HI Intensity mapping concept

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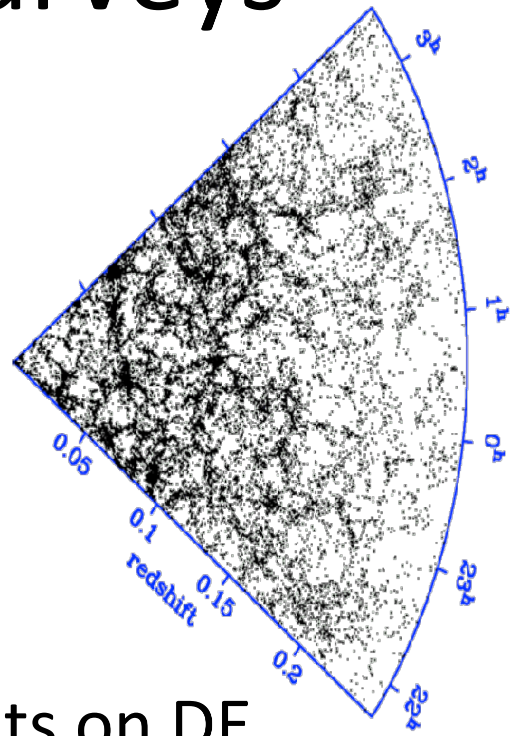
Galaxy Redshift Surveys



<u>Basic idea :</u>

galaxy positions and redshifts
measured in the optical eg. 2DF, SDSS

Density Perturbation =
Number Perturbation → $\Delta = \frac{N - \langle N \rangle}{\langle N \rangle}$

Use P(k) to deduce BAOs and constraints on DE
- also neutrino masses & redshift space distortions

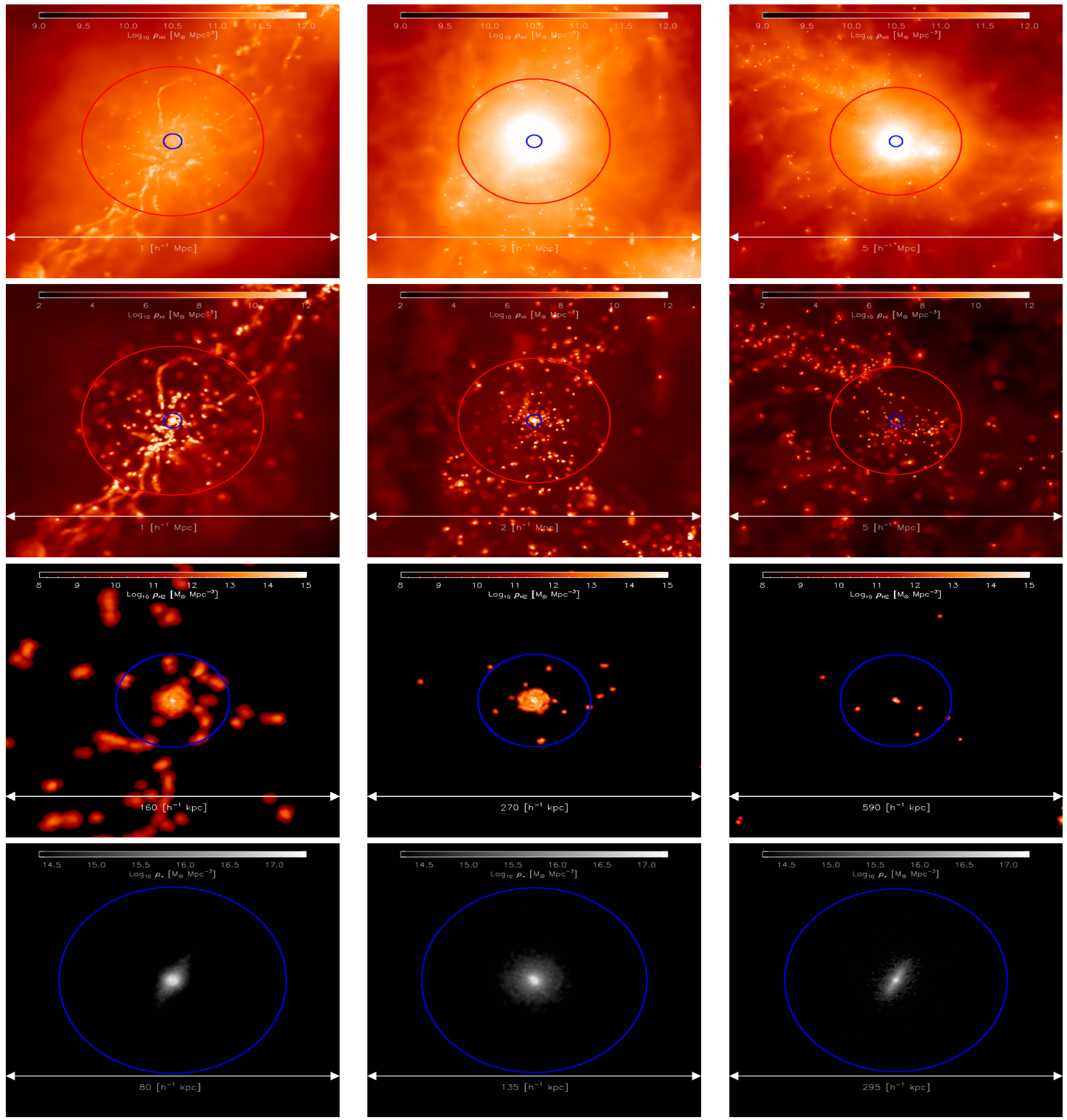
<u>"Inefficient"</u> : detection at 5σ throws away all but a small fraction of the detected photons !

Ionized gas : HII

Neutral gas : HI

Molecular gas : H_2

Stars



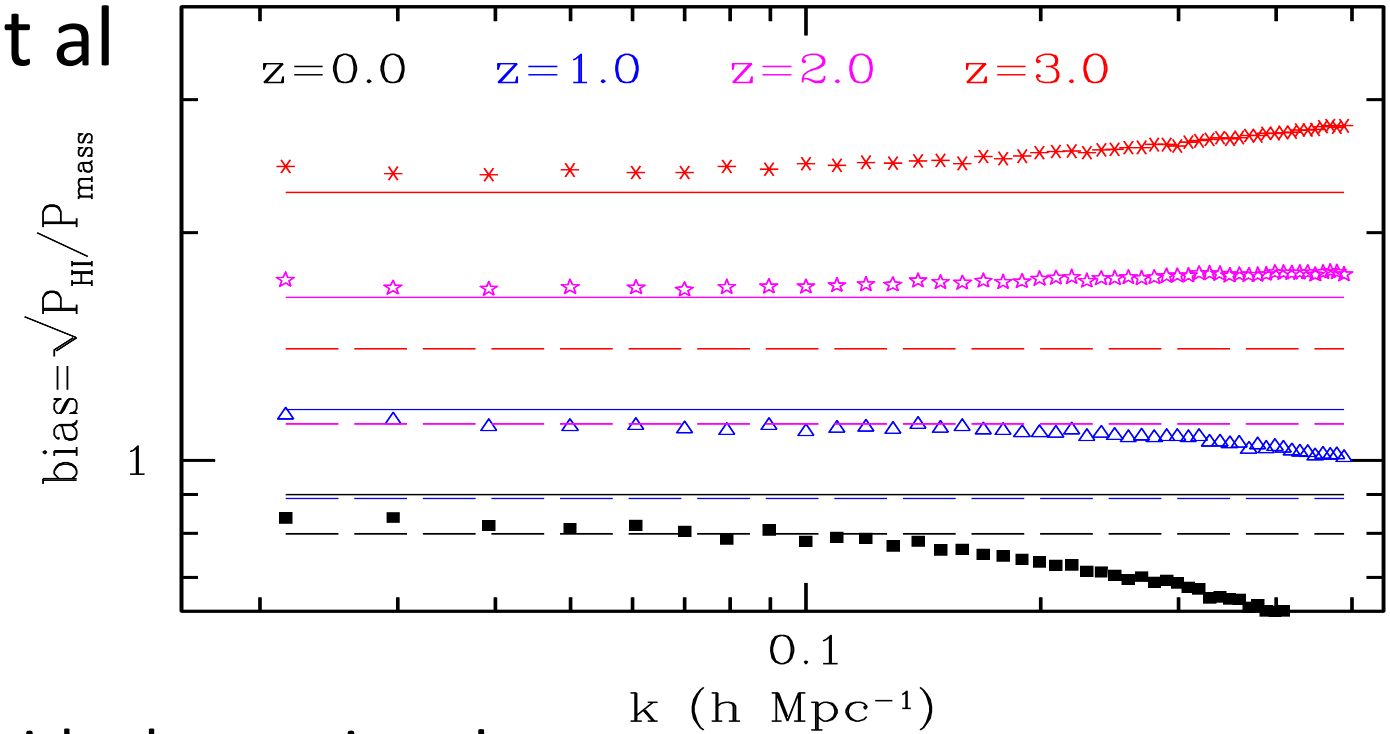
Galaxy Group Cluster

From Duffy, Kay, Battye, Dalla Vechia, Booth, Schaye (2012)

Views of the Universe

Bias

- Scale and redshift depdendent bias - problem
- Bias for HI surveys will be different to optical !
- Marin et al



Compatible with observations !

Galaxy redshift surveys using HI

- Problem : 21cm line is very weak
  - L_* galaxies at z=1 need $1km^2$ to detect in hours
  - Need the SKA Wilkinson, 1991
- Use 21cm line – detection plus redshift automatic
  - 10^9 galaxies out to z = 1.5 with SKA
  - strong constraints on DE Abdalla & Rawlings, 2005
- What has been done so far ?
  - HIPASS 10^4 galaxies; ALFALFA
  - Upcoming MEERKAT, ASKAP, APERTIF, FAST
- Question I asked myself around 10 years ago:
  - what can be done cheaply & quickly before SKA ?

HI surveys with a low resolution at high redshift

(Battye, Davies and Weller, 2004)

- Standard formula of radio astronomy

$$\frac{M_{\mathrm{HI}}}{M_\odot} = \frac{2.35 \times 10^5}{1+z} \left(\frac{d_{\mathrm{L}}(z)}{\mathrm{Mpc}}\right)^2 \left(\frac{S\Delta v}{\mathrm{Jy\,km\,sec^{-1}}}\right)$$

Radio astronomers are usually interested in collecting area – point source flux sensitivity as opposed to brightness temperature sensitivity

- Instrument with 10^4m^2 collecting area – 100m dish!

  - 10^{11} solar masses of HI -> 150μJy
  - can be detected in around an hour

- Clusters contains approx 10^{11} solar masses of HI !

- Problem confusion noise – ie the large-scale HI

HI intensity mapping

- Just deal with the intensity field T(f,θ,φ)
  - don't detect the galaxies
  - use the unresolved background
  - treat like the CMB

Peterson et al (2006)
Pen et al (2008)
Loeb & Wyithe (2008)
Ansari et al (2008)
Chang et al (2010)

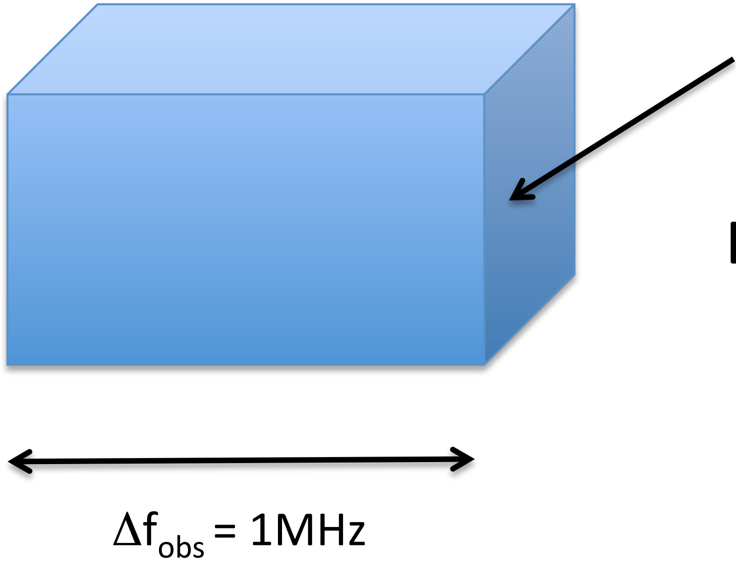
- Average temperature

$$\bar{T} = 44\,\mu\mathrm{K} \left(\frac{\Omega_{\mathrm{HI}}(z)h}{2.45 \times 10^{-4}} \right) \frac{(1+z)^2}{E(z)}$$

Calibrated to local HI density from HIPASS
- Factor 2ish change expected with redshift

Weak redshift/
Frequency dependence

Consider datacube at z=0.5



Equivalent to $(8h^{-1}Mpc)^3$

$\sigma_8 \sim 1$

Average HI mass in side the datacube = $1.2 \times 10^{10}\ M_{sun}$

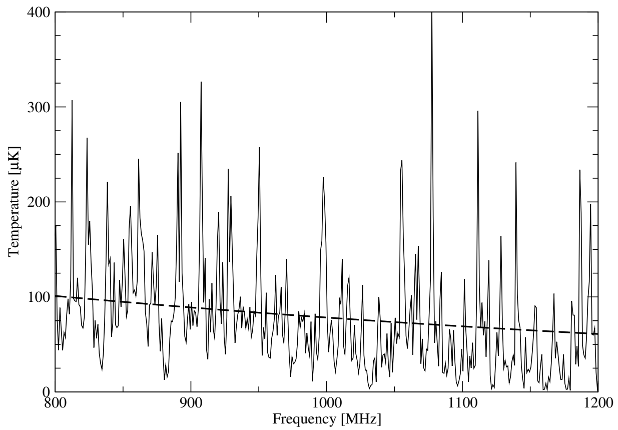
Brightness Temp = approx 100 μK with fluctuations = O(1)

Typical Noise Level on 1MHz is 50mKs$^{1/2}$
-> around 3days to detect 100 μK

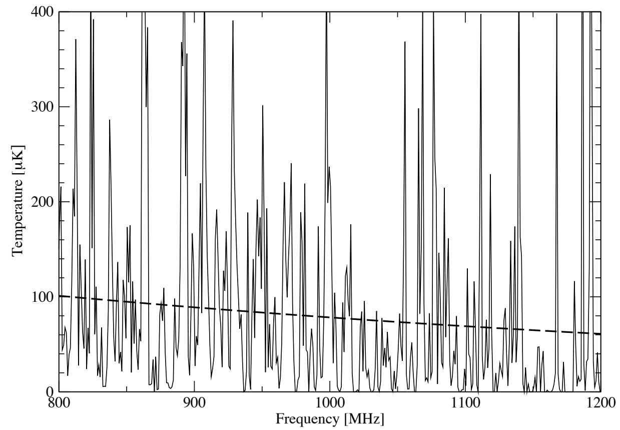
SKA Design Study Simulated Catalogue based on Millennium Simulation (Oberschkow, 2009)

Simulated spectra from S^3

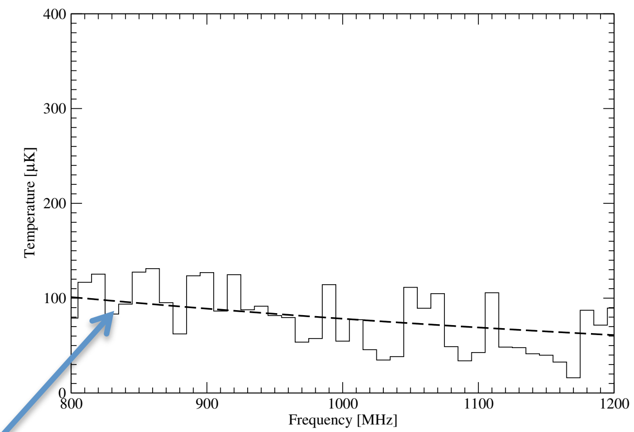
(Battye et al, 2012)



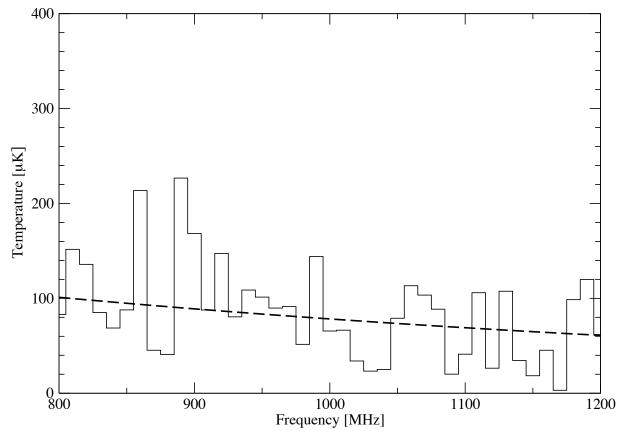
(a) $\Delta f = 1\,\text{MHz}, \theta_{\text{FWHM}} = 60\,\text{arcmin}$



(c) $\Delta f = 1\,\text{MHz}, \theta_{\text{FWHM}} = 20\,\text{arcmin}$



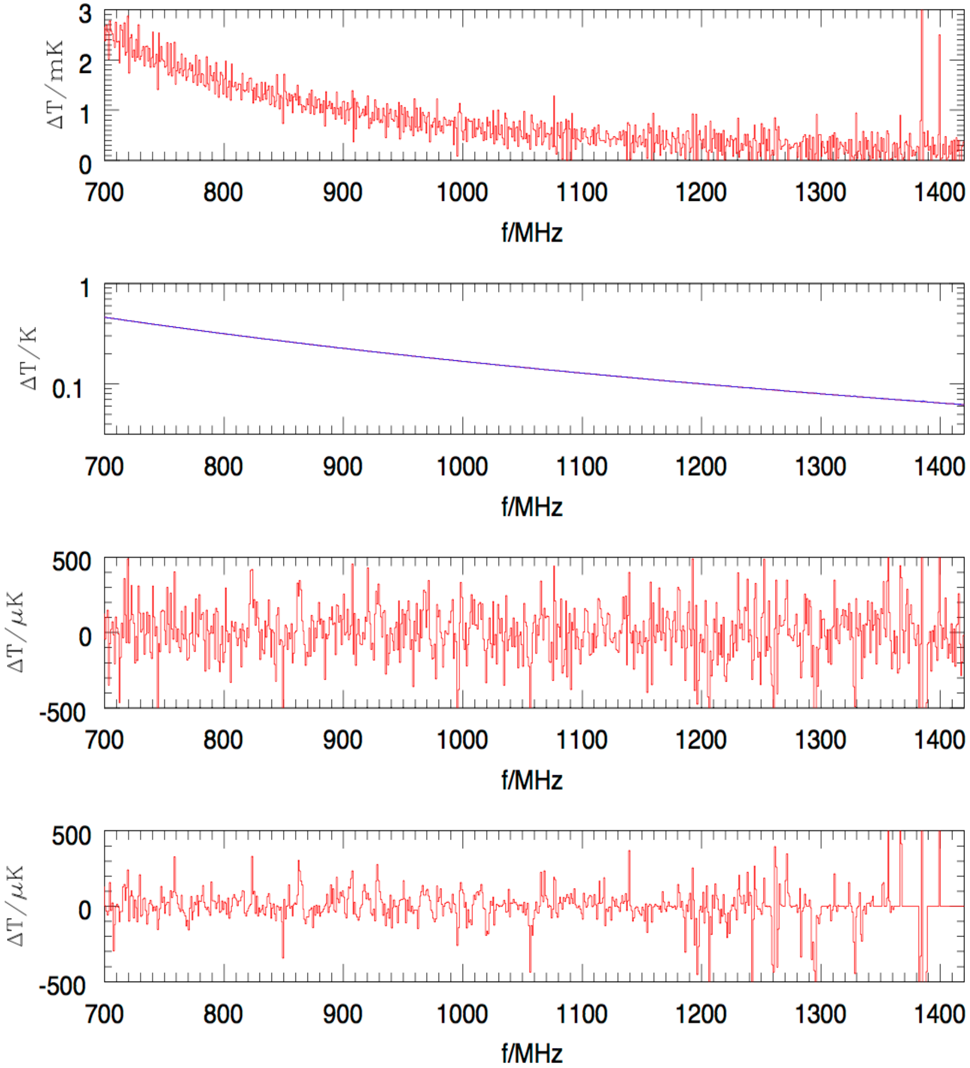
(b) $\Delta f = 10\,\text{MHz}, \theta_{\text{FWHM}} = 60\,\text{arcmin}$



(d) $\Delta f = 10\,\text{MHz}, \theta_{\text{FWHM}} = 20\,\text{arcmin}$

Average spectrum : $\bar{T} = 44\,\mu\text{K}\left(\frac{\Omega_{\text{HI}}(z)h}{2.45\times 10^{-4}}\right)\frac{(1+z)^2}{E(z)}$

Line + continuum signal



Frequency differenced

Total signal + noise

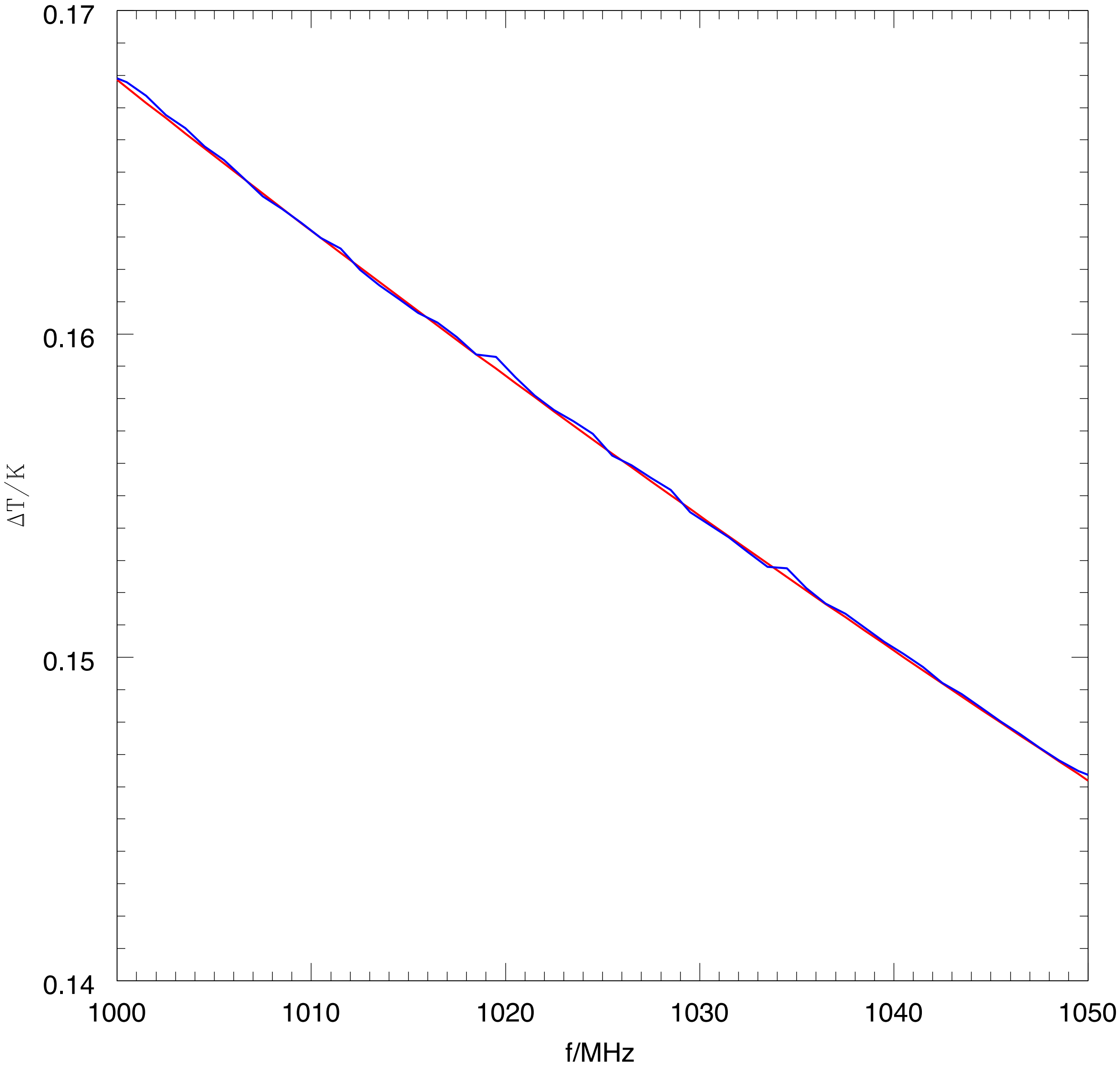
Continuum

Continuum
+ HI + noise

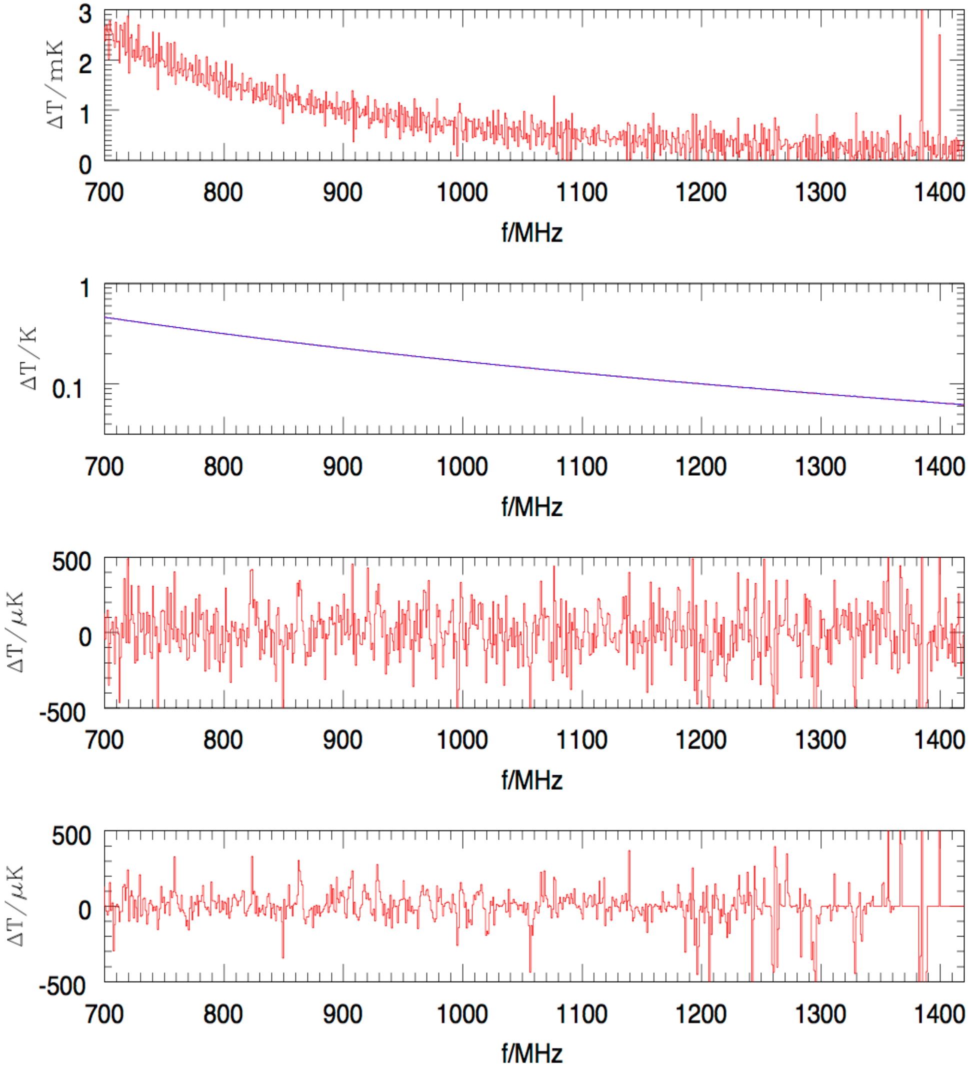
HI signal + noise from 3 days

HI Signal only

Zoom in on continuum



Line + continuum signal



Frequency differenced

Total signal + noise

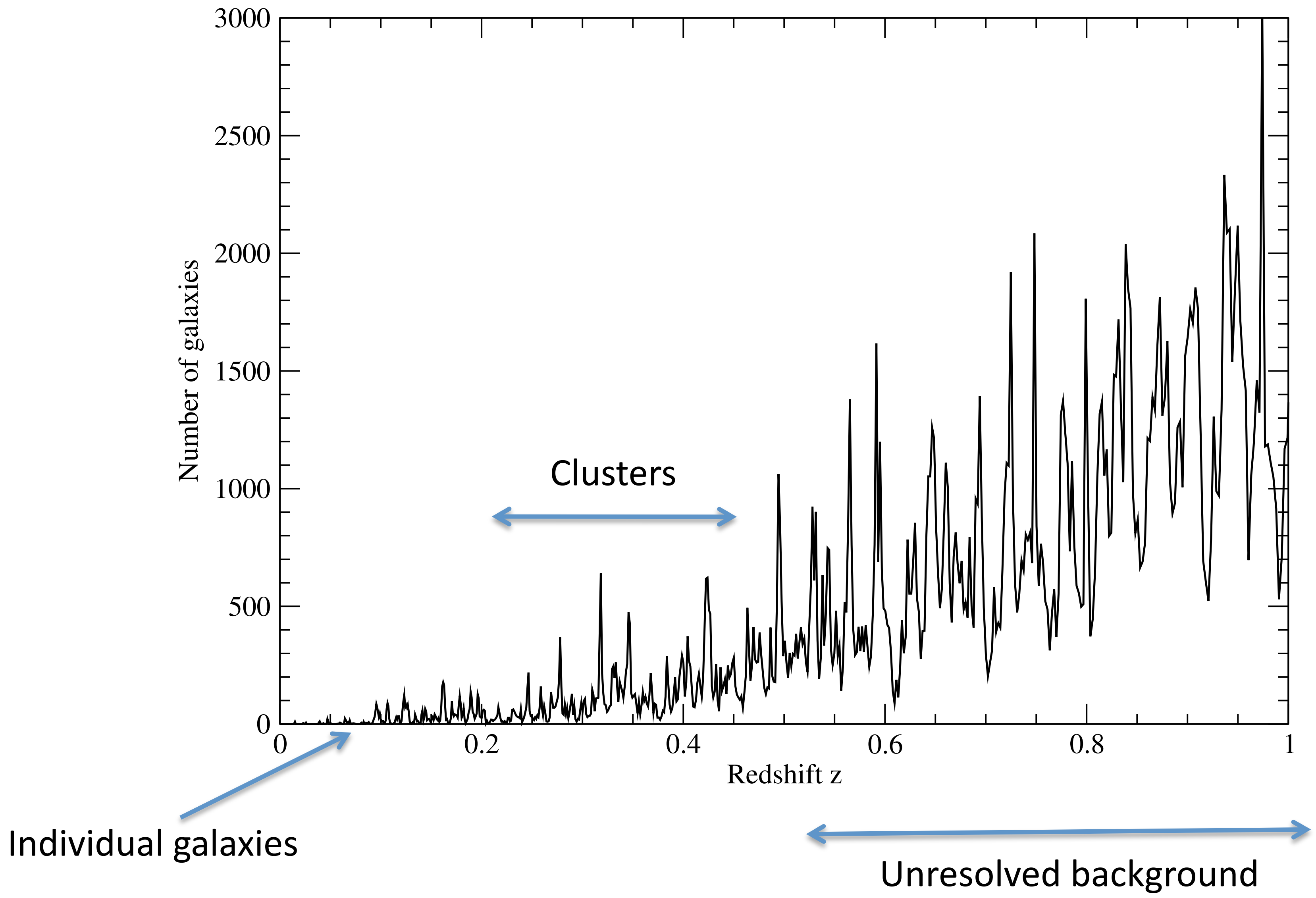
Continuum

Continuum + HI + noise

HI signal + noise from 3 days

HI Signal only

Galaxies – Clusters – "Background"
What makes up the signal ?



Other spectral lines

- Intensity mapping for any line?
- CO

  1-0 transition - 15GHz : z= 6.6   30GHz : z=2.8

  2-1 transition - 30GHz : z= 6.6   ↔ Potential confusion
- CII & Lyα – Peterson @ Moriond Cosmology
- HI is an isolated line

  - Very little opportunity for confusion

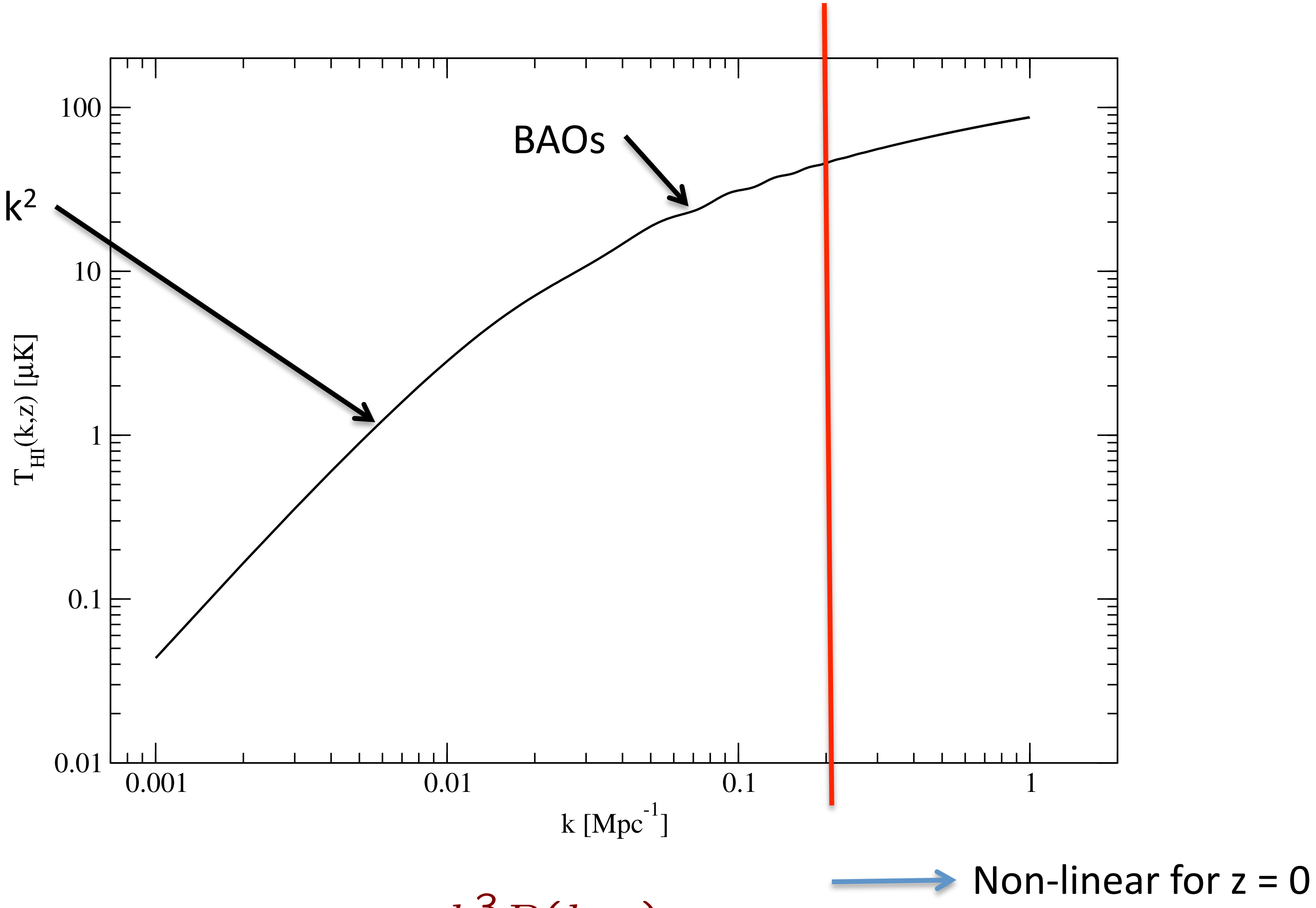
Calculating power spectra

- Ignore absorption, redshift space distortions
- Brightness temp

$$\delta T_{\mathrm{b}} \propto \delta \rho_{\mathrm{HI}}$$

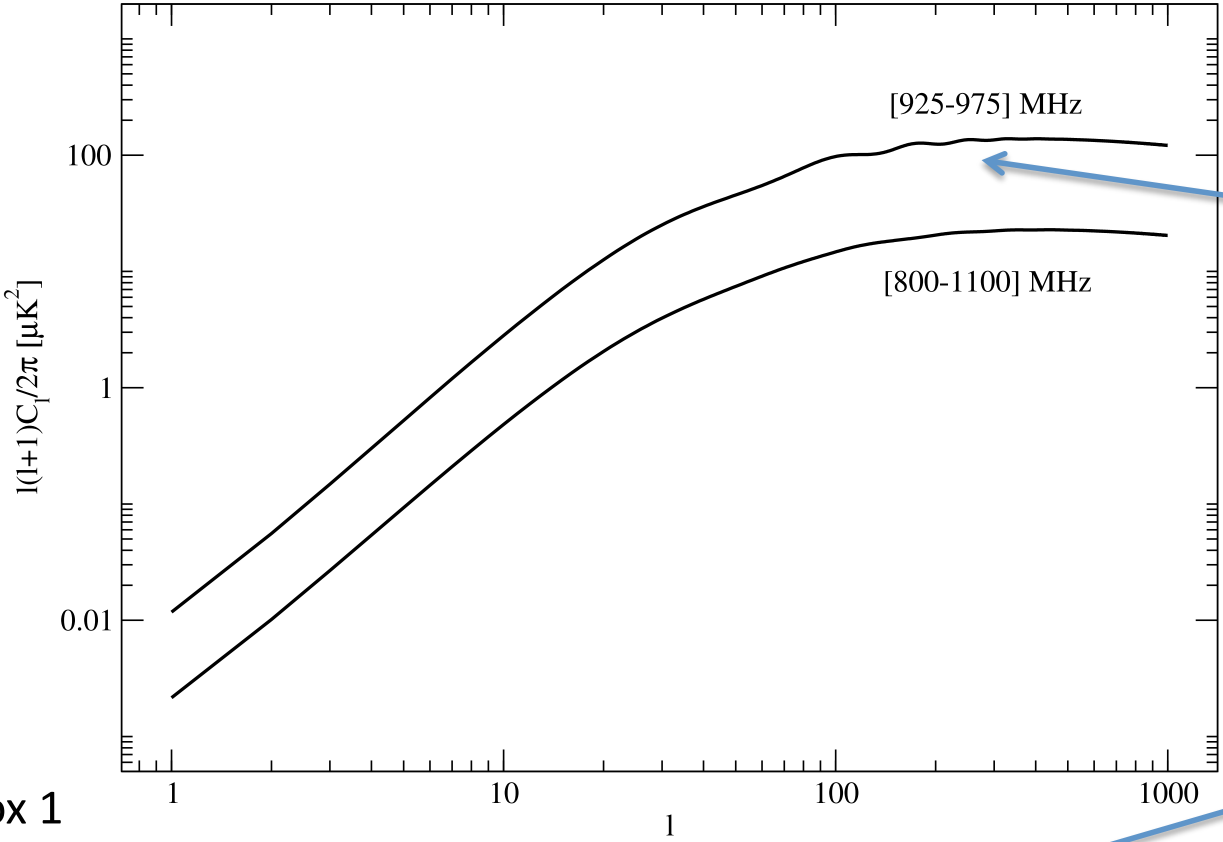
- Power spectra
  - 3D power spectrum
  - 2D power spectrum in Δf = 10 MHz

3D power spectrum



$$[T_{\rm HI}(k,z)]^2 = [\bar{T}(z)]^2 b^2 \frac{k^3 P(k,z)}{2\pi^2}$$

2D angular power spectra



BAOs

Growth function

Bias approx 1

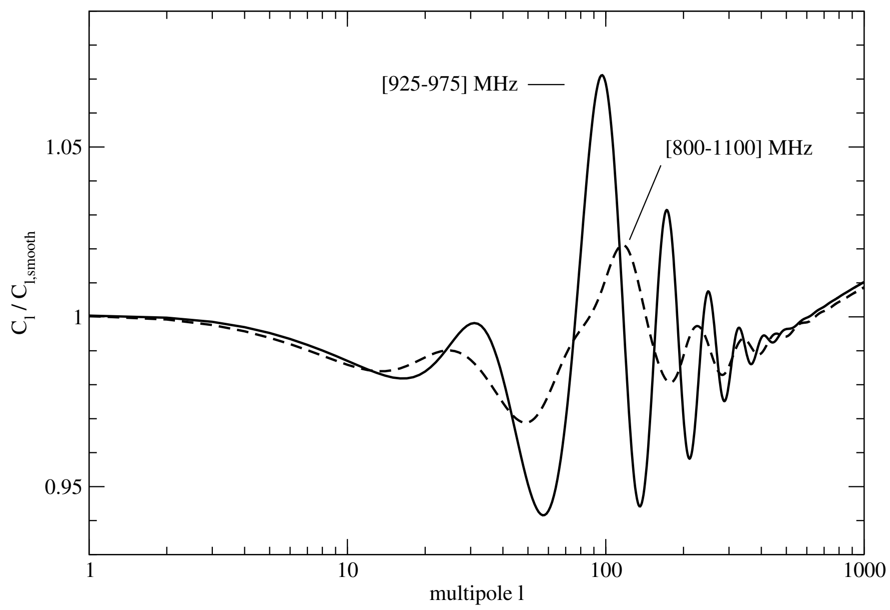
$$C_\ell = \frac{H_0 b^2}{c} \int dz\, E(z) \left[\frac{W(z)\bar{T}(z)D(z)}{r(z)}\right]^2 P_{\mathrm{cdm}}\left(\frac{\ell + 1/2}{r(z)}\right)$$

CDM power spectrum

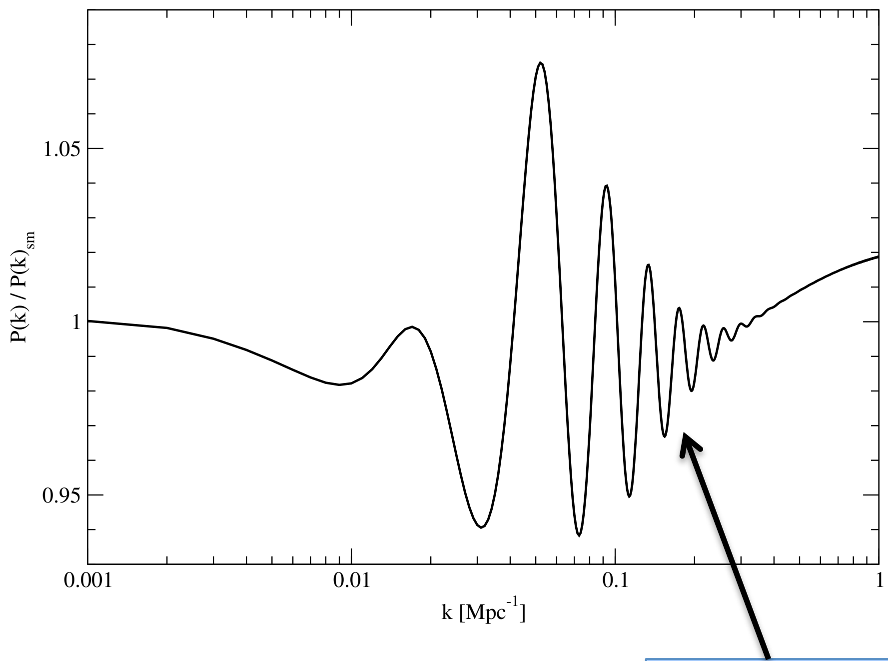
- similar to the cosmic shear power spectrum

BAOs in 2D v 3D spectra

2D angular power spectra



3D power spectra



Not much signal beyond $k = 0.2\ hMpc^{-1}$

50 MHz (equivalent to Δz=0.05) is optimal

Redshift space distortions

- Contribution from radial velocities

$$\frac{\delta T_{\mathrm{b}}}{\bar{T}} \propto \frac{\delta \rho_{\mathrm{HI}}}{\rho_{\mathrm{HI}}} - \frac{\delta v_{\mathrm{r}}}{v_{\mathrm{r}}}$$

- Power spectrum

Dependence on theory of gravity

$$P_{\mathrm{obs}}(k,\mu,z) = \left(b + [\Omega_{\mathrm{m}}(z)]^{\gamma}\mu^2\right)^2 [D(z)]^2 P_{\mathrm{i}}(k)$$

Bias – potentially z and k dependent

Angular dependence - $\cos^2\theta$

- Potentially powerful probe of modified gravity

(Masui, McDonald & Pen, 2010; Talk by Alex Hall)

Conclusions

- Signal r.m.s approx 100 μK for HI
- Adaptable to other spectral lines eg. CO
- Thermal noise relatively easy to achieve
- Many similarities with the CMB
  - Data analysis
  - Foregrounds
- Likely to be systematics/analysis limited
- Many observational initiatives being taken – which you will hear about today !