Applying the Halo Model to Large Scale Structure Measurements of the Luminous Red Galaxies: SDSS DR7 Preliminary Results

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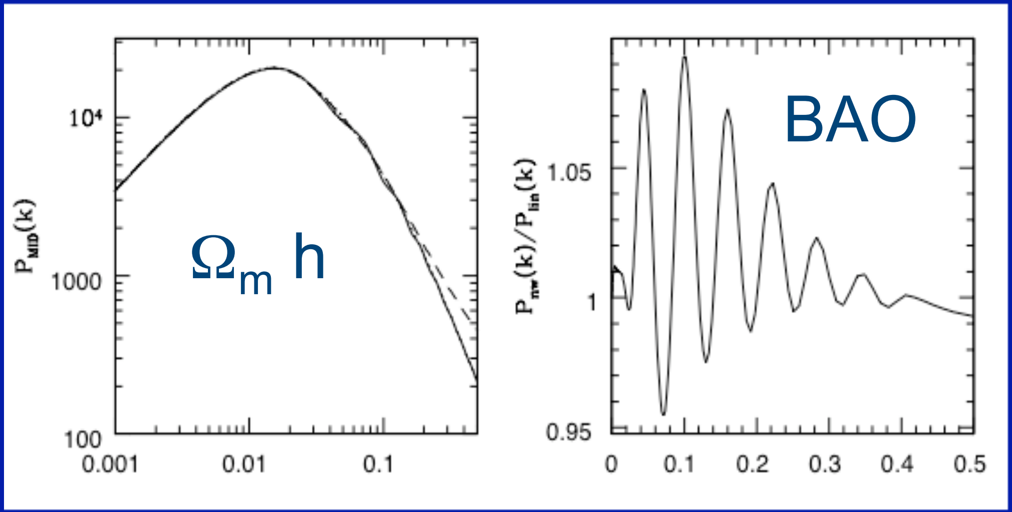
Outline

- Information in the galaxy P(k): Motivation and Challenges
- Halo Model Review
- Key Insight: Finding Counts-in-Cylinders groups
- Building high-fidelity mock LRG catalogs
- Modeling the Reconstructed Halo Density Field P(k)
- Cosmological Constraints from SDSS DR7

Measuring $P_{gal}(k)$: Motivation

- Constrain cosmological parameters from both T and P_{prim}: $P_{lin}(k) = T^2(k, \Omega_m, \Omega_b, h)\, P_{prim}(k)$



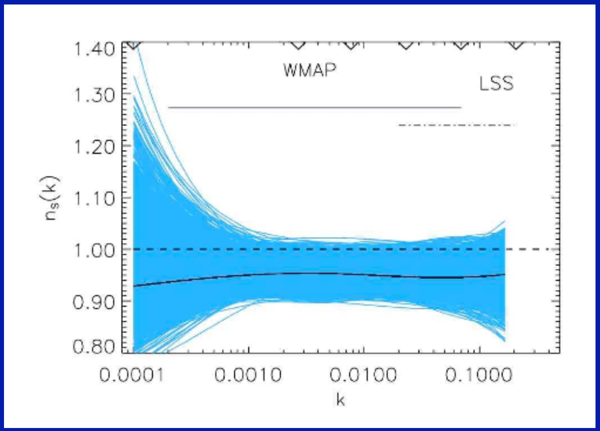
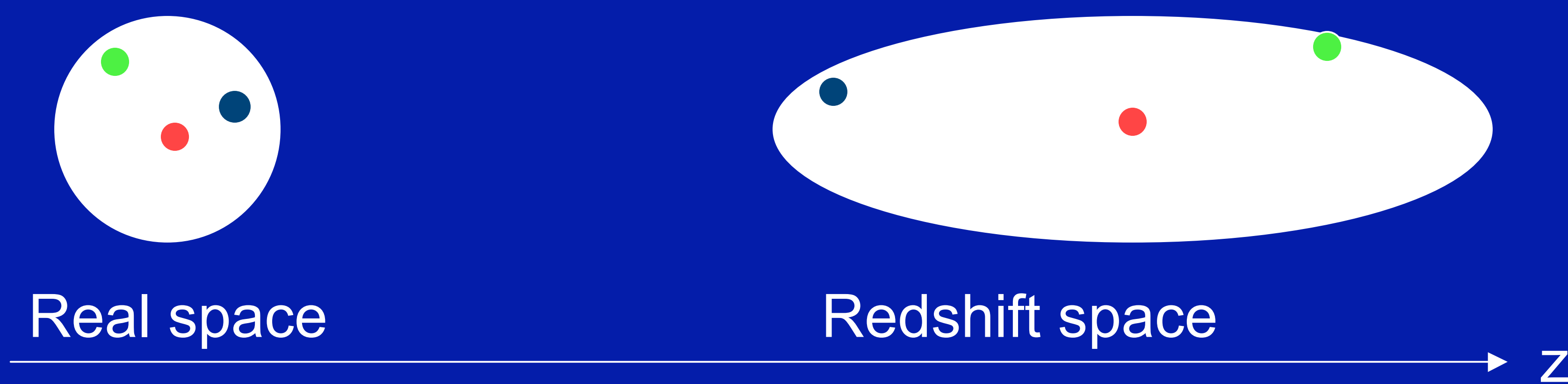


Fig 8 of Verde and Peiris, 2008

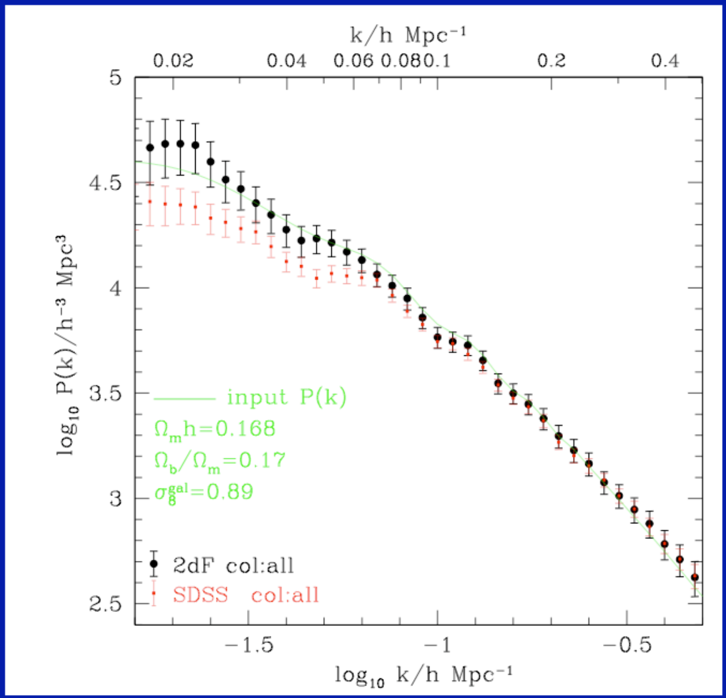
Measuring $P_{gal}(k)$: Challenges

- density field δ goes nonlinear
- uncertainty in the mapping between the galaxy and matter density fields
- Galaxy positions observed in redshift space



Why Study Galaxy Bias?

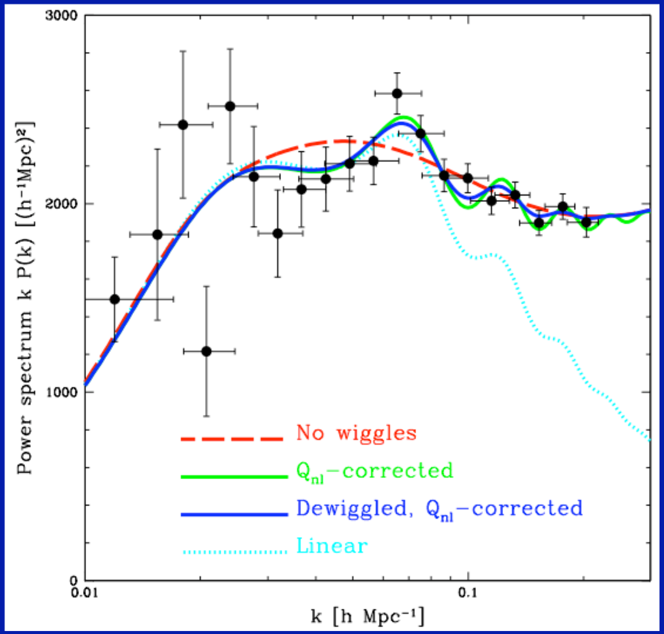
- P(k) and the best fit Ω_m h vary with galaxy type [Sanchez and Cole, 2007]

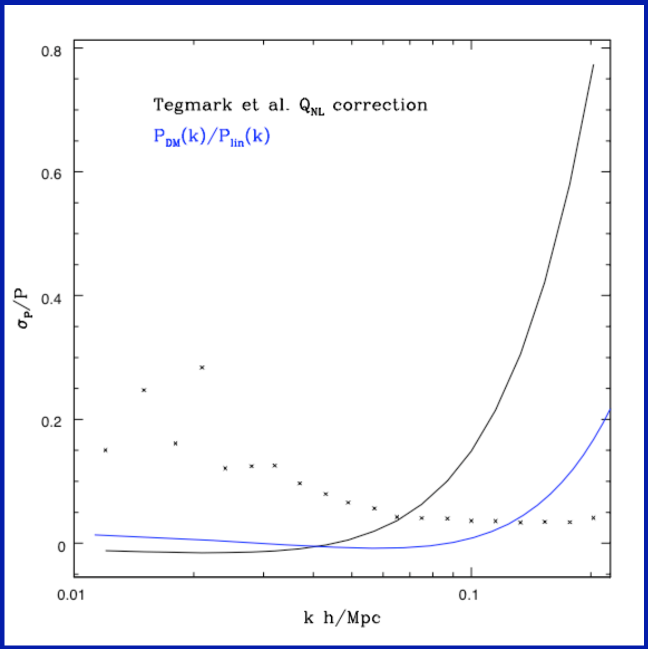


Why Study LRG bias?

- Statistical power compromised by Q_{NL} at $k < 0.09$! [Dunkley et al 2008, Verde and Peiris 2008]

$$P_g(k) = P_{\rm dewiggled}(k) b^2 \frac{1 + Q_{nl} k^2}{1 + 1.4k}$$





Galaxies in the Halo Model

- Halo Model Key Assumptions:
  - Galaxies only form/reside in ‘halos’
  - Halo mass entirely determines key galaxy properties
- Ingredients:
  - halo catalog [SO, FoF, …]
  - Halo Occupation Distribution $P(N_{LRG} \mid M)$
  - Galaxy Distribution within halo: ‘central’ and ‘satellite’ galaxies are distinct

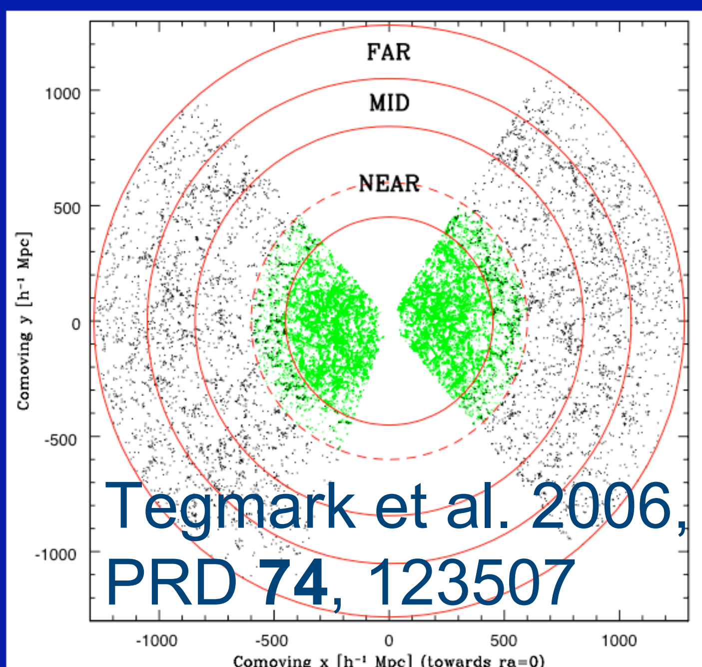
Halo Model P(k): real space

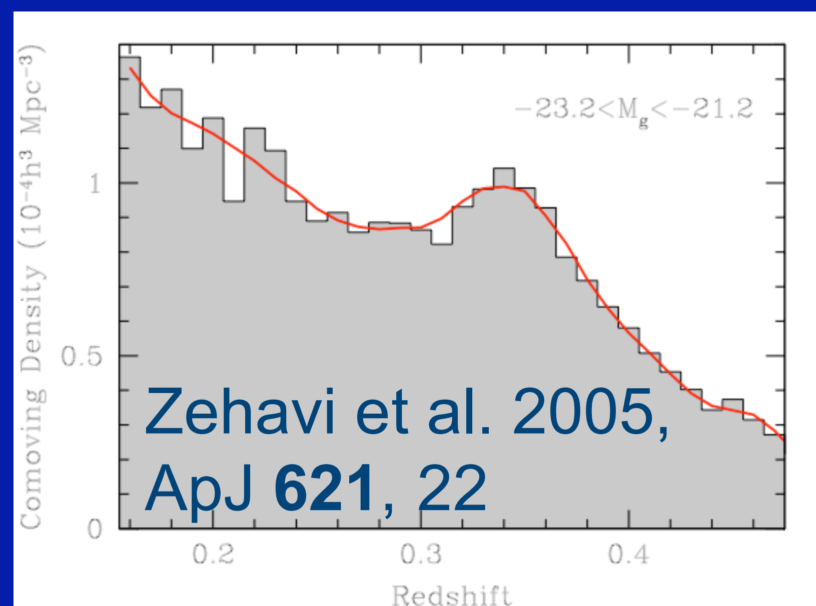
$$
\begin{aligned}
P_{LRG}(k) &= P_{LRG}^{1h}(k) + P_{LRG}^{2h}(k) \\
P_{LRG}^{1h} &= \int dM\, n(M) \frac{\langle N_{LRG}(N_{LRG}-1)|M)\rangle}{\bar{n}_{LRG}^2} \\
P_{LRG}^{2h}(k) &= b_{LRG}^2 P_{DM}(k)
\end{aligned}
$$

- P^{1h}: major source of ‘nonlinearity’ and variation in $P_{gal}(k)$ with galaxy type
- Redshift space: complicated by FOGs

SDSS LRGs

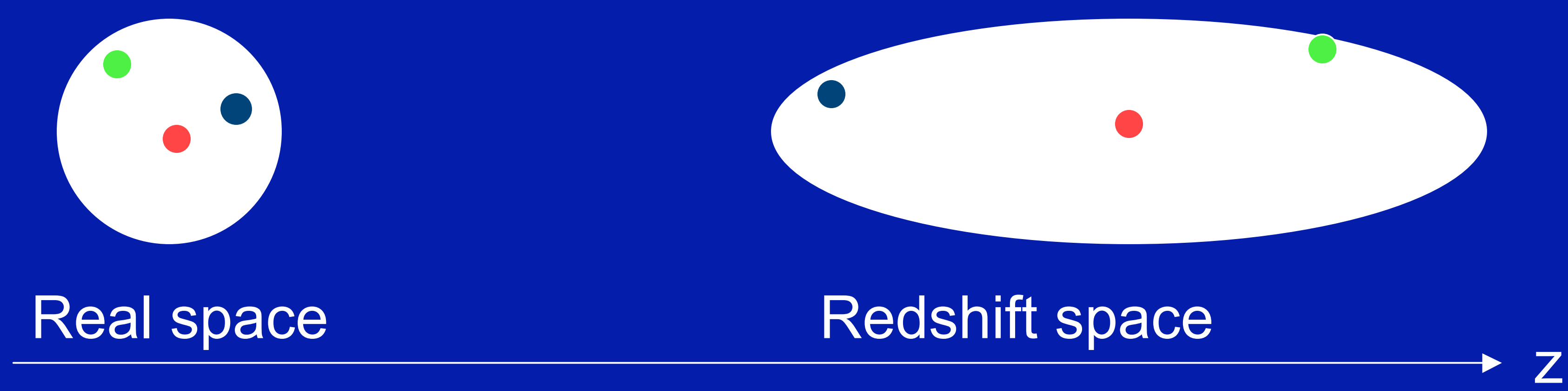
- Probes largest effective volume: ~ $(\mathrm{Gpc}/h)^3$
- 3-6% are satellite galaxies
- small $n_{LRG} \longrightarrow 1/n_{LRG}$, P^{1h} corrections large
  - Occupy massive halos $\longrightarrow$ large FOG features





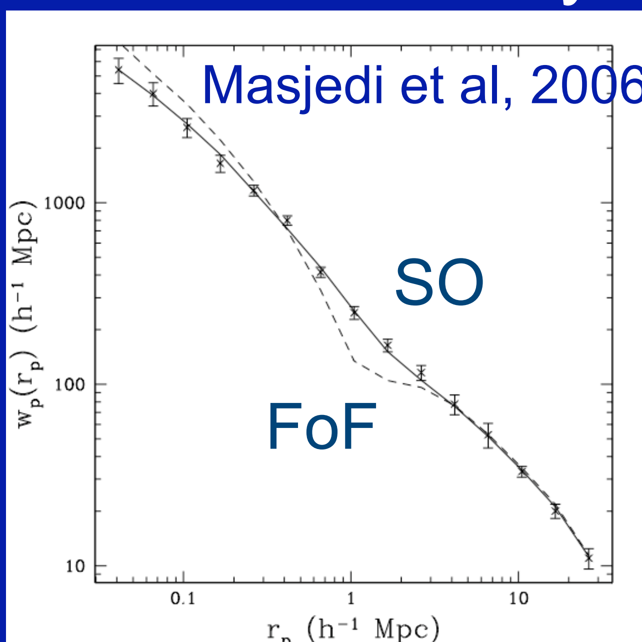
Key Insight

- Find galaxy groups in the density field using the FOG features
  - Measure the group multiplicity function, constrain the HOD $P(N_{LRG} \mid M)$, and make high fidelity mock catalogs
  - Reconstruct the halo density field for $P(k)$ analysis



Consistency Checks

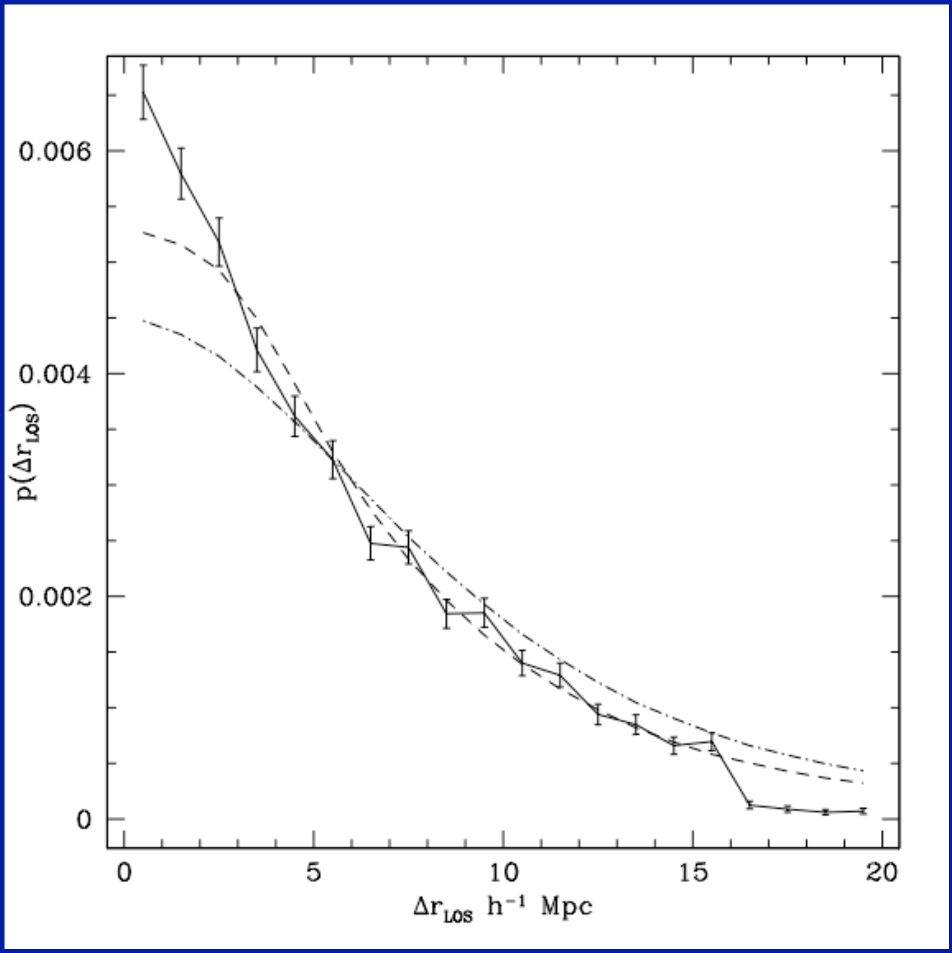
- Matches 2-pt clustering AND higher order statistic $N_{CiC}(n)$
  - can check by changing CiC parameters
  - uncovers systematics in 2-pt fits to HOD



n_{sat}	$N_{\mathrm{SDSSCiC,final}}$	$N_{\mathrm{SOMLHODCiC}}$	N_{FOF}	N_{Kulkarni}
0	40407.56	40546.1	40542.0	37855
1	2301.12	2190.4	2265.1	5202
2	285.86	323.2	301.3	998
3	54.29	65.8	53.7	343
4	20.20	15.2	13.4	155
5	4.13	4.7	4.0	82
6	1.05	1.5	1.6	48
7	1.02	0.2	0.92	30
8	0.02	0.16	0.28	21

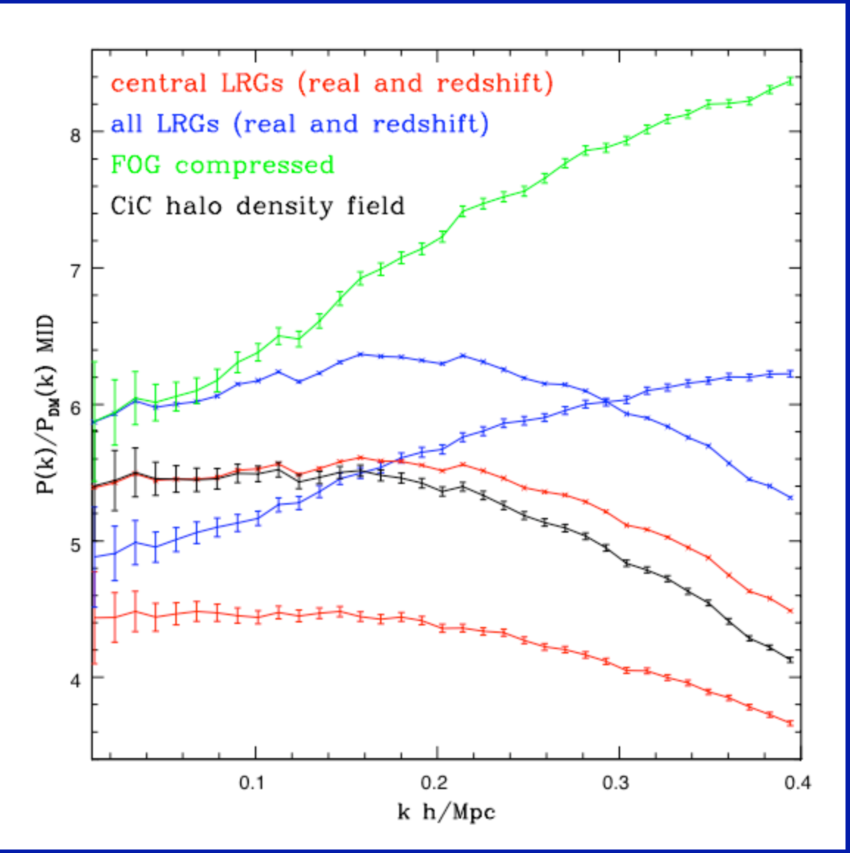
Consistency Checks

- Matches intragroup LOS separations



Results: Reconstructed halo density field P(k)

- Deviation from constant ratio for k < 0.1 (k < 0.2):
  - NEAR: 0% (4%)
  - MID: 0% (2.8%)
  - FAR: 1% (2.5%)
- FOG-compressed between k = 0.05 and k = 0.1:
  - NEAR: 6%
  - MID: 7%
  - FAR: 10%



Model P(k)

$$
\begin{aligned}
P_{\rm smear}(k,\mathbf{p}) &= P_{\rm lin}(k,\mathbf{p})e^{-k^2\sigma^2_{BAO}(\mathbf{p})/2} + P_{\rm nw}(k,\mathbf{p})\left(1-e^{-k^2\sigma^2_{BAO}(\mathbf{p})/2}\right)\\
r_{DM,nw}(k,\mathbf{p}) &= \frac{P_{DM}(k,\mathbf{p}_{\rm fid})}{P_{\rm smear,DM}(k,\mathbf{p}_{\rm fid})}\frac{P_{\rm lin,nw}(k,\mathbf{p}_{\rm fid})}{P_{\rm halofit,nw}(k,\mathbf{p}_{\rm fid})}\frac{P_{\rm halofit,nw}(k,\mathbf{p})}{P_{\rm lin,nw}(k,\mathbf{p})}\\
F_{nuis}(k) &= b_0^2(1+a_1k+a_2k^2)\\
P_{LRG}(k,\mathbf{p}) &= P_{\rm smear,LRG}(k,\mathbf{p})r_{DM,nw}(k,\mathbf{p})\frac{P_{LRG}(k,\mathbf{p}_{\rm fid})F_{nuis}(k)}{r_{DM,nw}(k,\mathbf{p}_{\rm fid})P_{\rm smear,LRG}(k,\mathbf{p}_{fid})}\\
P_{LRG}(k,\mathbf{p}) &= P_{\rm smear}(k,\mathbf{p})\frac{P_{\rm halofit,nw}(k,\mathbf{p})}{P_{\rm lin,nw}(k,\mathbf{p})}\frac{P_{\rm lin,nw}(k,\mathbf{p}_{\rm fid})}{P_{\rm halofit,nw}(k,\mathbf{p}_{\rm fid})}\frac{P_{LRG}(k,\mathbf{p}_{\rm fid})F_{nuis}(k)}{P_{\rm smear,LRG}(k,\mathbf{p}_{\rm fid})}
\end{aligned}
$$

Calibration at $\mathbf{p}_{\rm fid}$ = WMAP5

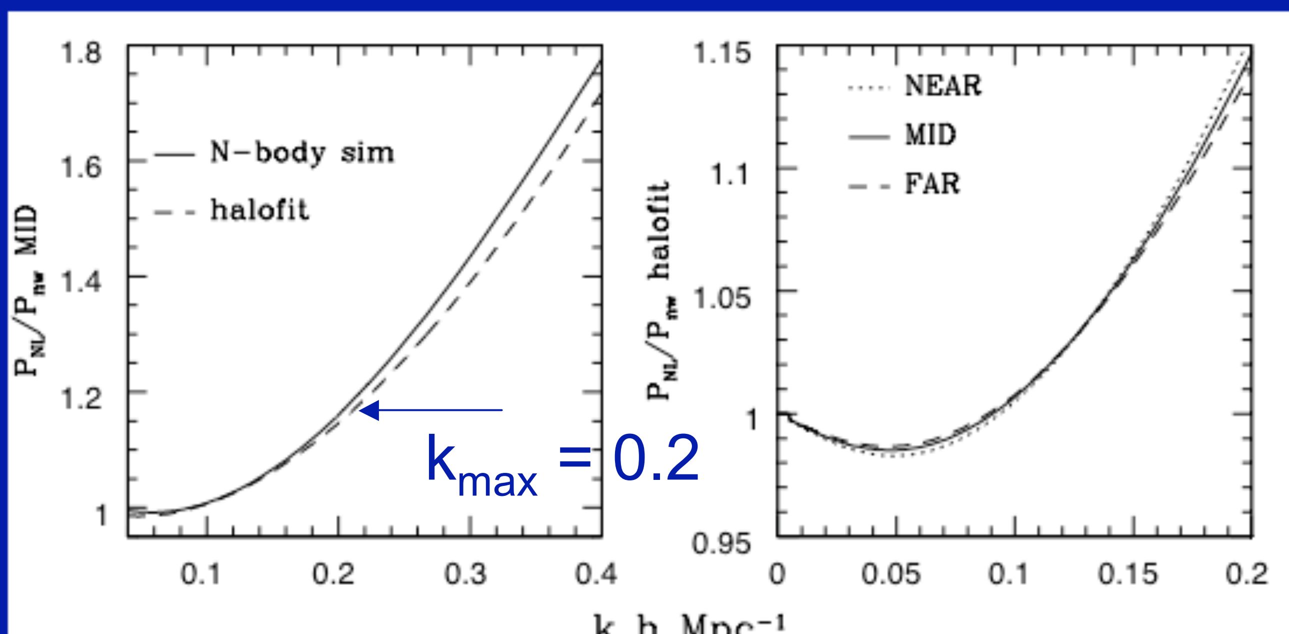
Cosmological parameter dependence

$$P_{LRG}(k,\mathbf{p}) = w_{NEAR}P_{NEAR}(k,\mathbf{p}) + w_{MID}P_{MID}(k,\mathbf{p}) + w_{FAR}P_{FAR}(k,\mathbf{p})$$

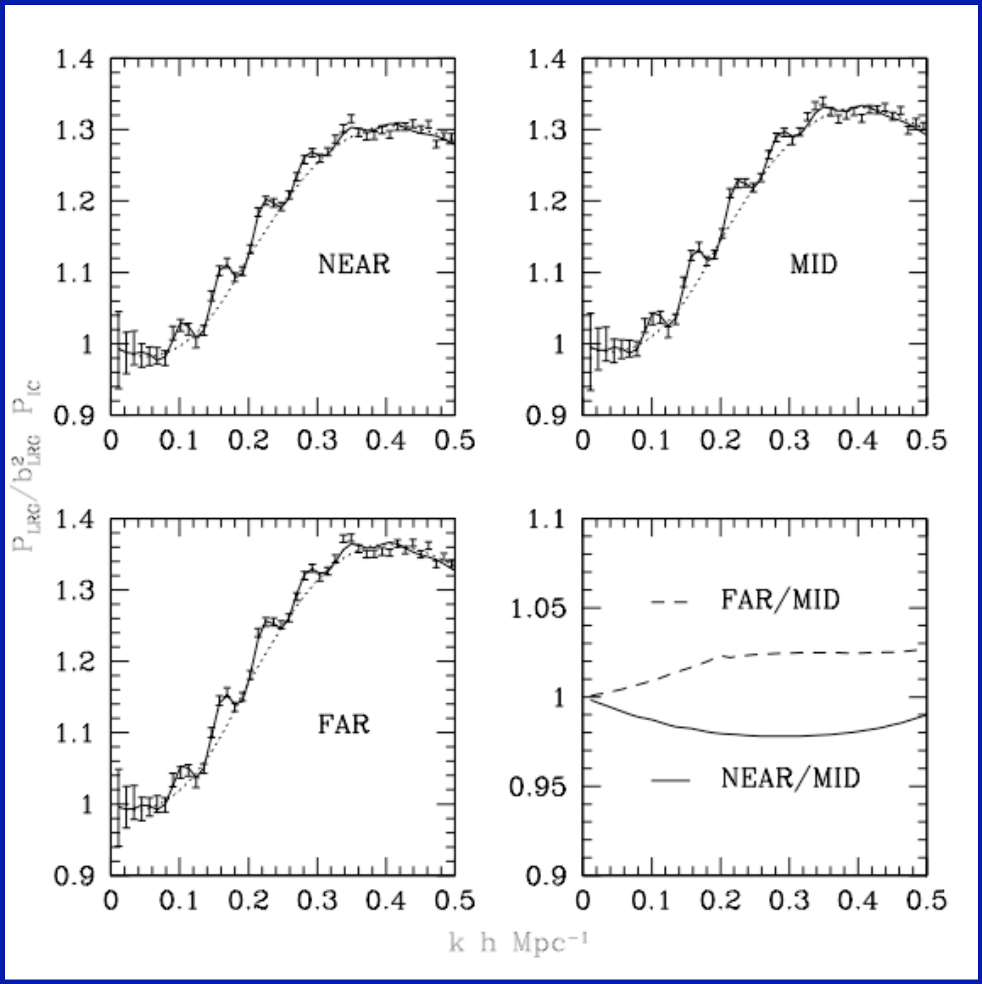
$\{z_{\rm NEAR}, z_{\rm MID}, z_{\rm FAR}\} = \{0.235, 0.342, 0.421\}$

Nonlinear Model $P_{mm}(k)$

- Halofit better when BAOs treated separately



Calibrating $P_{CiC}(k)$ on Mocks



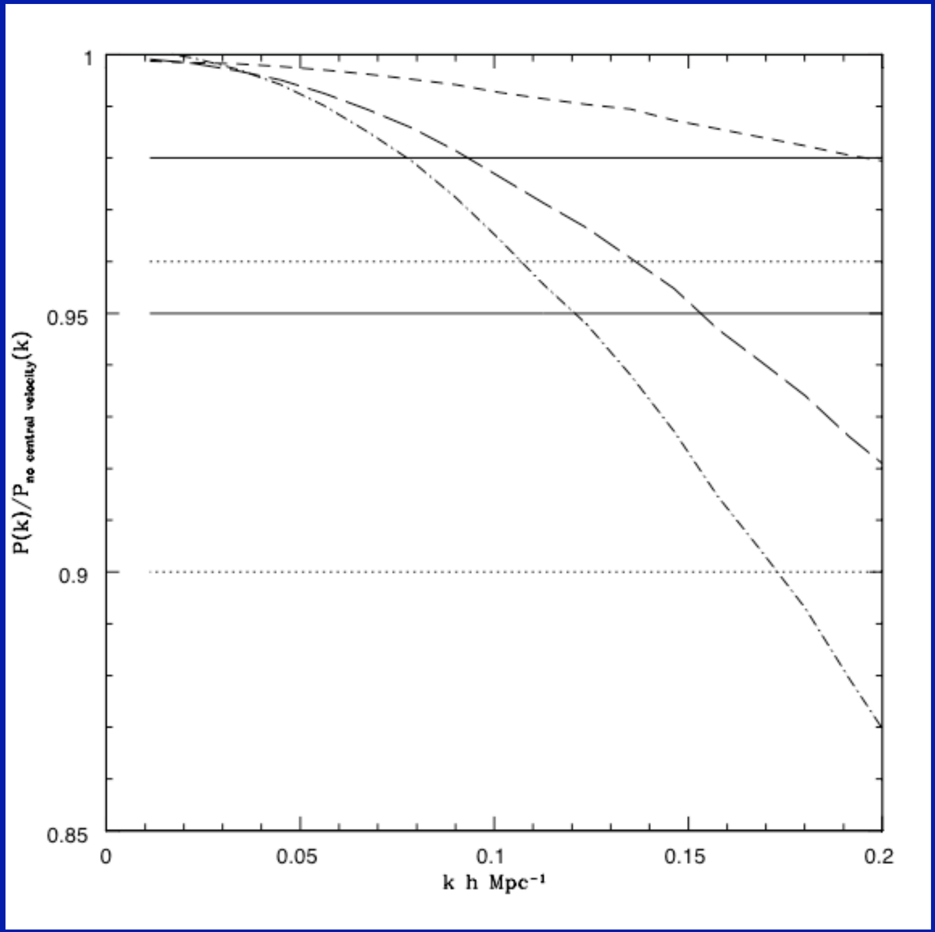
P(k) shape nearly independent of satellite fraction, z

Fixing Nuisance Parameters: $F_{nuis}(k) = b_o^2(1+a_1k+a_2k^2)$

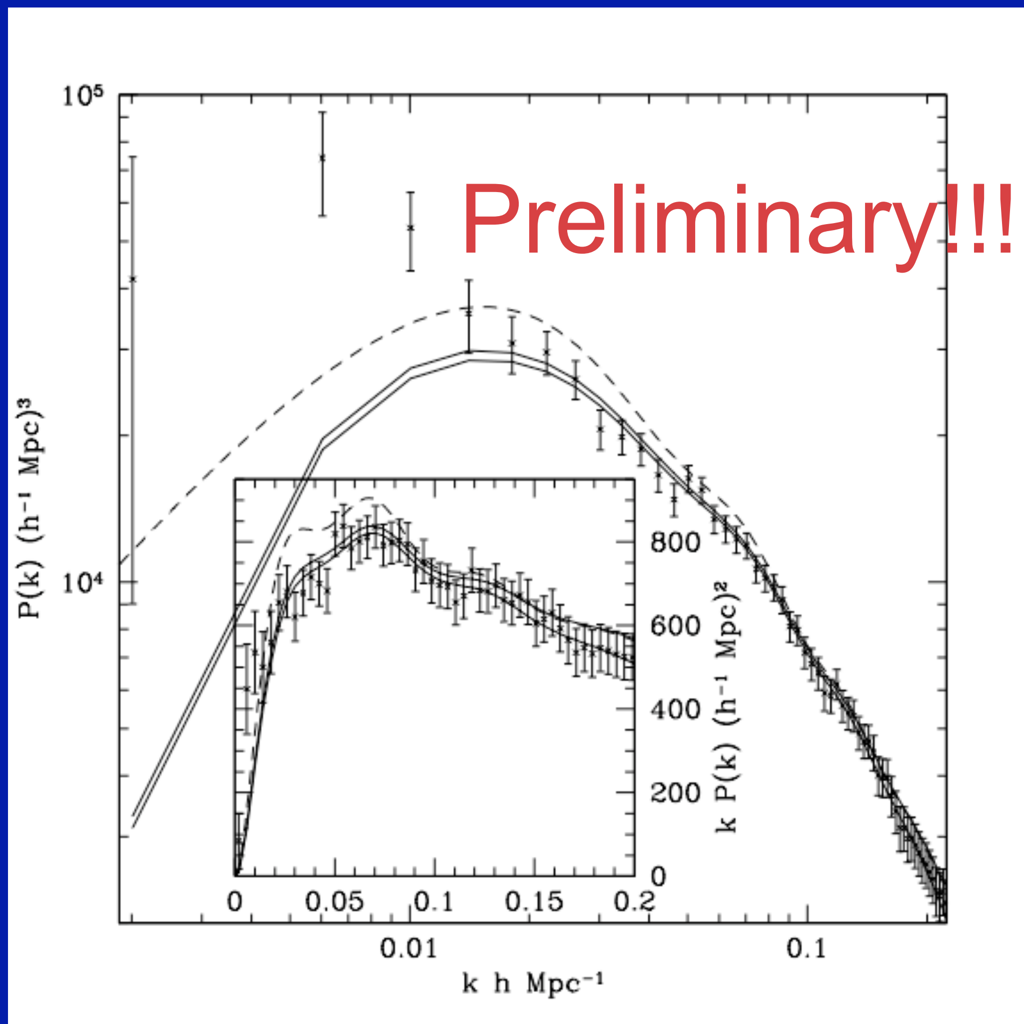
- P^{1h} subtracted to within 20% suggests
  - 2% uncertainty at k=0.1, 5% at k=0.2
  - Conservative: 4% (k=0.1), 10% (k=0.2)
- Marginalize numerically over allowed a_1-a_2 space

Systematic Error from Velocity Dispersion of Central LRG?

- “Extreme” velocity dispersion model has $\sigma_{cen}/\sigma_{DM} = 0.6$ and central/satellite misidentification 20% of the time [Skibba et al, prep]

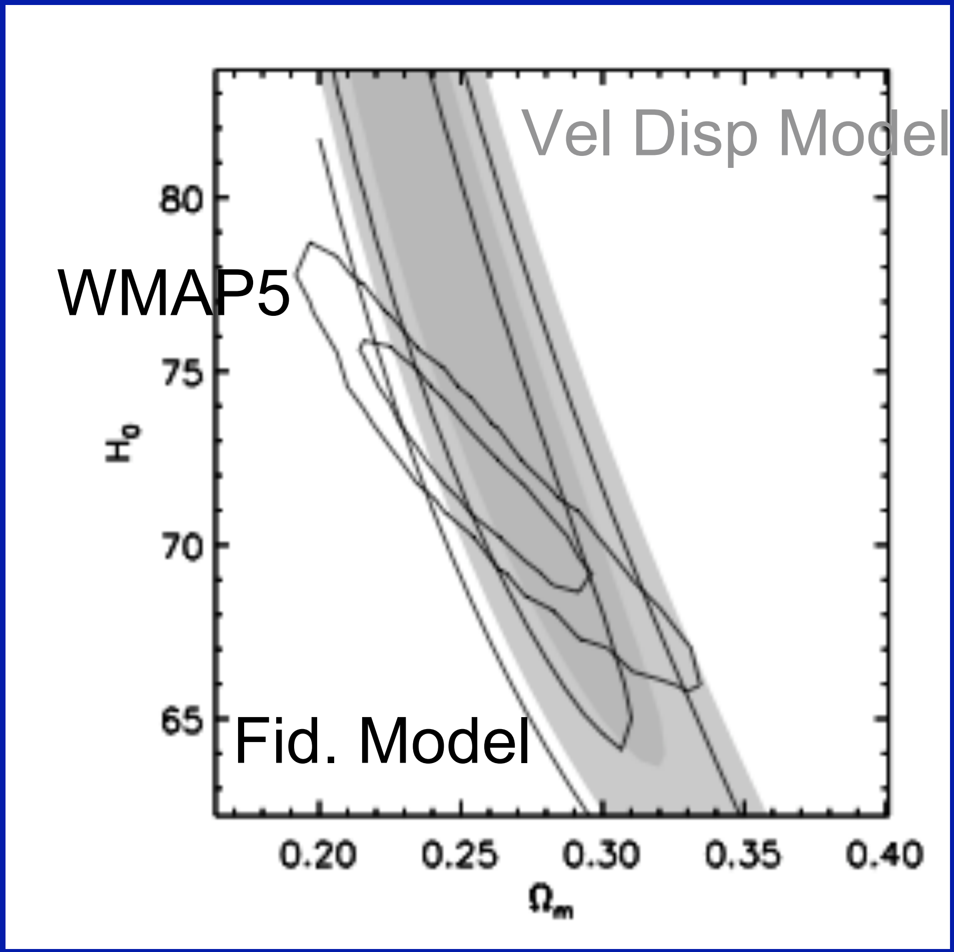


DR7 SDSS LRG vs Model P(k)



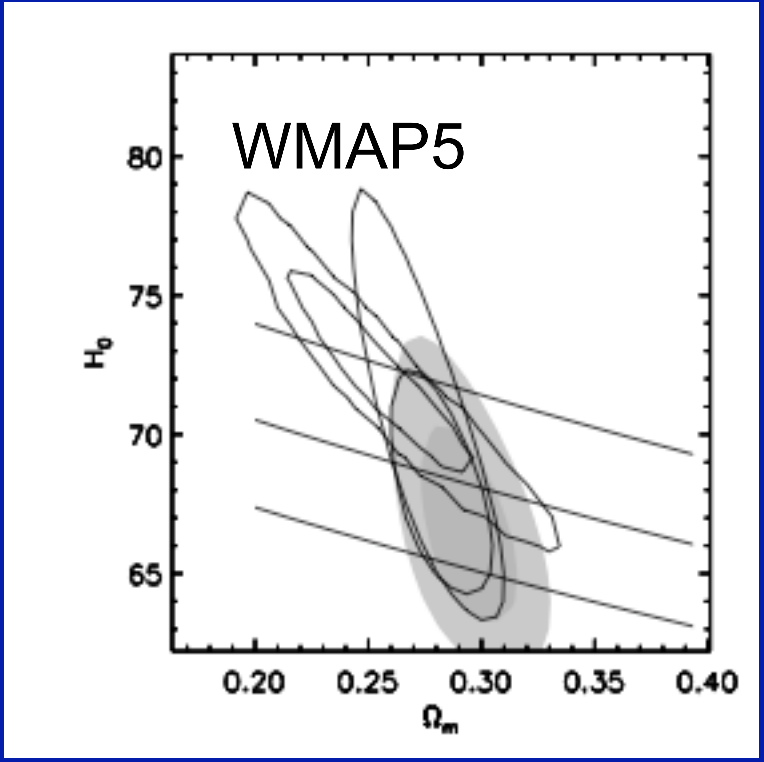
Cosmological Constraints I: Fits to ‘No wiggles’ P(k)

- $n_s = 0.96$, $\omega_b = 0.02265$, conservative $F_{nuis}(k)$
- Systematic Error from Velocity Dispersion << Statistical Error
- All information at k < 0.1



Cosmological Constraints II: P(k <= 0.2)

- Additional information comes from BAO
- $n_s = 0.96$, $\omega_b = 0.02265$, conservative $F_{nuis}(k)$

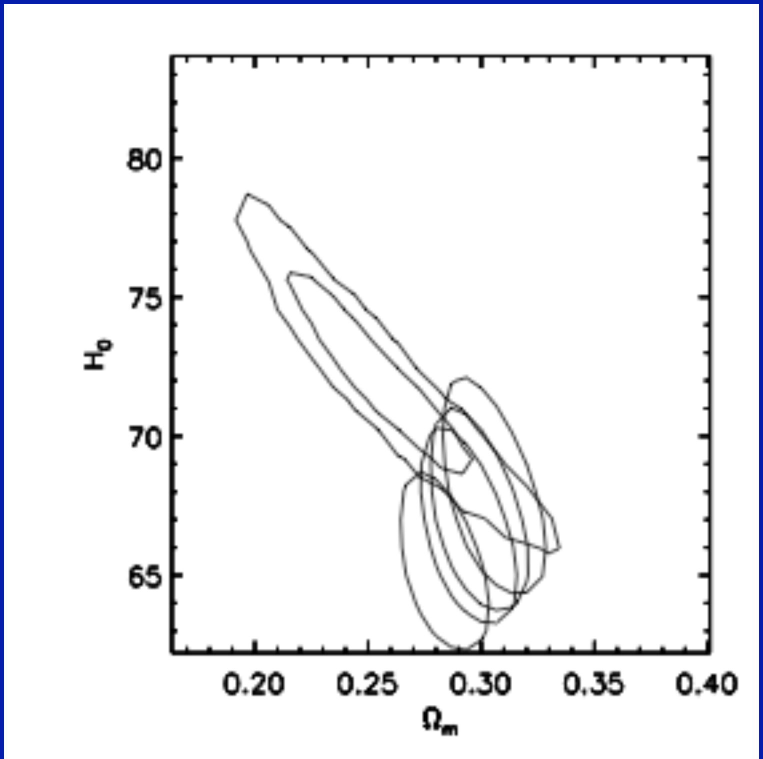


$k_{max} = 0.1, 0.15, 0.2$

Eisenstein et al 2005 Dv(z=0.35) +/- 1σ

Cosmological Constraints III: Degeneracy with n_s

- Systematic shift from velocity dispersion is subdominant



$n_s = 0.90$

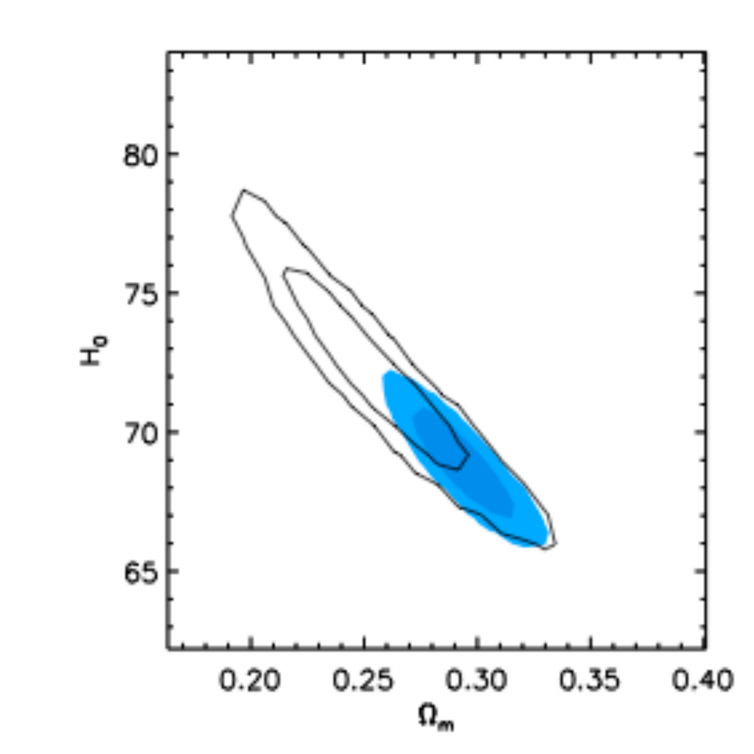
$n_s = 0.96$, vel disp model

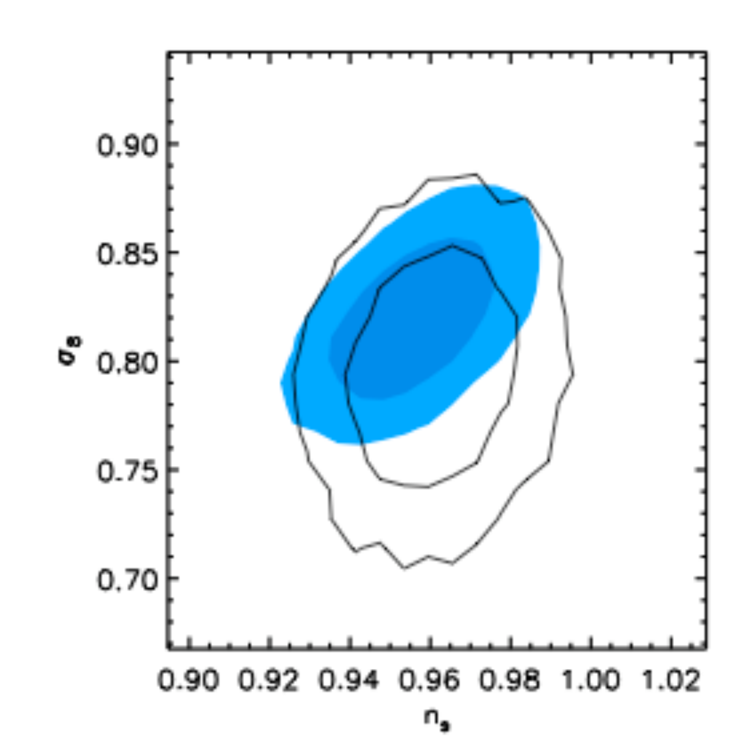
$n_s = 0.96$, fiducial

$n_s = 1.02$

Combined constraints: DR7 LRGs +WMAP5

- $k_{min} = 0.02$, $k_{max} = 0.2$, no velocity disp





Advantages of our approach

- Eliminate P^{1h} and systematic variation with n_{LRG} or z
- Make high fidelity mocks and calibrate model in the quasi-linear regime ($k < 0.2$)
  - Constrain both shape and BAO scale
- Use the Halo Model framework to
  - Fix tight constraints on nuisance parameters
  - Propagate uncertainties to understand systematics on cosmological parameters

Conclusions

- Particulars of galaxies $\longrightarrow$ mass can matter even at $k < 0.1$!
- Modeling the shape up to $k=0.2$ does not provide more information on ΛCDM
- BUT.. allows us to extract BAO+shape information simultaneously
- BUT.. may be useful in more general models (e.g., w_o-w_1)?