A Ground-based 21cm BAO survey

(Seo et al. in preparation)

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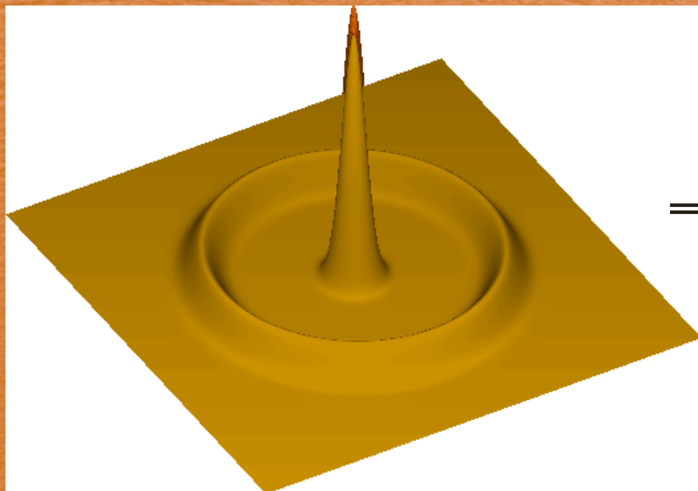
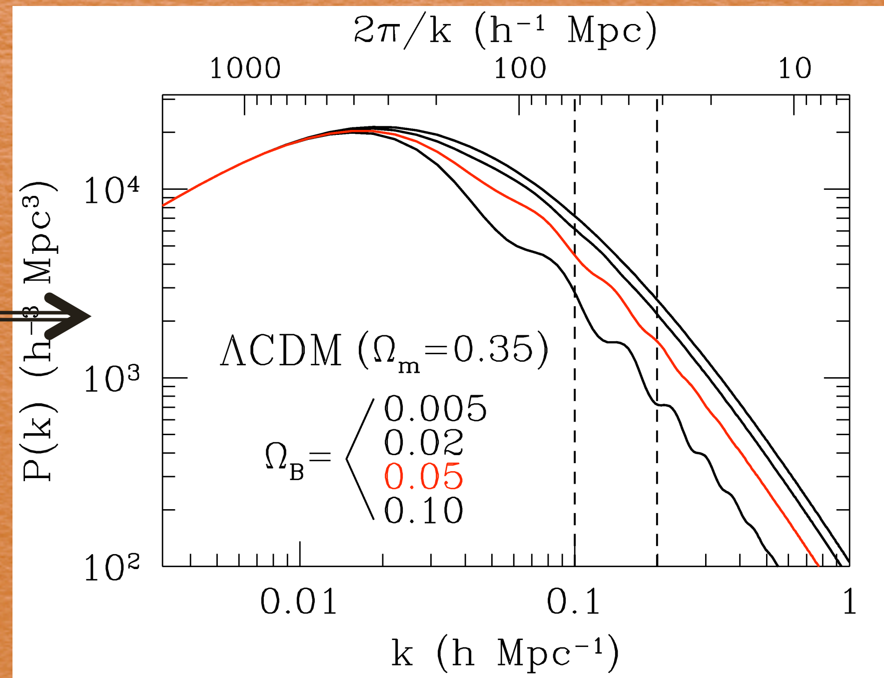
Albert Stebbins,
And other Fermilab 21cm BAO group members.

BAO





1. A robust standard ruler - most systematics free.
2. Mostly considered in optical/IR surveys.

Feasibility for a ground-based 21cm intensity mapping (Chang et al. 2008, Withe et al. 2008)

=> We consider engineering reality and the effect of angular resolution more seriously.

Outlines

1. Signal to Noise on P(k) from a Radio Telescope
2. Effect of an Angular resolution
3. FoM as a function of Telescope configuration
4. Summary

Signal to Noise of P(k)

The total survey volume

Shot noise

$$\frac{S}{N} = \sqrt{\frac{4\pi k^2 dk V_{\rm survey}}{2(2\pi)^3} \frac{P_{\rm HI}}{P_{\rm HI} + \left[\frac{(g\bar{T}_{\rm sky} + \bar{T}_a)}{g\bar{T}_{\rm sig}\sqrt{t_{\rm int}\Delta f}}\right]^2 V_R + \frac{1}{\bar{n}}}}$$

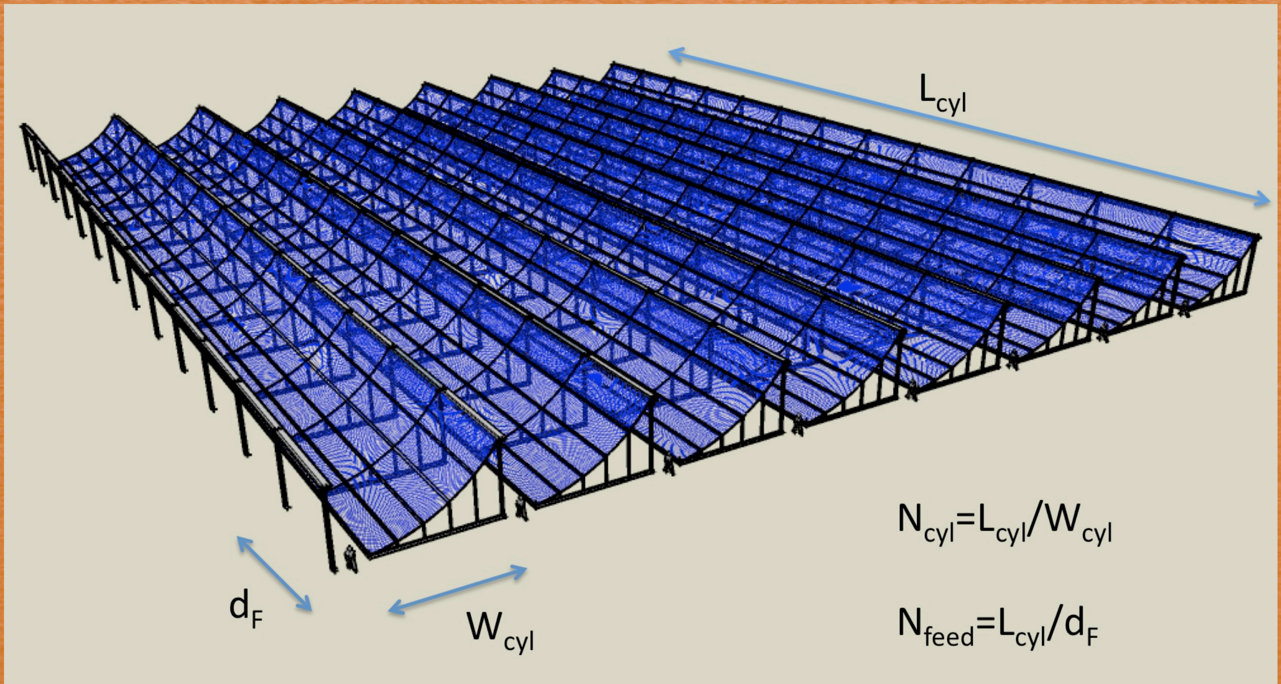
Power due to the large scale structure of HI

dT/T_{sig}

the volume of a pixel

- Assume that a foreground can be subtracted to the accuracy of the statistical errors.
- Shot noise $P_{shot} = 1/n \sim 100\ h^{-3}\ \mathrm{Mpc}^3$ from Albert's calculation.

Fiducial CRT Configuration



Assume a packed rectangular CRT array

$$\Delta\theta = \lambda / L_{cyl}$$

$$A_{survey} = 2\pi \lambda / d_F$$

$$t_{int} = N_{year} D_f \lambda / (2\pi W_{cyl})$$

Fiducial CRT Configuration

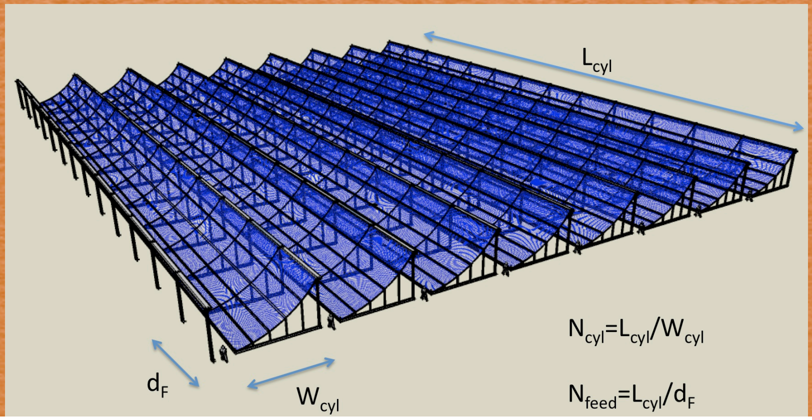
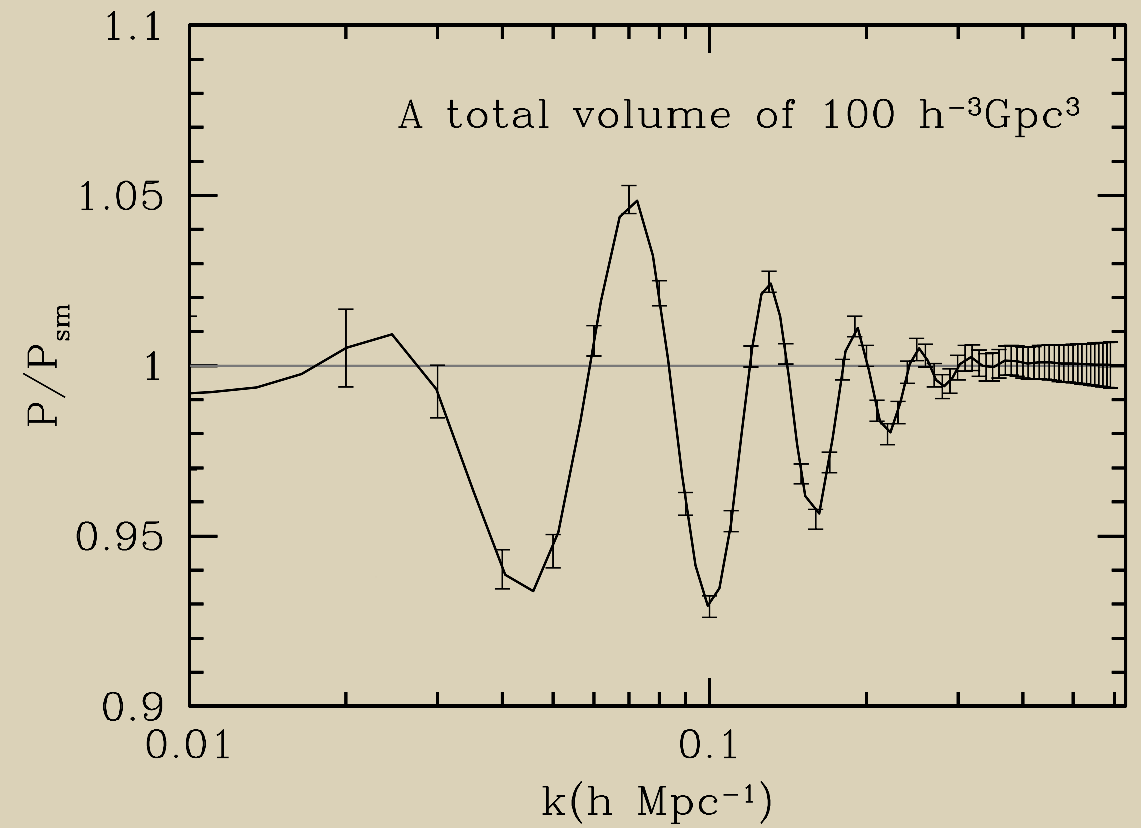


TABLE 1
FIDUCIAL CRT CONFIGURATION.

Parameters	Low redshift $0.66 < z < 1.24$	High redshift $1.22 < z < 2.11$
Length of Cylinder, $L_{\rm cyl}$ (m)	99.8	142.8
Feed spacing, d_F (m)	0.39	0.558
Width of Cylinder, $W_{\rm cyl}$ (m)	14.3	14.3
Duty factor, D_f	0.5	0.5
$N_{\rm year}$ (years)	1.40	0.87
$\Omega_{\rm HI}$	0.0005	0.0005
bias	1.0	1.0
Sky temperature, $\bar{T}_{\rm sky}$ (K)	10	10
Antenna temperature, $\bar{T}_a$ (K)	50	50
gain, g	0.8	0.8
$P_{\rm shot}$	100.0	100.0

Fiducial CRT Configuration



Fisher matrix calculations

1. Use Seo & Eisenstein 2007 method.
2. Reconstruction (Eisenstein et al. 2007) only for $P_{HI} / (P_N + P_{shot}) > 2$.
3. In addition to the redshift dependent nonlinear degradation on BAO, we apply

$$k_{max} = k_{nyq} - 0.06\ h^{-1}\ \mathrm{Mpc}$$

to approximately account for the effect of Nyquist frequency and aliasing effect due to an angular resolution.

Effect of an angular resolution

1. Increases the noise per pixel through V_R.

$$\frac{S}{N} = \sqrt{\frac{4\pi k^2 dk V_{\rm survey}}{2(2\pi)^3}} \frac{P_{\rm HI}}{P_{\rm HI} + \left[\frac{(g\bar{T}_{\rm sky} + \bar{T}_a)}{g\bar{T}_{\rm sig}\sqrt{t_{\rm int}\Delta f}}\right]^2 V_R + \frac{1}{\bar{n}}}$$

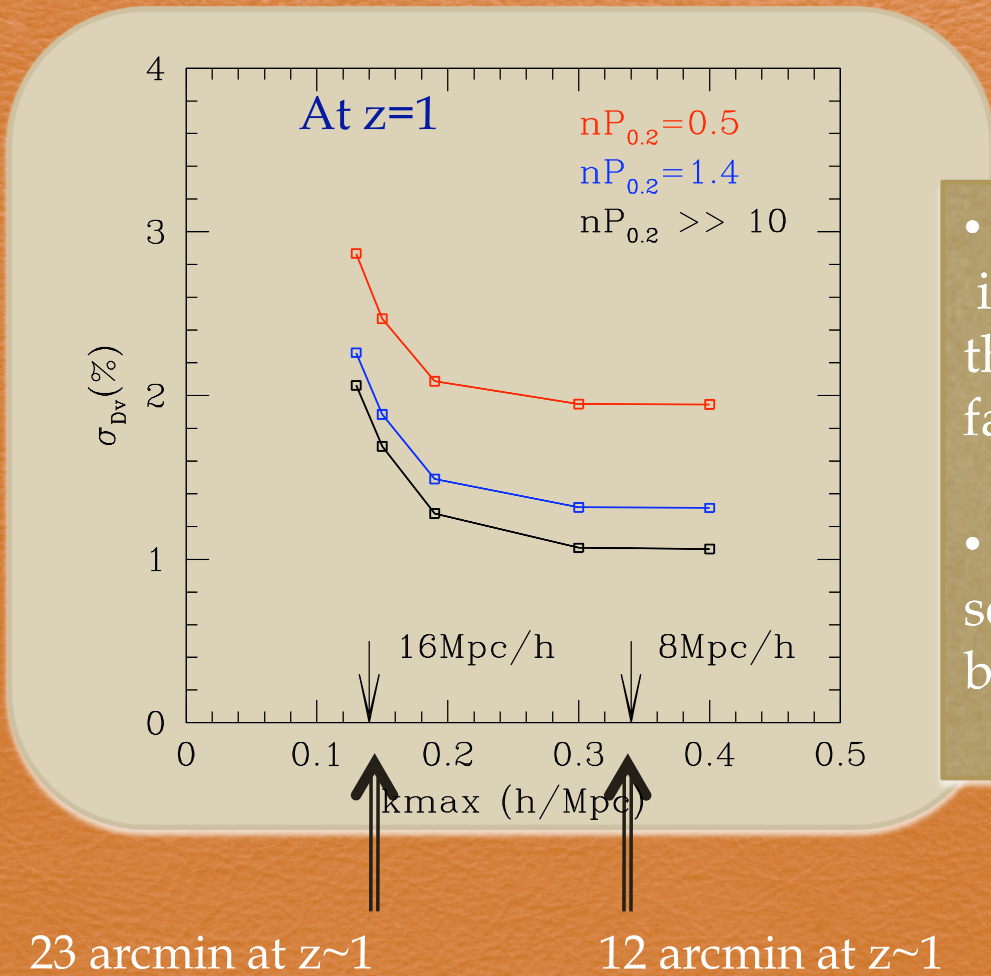
Effect of an angular resolution

1. Increases the noise per pixel through $V_{R.}$
2. In fact, the signal to noise decreases beyond this due to the Nyquist frequency limit.

k=0.3-0.5 h Mpc^{-1} --- BAO negligible.
But $k < 0.3$ h Mpc^{-1} --- BAO partially survive.

Especially, when considering reconstruction, we want the scales that can be reached by reconstruction to lie beyond Nyquist frequency.

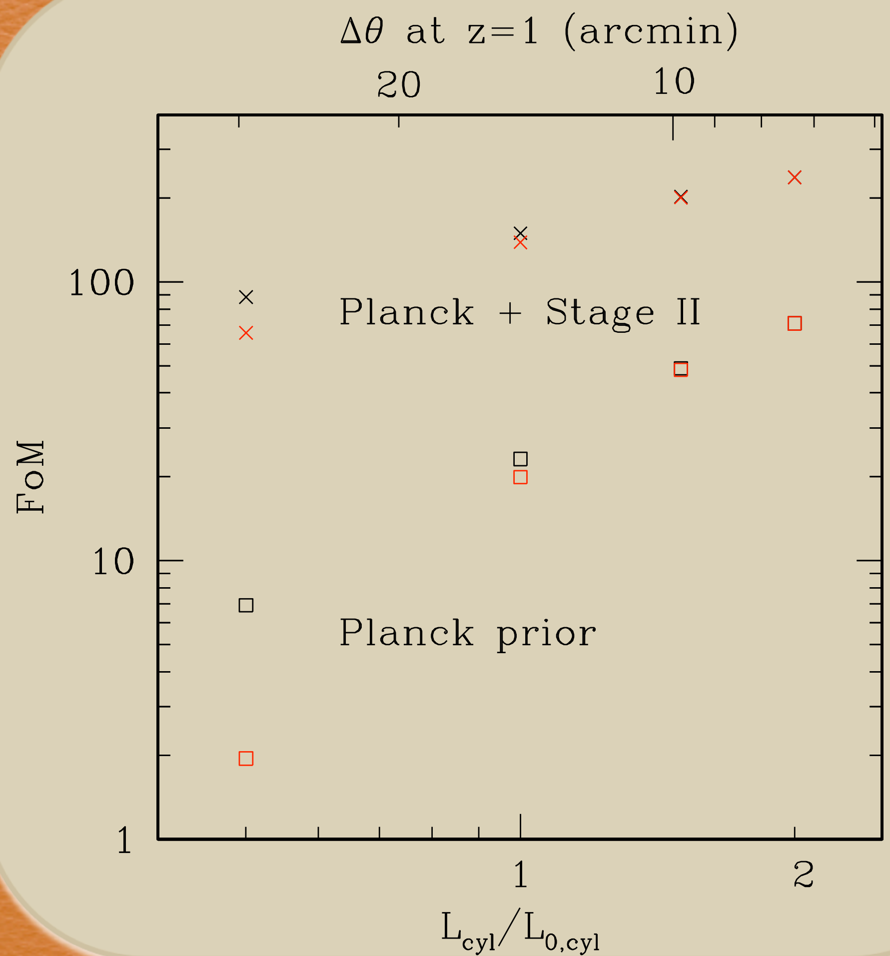
Effect of an angular resolution



- $k_{max=}k_{nyq}$ – 0.06 h^{-1} Mpc increases the errors on the acoustic scale up to a factor of 2.

- The effect will be more severe at high redshift bins.

Effect of an angular resolution



- The effect is less severe in FoM as DETF FoM strongly weights low redshift information where we have a good angular resolution.

Effect of an angular resolution

1. Increases the noise per pixel through $V_{R.}$
2. In fact, the signal to noise decreases beyond this due to the Nyquist frequency limit.
3. A poor angular resolution, i.e., a short range of the wavenumbers makes the correct estimation of the broadband shape very difficult. This can bias the acoustic scale as well as increasing errors of the BAO measurement.

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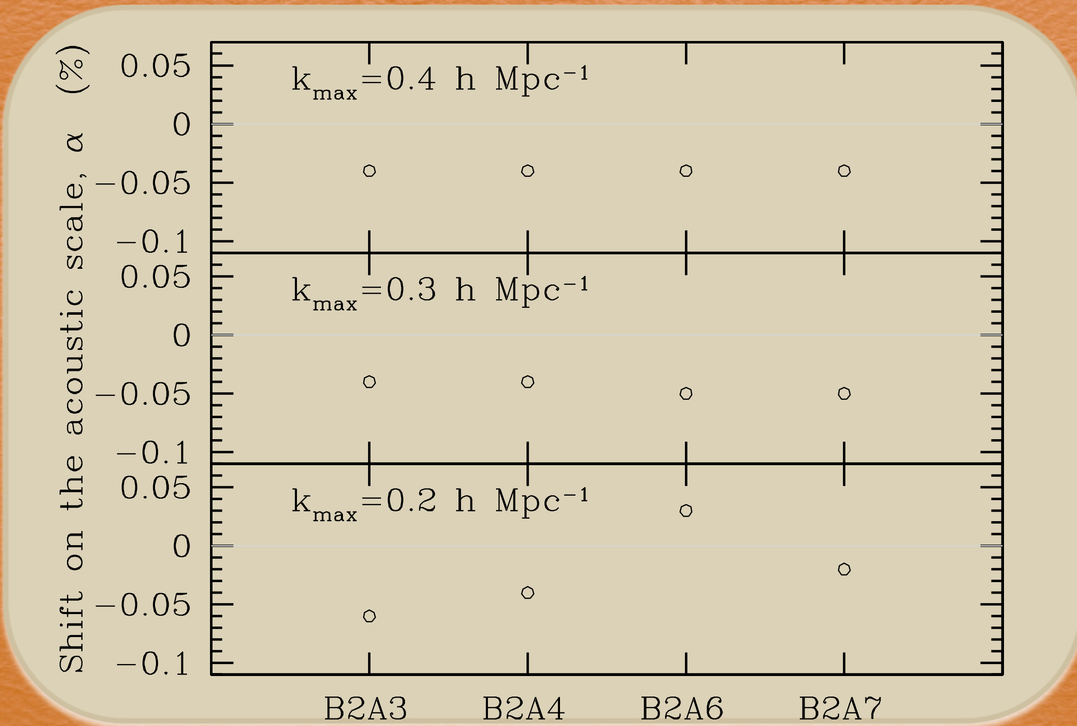
4. Aliasing of a structure on scales smaller than the Nyquist frequency onto a larger scale – any BAO that partially survived in the sub-Nyquist scales may mix up in off-phase and introduce a bias on the acoustic scale.

Effect of an angular resolution

Monte Carlo simulations of density field at z=1.

- $488h^{-3}Gpc^3$ of random Gaussian density field.
- BAO smoothed according to the expected nonlinear degradation at z=1 in real space.
- Account for the angular resolution effect by rebinning the density fields using a different size of mesh - 4, 8, and 16 h^{-1} Mpc -> FFT -> P(k)
- χ^2 analysis + Jackknife resampling to meaure the mean of the acoustic scale and the associated errors (Seo et al. 2008).

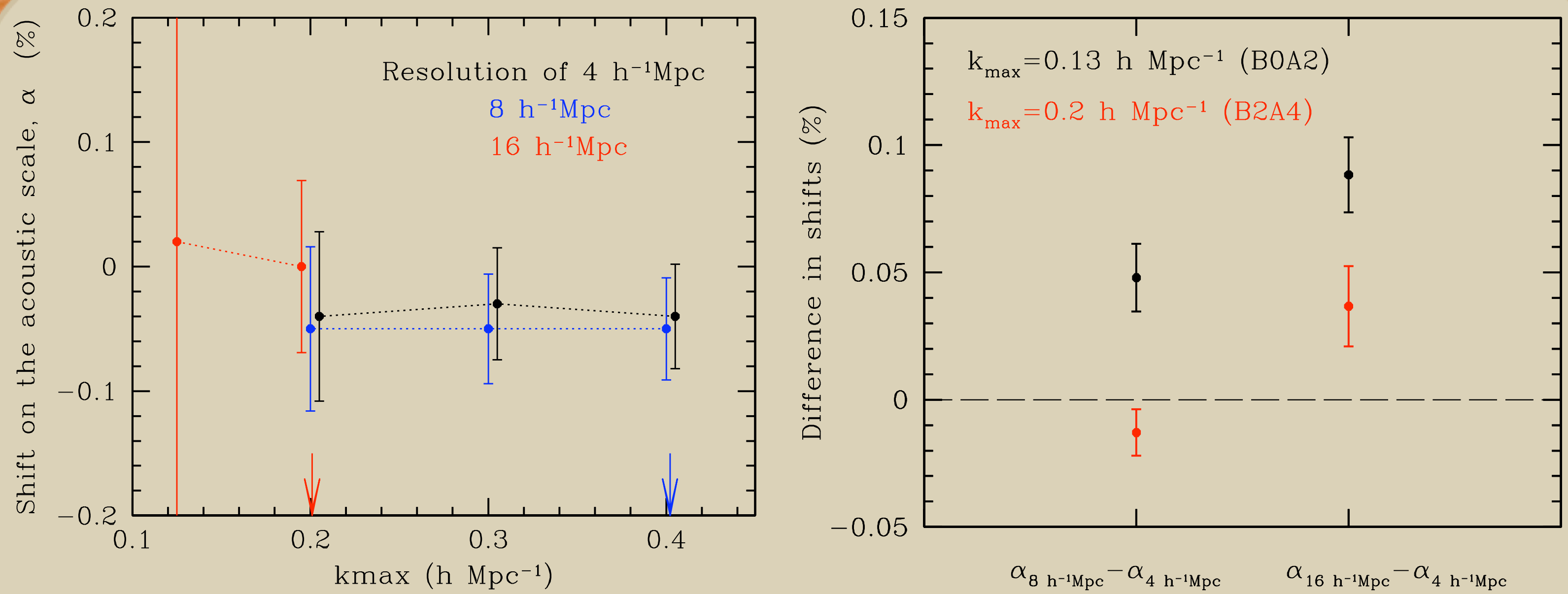
Effect of an angular resolution



1 realization of $4\ h^{-1}$ Mpc resolution

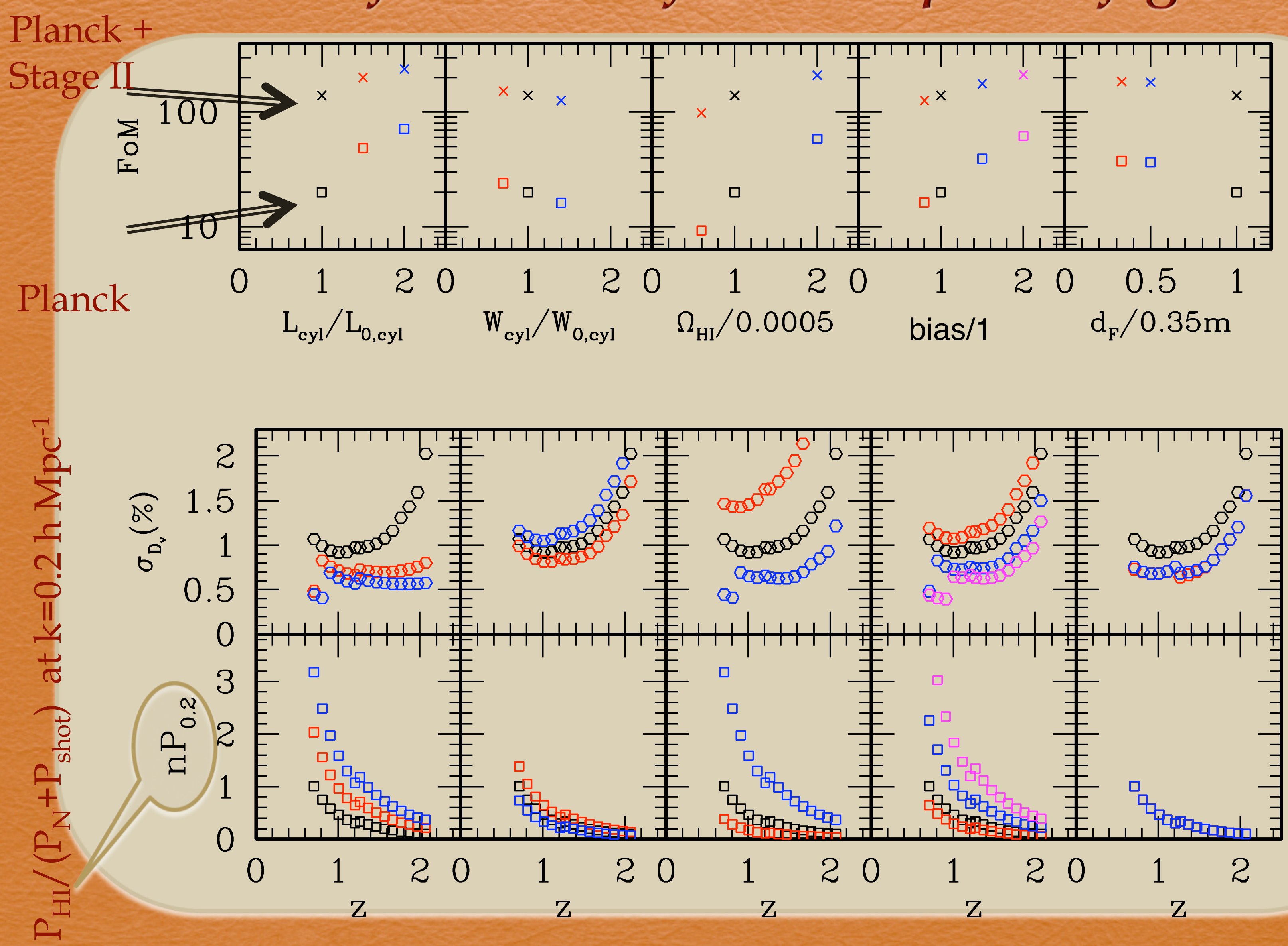
1. A short range of wavenumbers due to a poor angular resolution makes a robust standard ruler test difficult.

Effect of an angular resolution



1. Increase in errors with decreasing k_{max} below 0.3.
2. Shift in the acoustic scale for low angular resolution – due to an aliasing effect or due to instability of the fit.

FoM as a function of Telescope configration



Summary

1. We tested the feasibility of measuring BAO using a ground-based CRT with an emphasis on the engineering reality and the angular resolution effect.
2. Angular resolution effect is more than the effect on Fisher matrix estimates. -> We probably want it to be smaller than we previously have thought.
3. We investigated the performance of a telescope as a function of various telescope configuration.