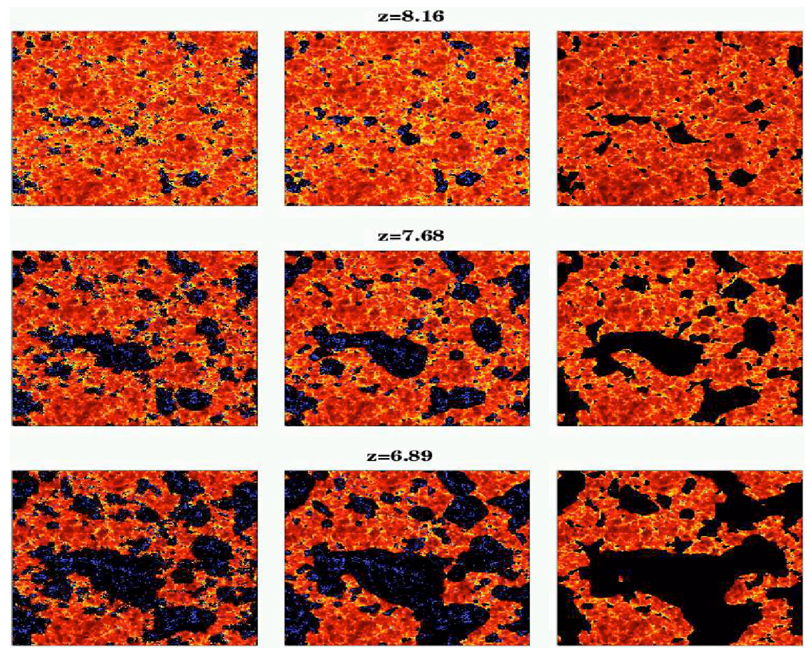


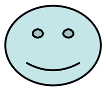
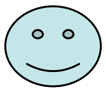
Outline

- A few words about models of reionization.

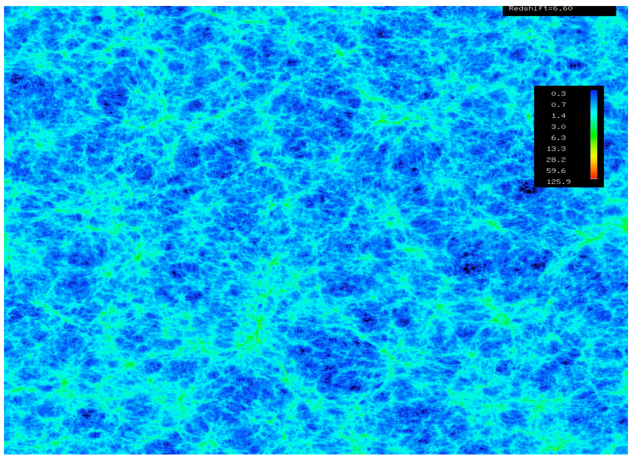
- Forecasts for 21 cm observations.
  a) Power Spectrum
  b) Cross Spectrum with Galaxies

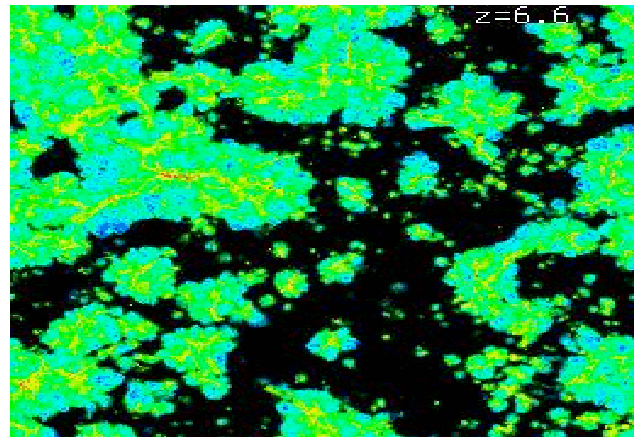
- Some open questions.

Collaborators

- Mark Dijkstra (Melbourne/CfA)
- Suvendra Dutta (CfA)
- Claude-Andre Faucher-Giguere (CfA)
- Steve Furlanetto (UCLA)
- Lars Hernquist (CfA)
- Matt McQuinn (CfA) 
- Peng Oh (UC Santa Barbara)
- Oliver Zahn (CfA/Berkeley) 
- Matias Zaldarriaga (CfA)

Simulating Hydrogen Reionization





- Large volume to sample H II regions ~ 100 Mpc, 200 Mpc
- N=1024^3 particles to resolve small mass galaxies
- Radiative Transfer

(**McQuinn+,** Altay & Croft, Ciardi+, Gnedin+,Iliev+, Trac & Cen)

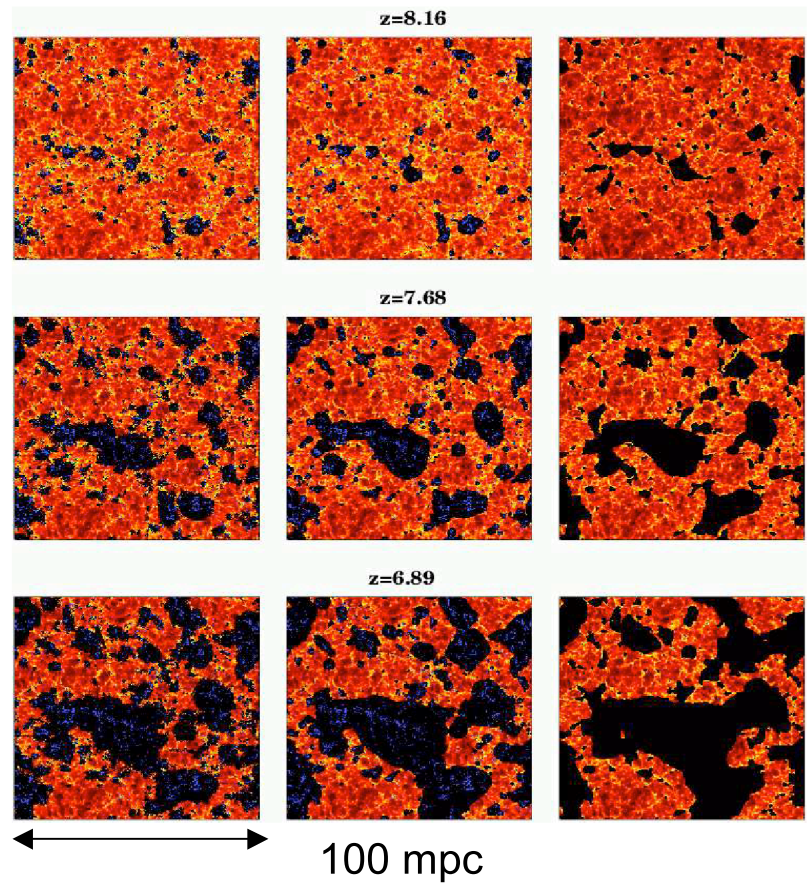
M. McQuinn 100 Mpc ~ 1/2 degree on sky

Large HII regions during reionization

- Semi-analytic models match basic features well.

- Useful for exploring parameter space: 21 cm fast?

see also:
Mesinger & Furlanetto(2007)
Geil & Wyithe (2008)
Choudhury, Haehnelt, & Regan



Zahn, AL, McQuinn, et al. 2006

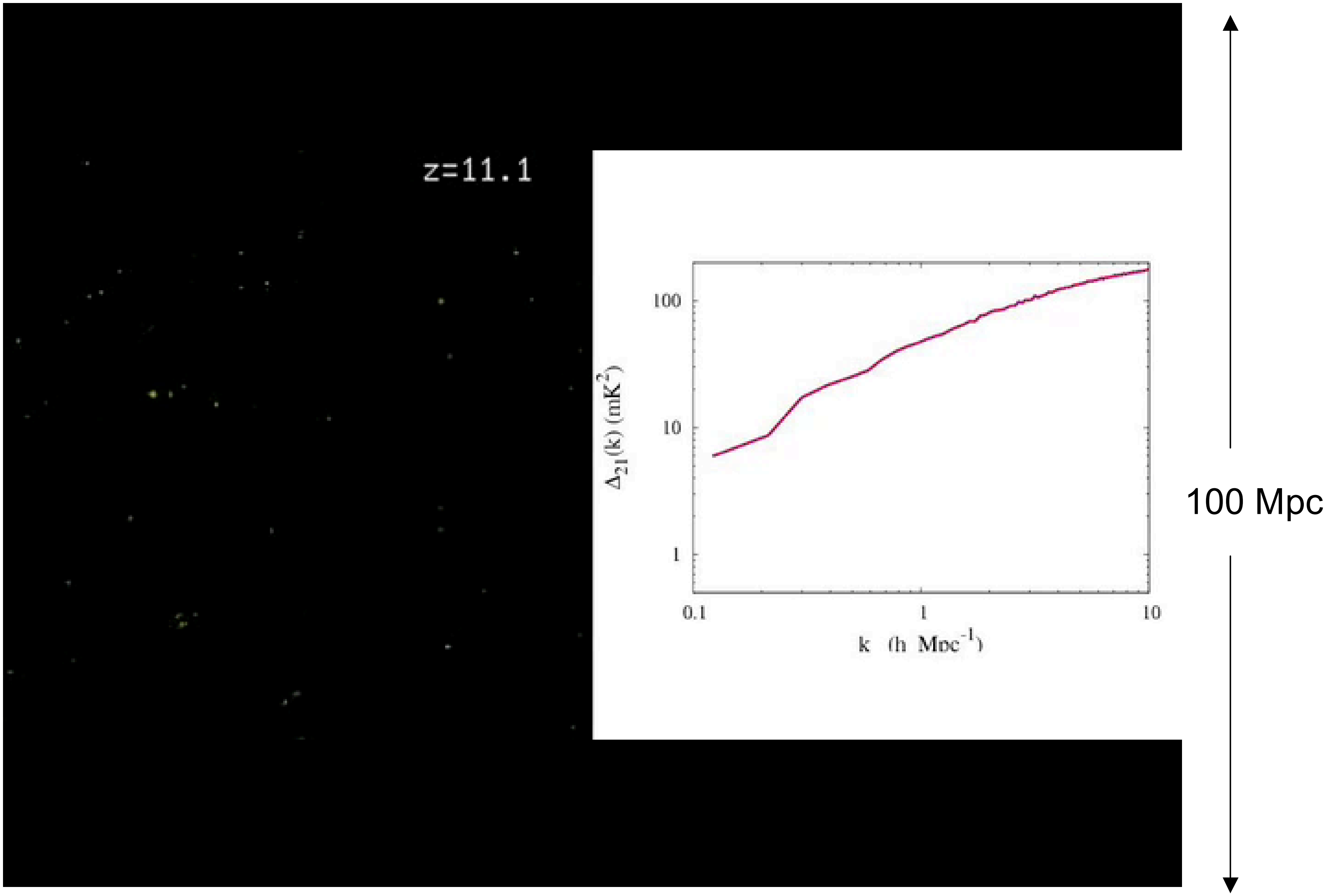
Recap: Qualitative Features

- Reionization is extended process, not event.
- Sources are highly clustered. Ionized bubbles grow around individual sources, quickly overlap and grow collectively as “uber-bubbles”. Large bubbles --> good for 21 cm detection.
- Sources massive, highly clustered --> larger bubbles.
- Abundant sinks --> smaller bubbles.
- Large scale overdense regions ionize first.

Murchison Widefield Array

- 500 antenna tiles
- Each tile is 16 dipole antennas in 4m x 4m grid.
- 80-300 Mhz
- ~ 800 deg^2 field of view
- 32 Mhz instantaneous bandwidth

Bowman et al. (2007)

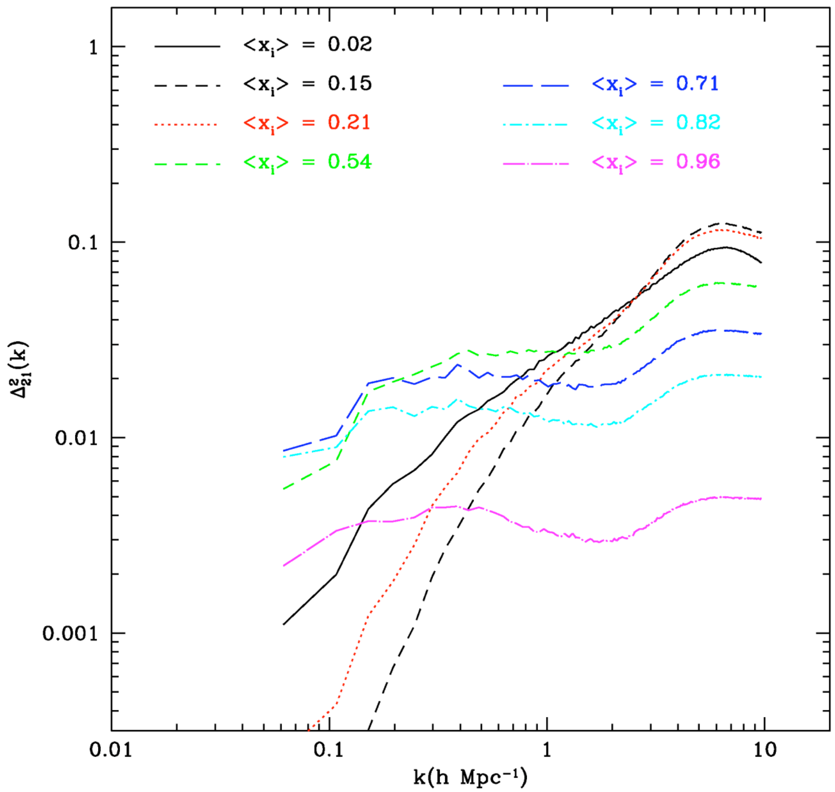


M. McQuinn

100 Mpc ~ 1/2 degree on sky

The 21 cm Power Spectrum

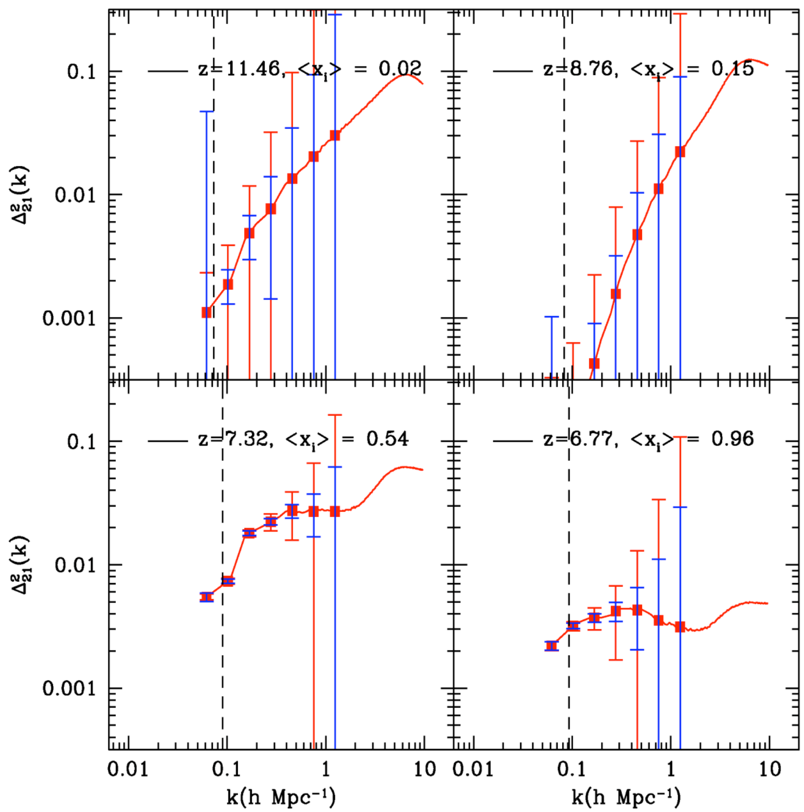
- Presence of large HII regions imprints a `knee' in the 21 cm power spectrum.
- First generation surveys sensitive to k~0.1-1 h/Mpc



Lidz et al. (2007)

MWA Sensitivity

- t_int = 1,000 hrs., B=6 Mhz
- Sensitivity depends on antenna distribution!
- Red: 20 m core with antennas packed, then r^(-2) distribution to 750 m.
- Blue: all antennas packed tightly within 50 meter core.
- MWA can potentially detect very early and very late stages!



Lidz et al. (2007)

Sensitivity to Antenna Distribution

- Sensitivity of arrays is much higher for modes in the frequency direction, than for modes in the transverse direction.

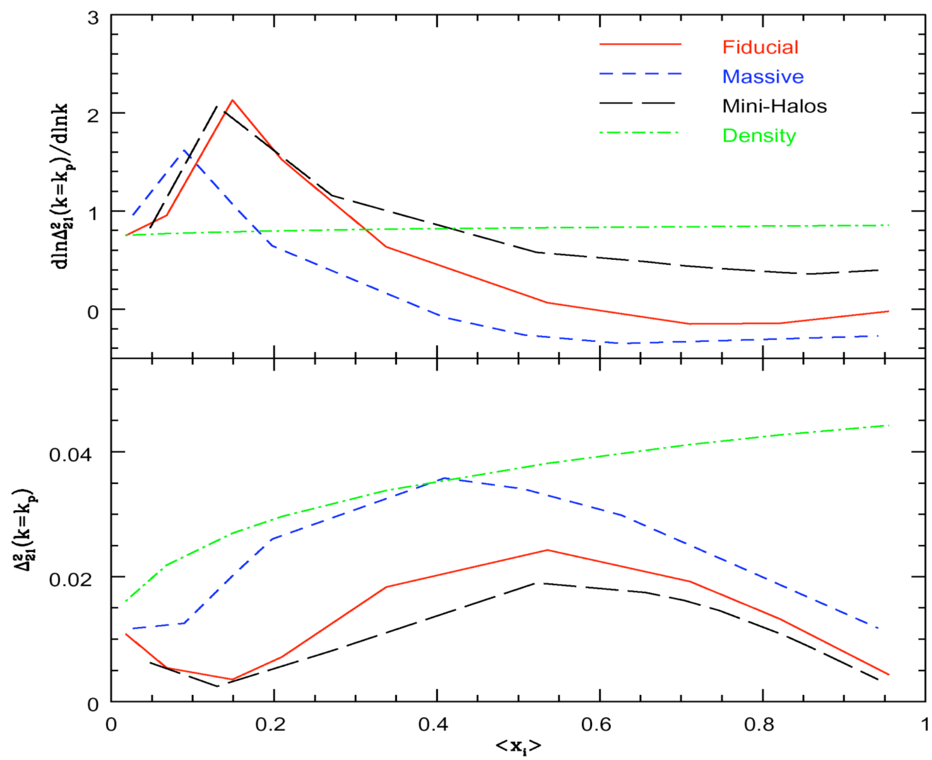
- Any high-k sensitivity comes from modes with low $k_{\perp}$, but high $k_{||}$.

- Generally best to stack antennas as close together as possible to maximize low $k_{\perp}$ sensitivity.

- Some long baselines needed for antenna calib., but simple estimates suggest only ~50.

The Rise and Fall of 21cm Fluctuations

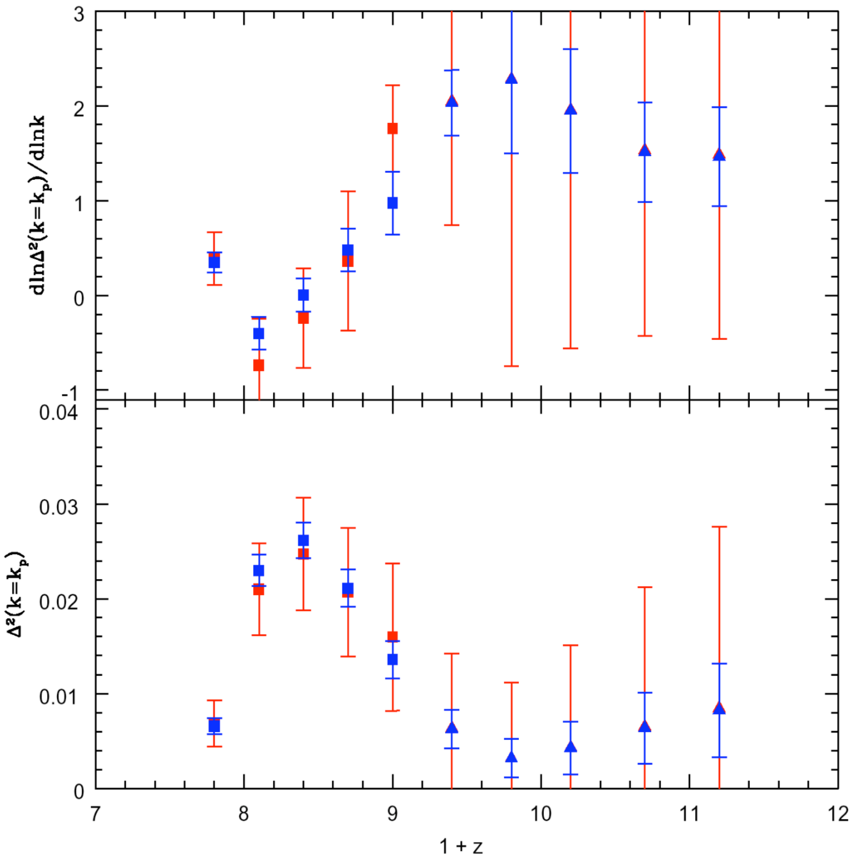
- Amplitude of power in MWA band first increases with ionized fraction, and then decreases.
- Slope flattens with increasing <x> as bubbles grow.
- Details depend on model, but trends are generic.



Lidz et al. (2007)

MWA can measure this

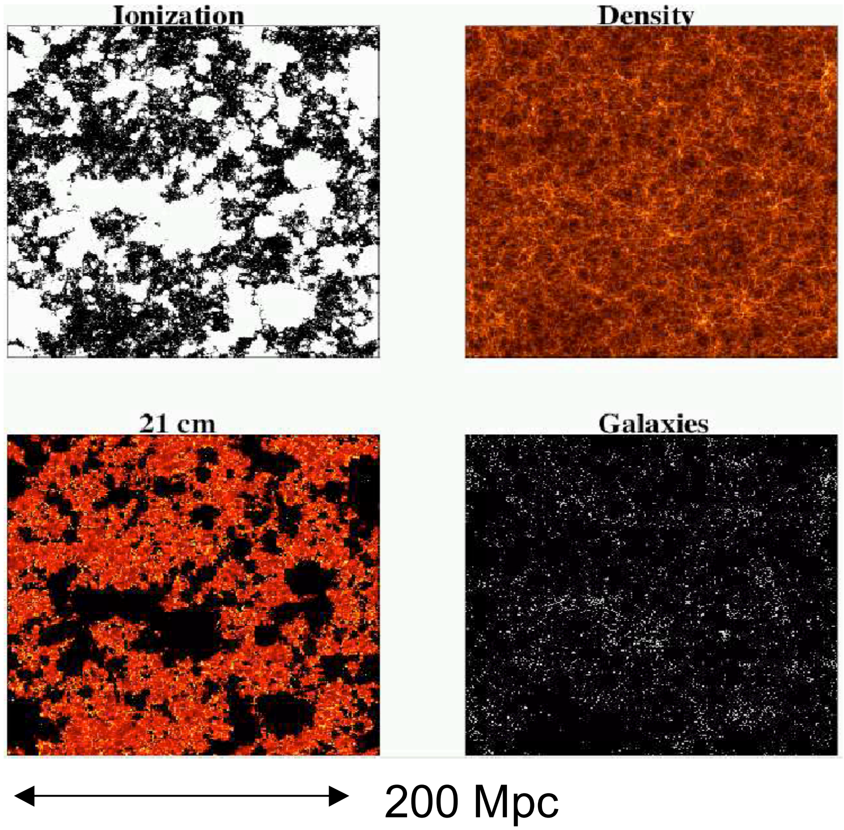
- If slope is relatively flat, implies *a lower limit* on <x>.
- If amplitude goes up and down likely passing through z where <x>~0.5. How fast is the rise and fall?
- No reason residual foregrounds should have this behavior. Good consistency check.
- Antenna configuration is quite important!



Lidz et al. (2007)

21 cm-Galaxy Cross Power Spectrum

- Ionized regions trace galaxies.
- Cross-correlate high redshift 21 cm signal with a high redshift galaxy survey!
- 21 cm and galaxy fields should be anti-correlated.
- Detailed signal depends on properties of first sources.

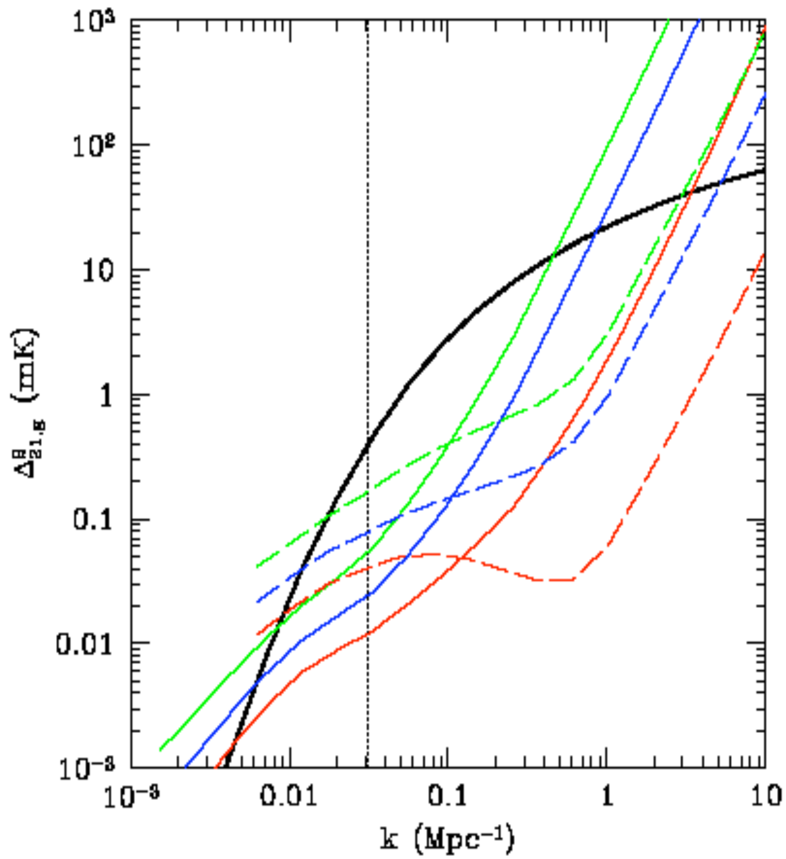


Lidz et al. (2008)
Furlanetto & Lidz (2007)
Wyithe & Loeb (2007)

21 cm - Galaxy Cross Correlation

- Foreground removal requirements much less stringent!!

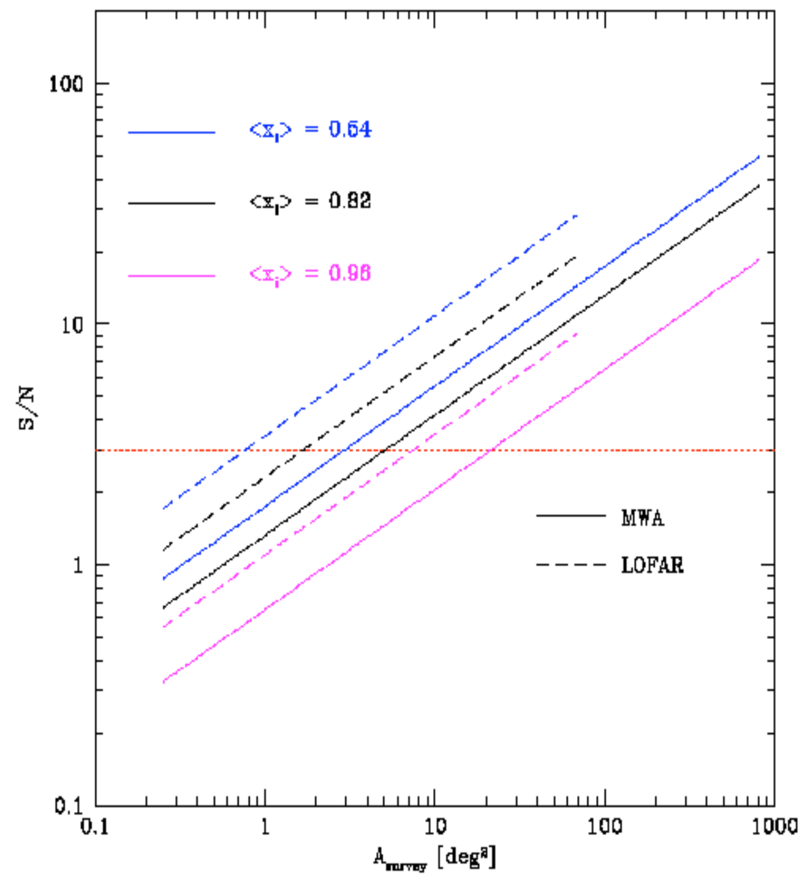
- Most of 21 cm foregrounds come from e.g. galactic synchrotron -- no reason they should correlate with high redshift galaxy survey! Only *signal from high redshift* will correlate.



Furlanetto & Lidz (2006)

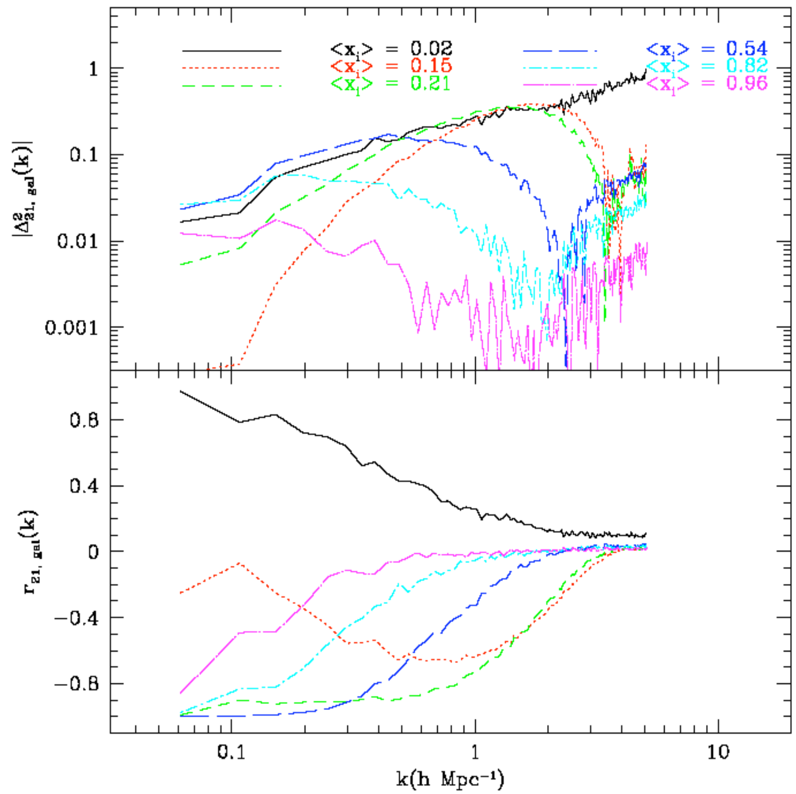
21 cm-Galaxy Cross Detectability

- If IGM is >~20% neutral at z~6.6, cross spectrum detectable with mild extension to Subaru survey.
- LOFAR has more collecting area, but smaller field of view than MWA. Comparable sensitivity for auto spectrum, but better sensitivity for cross spectrum.



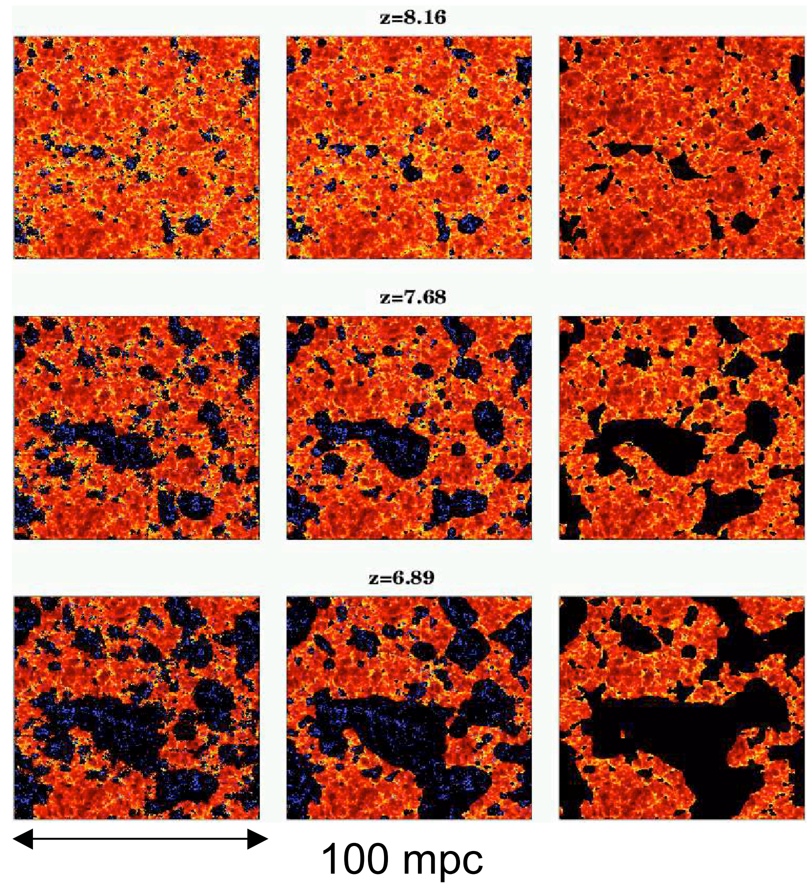
21 cm-Galaxy Cross Signal

- Signal turns over on scales smaller than that of HII regions
- Measuring luminosity dependence tells size of bubbles vs. L.
- To measure details, requires wide-field galaxy survey at z~8!



21 cm signal is non-Gaussian!

- How to best extract info about bubbles when S/N per pixel is very low?
- "Edge" or "Blob"-finding in noisy data set? (Peng Oh)
- Higher order moments?



Zahn,Lidz et al. 2006

Conclusion/Questions

- Redshift evolution of 21 cm power spectrum from first generation experiments will be interesting: <x>, sources.
- Best way to analyze non-Gaussian data set? How much more info than power spectrum for first gen. surveys?
- Diagnostics to help convince us any measured signal comes from the high redshift IGM?
- Smoothly match models to z~5 Ly-a forest, Lyman-limit systems.
- Precise impact of spin temperature fluctuations? Mostly ignored so far in simulations.
- End-to-end simulations of the MWA and other pipelines? Impact on sensitivity estimates?