Baryon acoustic oscillations and Galaxy bias

Hee-Jong Seo
BCCP, UC Berkeley

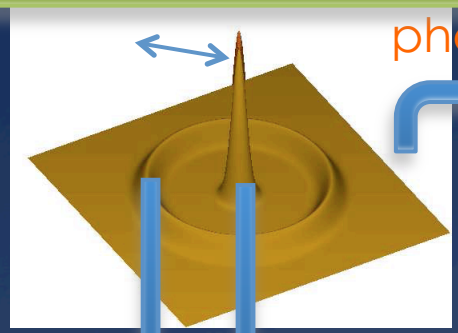
BERKELEY CENTER *for* COSMOLOGICAL PHYSICS

"Galaxy bias and its Effects on the BAO measurements"
K. Mehta, H-JS, J. Eckel, D. Eisenstein et al. Submitted to ApJ

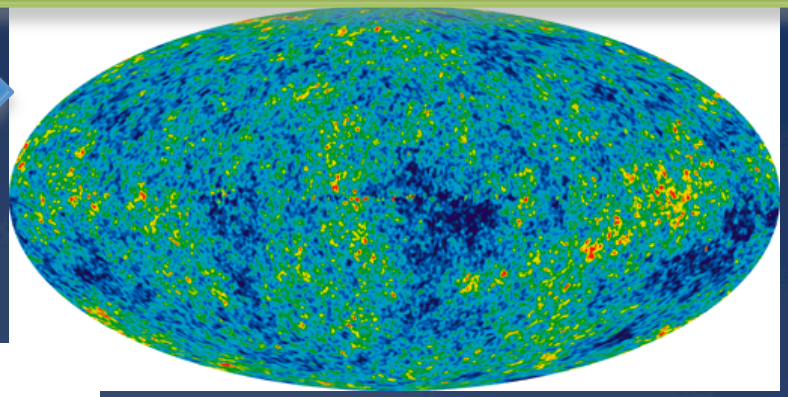
Essential Cosmology for the Next Generation Jan 10-14, 2011

Baryon Acoustic Oscillations

A spherical peak at the distance that the wave has travelled before the recombination
→ **the sound horizon scale** at recombination (150 Mpc).

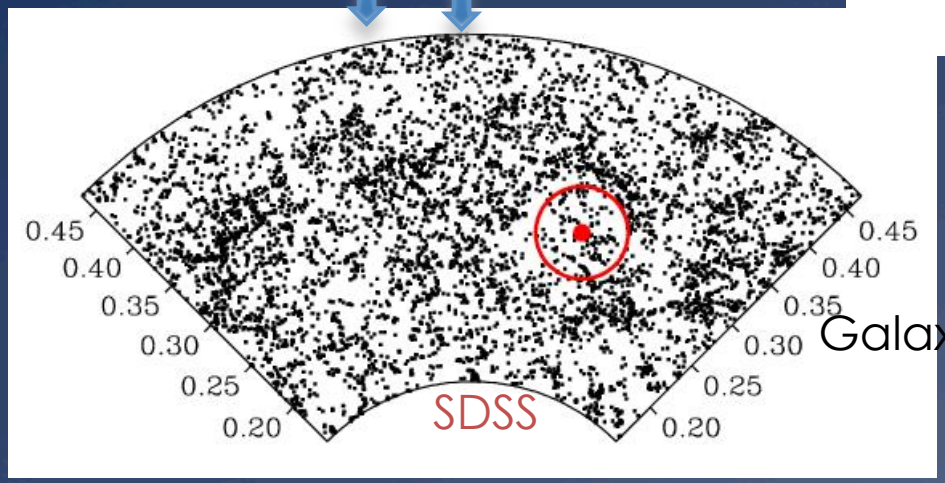


photons



WMAP 7yr
Larson 2010

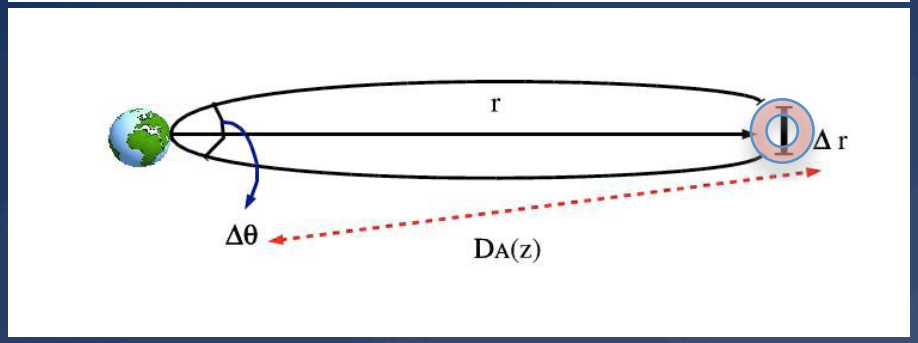
Baryons
+DM



Galaxy surveys, 21cm surveys

Standard ruler test

$$\Delta r_{\parallel} = \frac{c\Delta z}{H}$$



$$\Delta r_{\perp} = (1+z) D_A \Delta\theta$$

$$D_A = \frac{1}{1+z} \int \frac{c dz}{H(z)}$$

Knowing Δr → D_A and H separately measured: **Standard ruler test**

$$\frac{dH}{dz}, \frac{d^2 D_A}{dz^2}$$

→ Dark Energy density as a function of redshift → w_0 and w_a

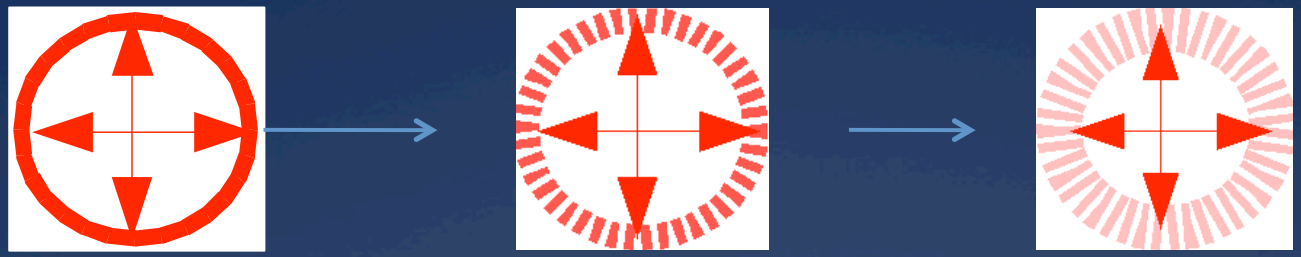
Systematic effects?

* Nonlinear structure growth (eg. Meiksin et al. 1999, SE 2005, Crocce & Scoccimarro 2008, etc)
* Redshift distortions (Shun's talk)
* Galaxy bias – We observe biased tracers rather than the mass distribution. Does this affect the BAO feature?

Nontrivial to include the effects of observing galaxies as mass tracers.

Systematic effects?

Broadening the BAO peak in correlation function/
Damping of the BAO in P(k)

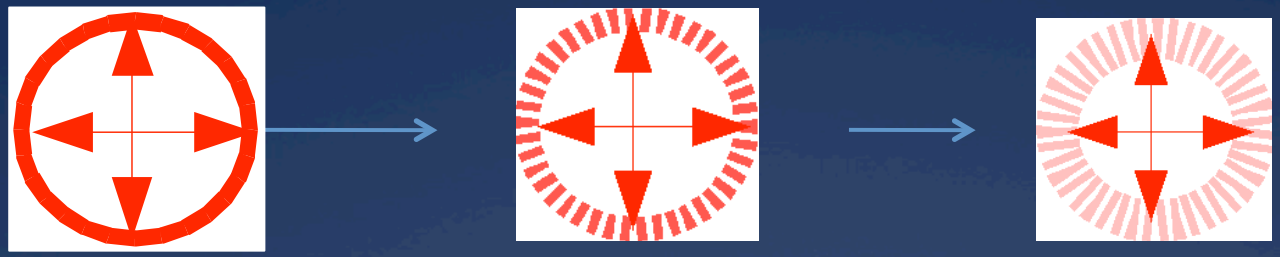


Broadened peak -> Harder to centroid the peak location
-> Bigger error in the standard ruler test ! -> reduces precision

Naively, precision of the standard ruler test will decrease with decreasing redshift.

Systematic effects?

Shift of the BAO peak (off-phase wiggles in mode-coupling term)



Shrinking ruler !
→Biased measurement of dark energy parameters (e.g., Smith et al. 2008, Crocce & Scoccimarro 2008. Padmanahan & White 2009) -> reduces accuracy.

Reconstruction

- Recover the shift and the erased portion of the BAO by undoing displacements during the structure evolution and redshift distortions (Eisenstein, H-JS, Sirko, & Spergel 2007)
- The displacement field is estimated from the observed nonlinear density field by the linear continuity eq.

$$\nabla \cdot \vec{q} = -\frac{\delta_{\rm obs}}{b}$$

$$\vec{q}_z^{\,\rm red} = \frac{1+f}{1+\beta}\vec{q}_z$$

$$\vec{q}_{x,y}^{\,\rm red} = \vec{q}_{x,y}$$

Systematic effects?

* Galaxy bias – We observe biased tracers rather than the mass distribution.

  Does this affect the BAO feature?

Analytic works that estimate the effect of the galaxy bias – Matsubara 2008, Padmanabhan & White 2009.

But we need to measure this effect precisely with N-body sims.

* eg. SE2005, Huff et al. 2007, Angulo 2008, Sanchez 2008

- but previous studies suffer sample variance (1~3 (Gpc/h)$^{3)}$. We will use 44 (Gpc/h)^3 of high mass and force res. sims.

Halo/Galaxy bias At z=1

(Mehta, H-JS, Eckel, Eisenstein et al. submitted to ApJ)

- Take a look at systematics as a function of galaxy bias and shot noise: shift (accuracy) and the errors (precision) on the shift in the acoustic scale when measured from galaxies
- Feasibility of reconstruction in the presence of galaxy bias and large shot noise (Huff et al. 2007 and Noh et al. 2010 for ~1-2 (Gpc/h)3).
- Use the highest resolution sim (G1024) from Seo et al. 2010. At z=1. Cosmic volume of 44 $(Gpc/h)^3$ and compare to the mass case.

TABLE 1
N-BODY SETS USED IN THIS PAPER.

Sample	Box size (h^{-1} Gpc)	$N_{\rm particles}$	Force resolution (h^{-1} Mpc)	Total Volume (h^{-3} Gpc^3)	Code
G576	2	576^3	0.1736	504	Metchnik & Pinto
G1024	1	1024^3	0.0488	44	Metchnik & Pinto
T256	1	256^3	3.9062	5000	Gadget-2 PM

NOTE. — Parameters of the simulations used in this paper.

Seo et al.2010

Halo/Galaxy bias

HOD models: $N_g = 0$ if $M<M_{cen}$

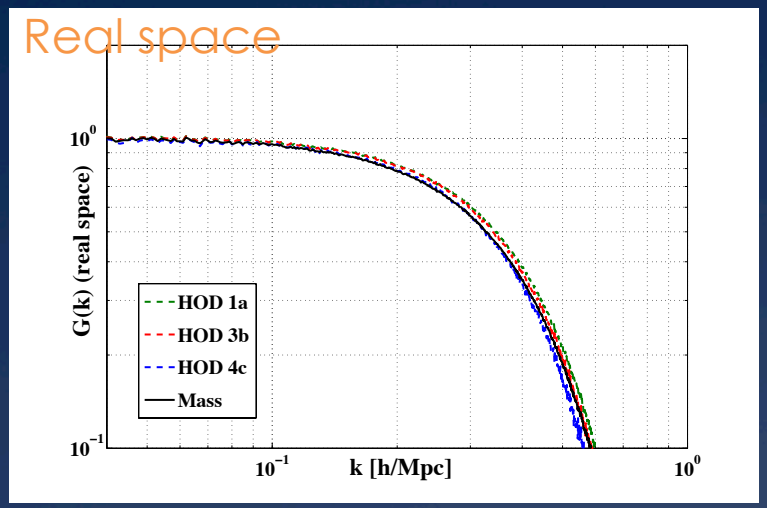
$= 1 + \mathrm{Poisson}(M_{sat}/M)$ if $M>M_{cen}$

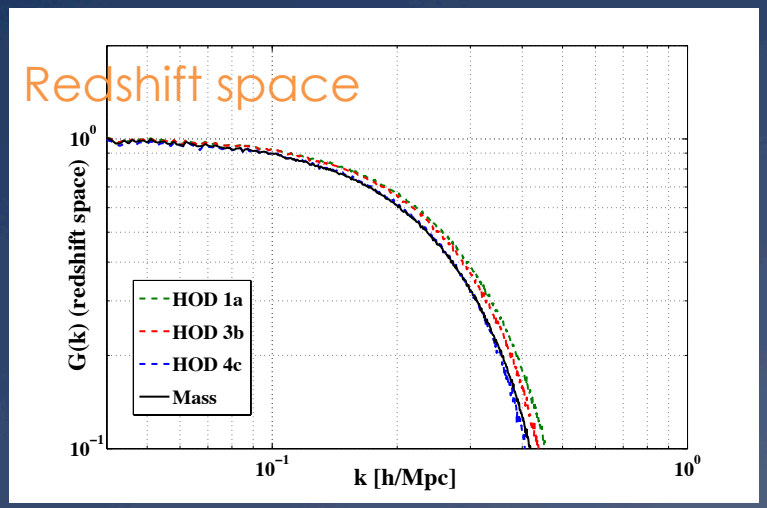
TABLE 1
HALO OCCUPATION DISTRIBUTIONS (HODs) AND THEIR PROPERTIES.

Model	Total Number of Galaxies	Satellite Fraction (%)	M_{cen}	M_{sat}	bias	n_{eff} (h^3 Mpc^{-3})	$n_{eff}P(k = 0.2\ h\ \mathrm{Mpc}^{-1})$
HOD1a	2×10^6	0	19	...	1.75	1.14×10^{-3}	2.59
HOD1b	2×10^6	5	19	1280	1.79	1.10×10^{-3}	2.59
HOD1c	2×10^6	10	19	610	1.82	1.05×10^{-3}	2.58
HOD2a	1×10^6	0	35	...	1.98	6.79×10^{-4}	1.97
HOD2b	1×10^6	5	36	2110	2.03	6.37×10^{-4}	1.93
HOD2c	1×10^6	10	38	1040	2.08	5.80×10^{-4}	1.86
HOD3a	3×10^5	0	86	...	2.46	2.67×10^{-4}	1.20
HOD3b	3×10^5	5	89	4250	2.52	2.45×10^{-4}	1.15
HOD3c	3×10^5	10	93	2050	2.58	2.23×10^{-4}	1.09
HOD4a	1×10^5	0	200	...	3.17	9.10×10^{-5}	0.68
HOD4b	1×10^5	5	208	8300	3.23	8.22×10^{-5}	0.63
HOD4c	1×10^5	10	215	4000	3.29	7.51×10^{-5}	0.60

Propagators = damping of the BAO

Z=1.0

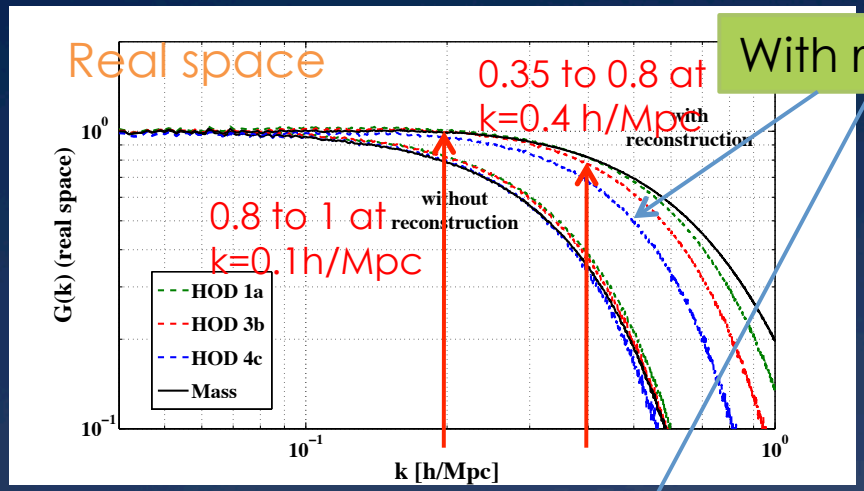




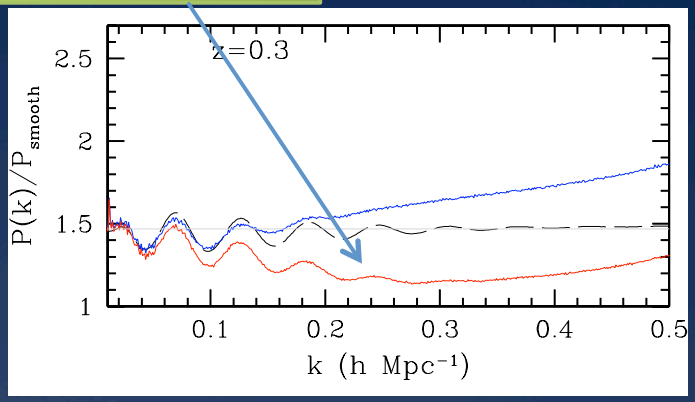
- Propagators of various HOD models are very similar with each other.
- Similar to mass case. Actually better than the mass case.
- Difference more pronounced in redshift space due to FoG effect.
- Biased cases (w/ small satellite fraction) suffer less random motions.
- Galaxy bias does not damp BAO.

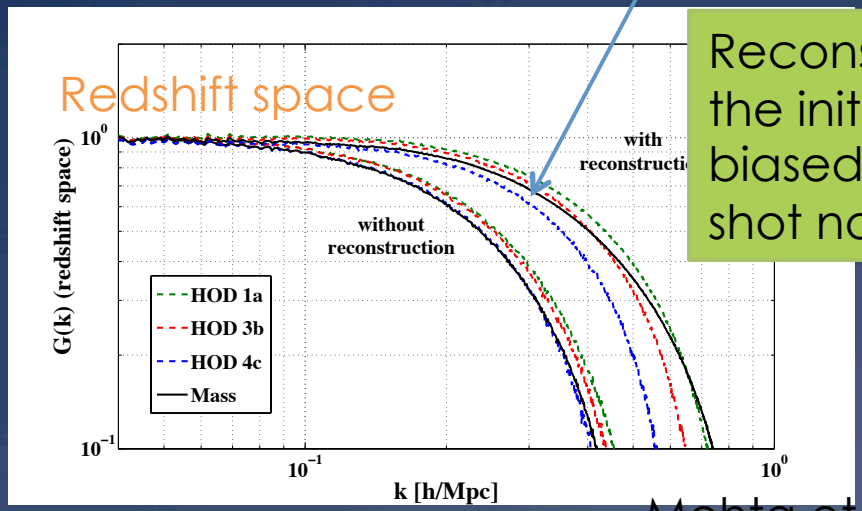
Mehta et. al. Submitted to ApJ

Propagators with galaxy bias



With reconstruction





Reconstruction recovers correlation bt the initial and the final redshift even for biased tracers with a realistic level of shot noise.

Mehta et. al. submitted to ApJ

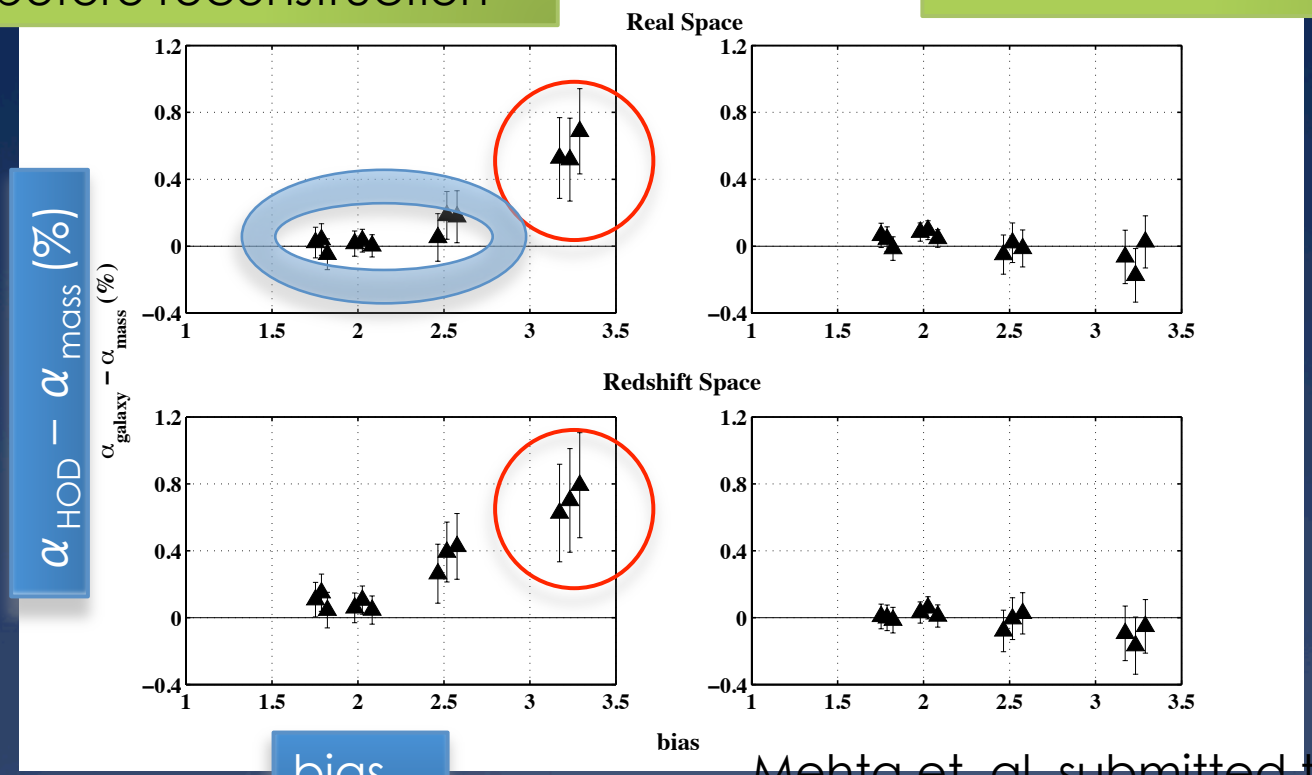
Acoustic scale with galaxy bias

* Seo et al. 2010: From G576, $\alpha_{mass} = 0.158 \pm 0.061$ (%) at z=1.

Acoustic scale with galaxy bias

before reconstruction

after reconstruction



$\alpha_{HOD} - \alpha_{mass}$ (%)

bias

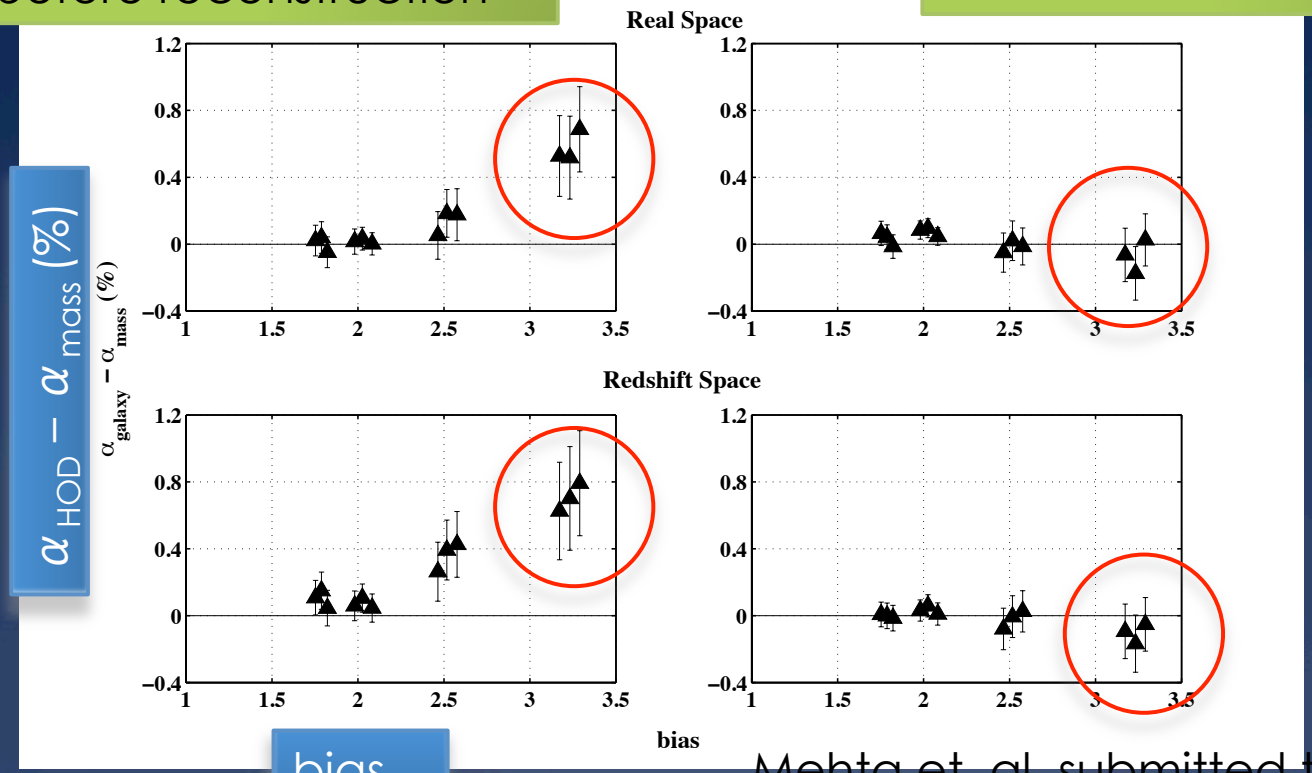
Mehta et. al. submitted to ApJ

- No detection of shift for b<3: typically (0.10 ± 0.10) %.
- For b>3, shift at a moderate significance. (0.79±0.31)%.

Acoustic scale with galaxy bias

before reconstruction

after reconstruction



$\alpha_{HOD} - \alpha_{mass}$ (%)

bias

Mehta et. al. submitted to ApJ

- After reconstruction, the shifts from the galaxy cases and the dark matter case are consistent with no shift and with each other within 1 σ errors of 0.07% – 0.15%.

Robustness of the reconstruction

* To implement reconstruction, we need to estimate a galaxy bias on large scales.

  How well do we need to know "b" ?

$$\nabla \cdot \vec{q} = -\frac{\delta_{\rm obs}}{b}$$

$$\vec{q}_z^{\,\rm red} = \frac{1+f}{1+\beta}\vec{q}_z$$

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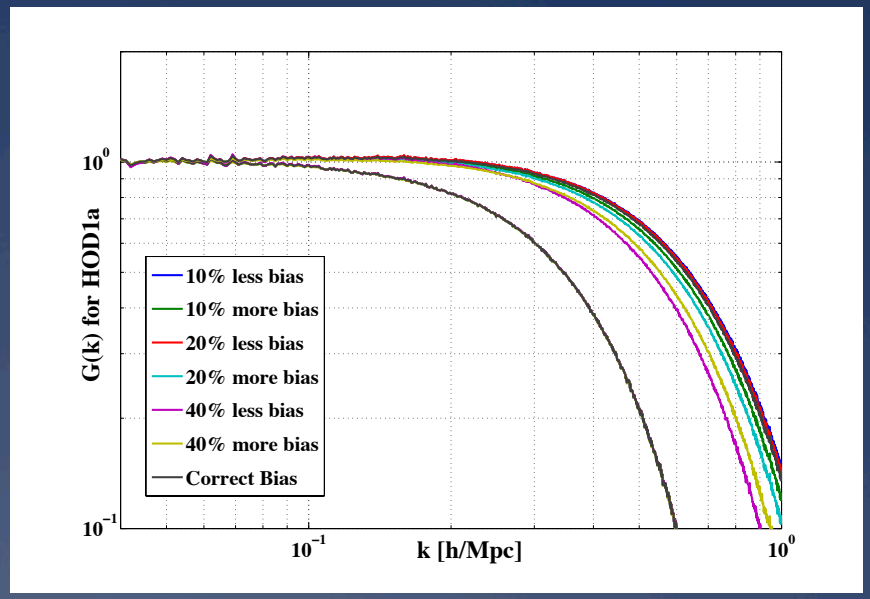
How well do we need to know "b" ?

NOT VERY WELL!

Very small effect for 10% offset in bias → Propagators are very similar and shift difference less than 0.05% in acoustic scale.

40% offset in bias → moderate difference in propagator and 0.1% in acoustic scale.



Summary

- Galaxy bias has little effect on the propagators at BAO scale → The highest biased case is close to the mass case. Reconstruction removes most of the degradation.

For b<3, no detection of additional shift (0.1% +- 0.1%) relative to the no-bias case.

For b>3, an additional shift of 0.79% +- 0.31% relative to the no-bias case.

- Reconstruction works well even in the presence of galaxy bias and shot noise. After reconstruction, shift can be removed better than 0.15%.