GALAXY-HALO CONNECTION FOR MASSIVE GALAXIES FROM BOSS

or... the curse of ridiculously small error bars ...

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With Shun Saito (talk at 15:50) and the BOSS collaboration
Goals and Data

- Probe 2d redshift space clustering deep into the non-linear regime. Few studies on these scales!
- Information on scales $R = 0.8$ to $32 \, h^{-1} \, Mpc$?
- Galaxy-halo connection for massive galaxies at $z = 0.57$
- Velocity dispersions of satellites relative to their parent halos.
- Check assumptions on $\sigma_{\text{FOG}}$
- Growth rate of cosmic structure, $f\sigma_8$
- Constraints on these scales are particularly interesting for constraining modified gravity models

**BOSS: Baryon Oscillation Spectroscopic Survey**
1.5 million galaxies

"CMASS" $z = [0.43, 0.7]$
2D Redshift Space Correlation Function

\[ \xi(s) \quad (s^2 = r_\sigma^2 + r_\pi^2) \]

**Fiber collision scale**

- **Multipoles**
  - \( L_0(\mu)=1 \)
  - \( L_2(\mu)=1.5 \mu^2-0.5 \)

\[ \xi_\ell(s_i) = \frac{2\ell + 1}{2} \int d\mu_s \xi(s_i, \mu_s) L_\ell(\mu_s), \quad \sim \text{angle } \theta \]

- Spherical average \( \xi_0(s) \).
- Anisotropy \( \xi_2(s) \).

- **“xi-hat” statistic**

\[ \hat{\xi}_\ell(s_i) = \frac{2\ell + 1}{2} \int_{0}^{\mu_{\text{max}}(s_i)} d\mu_s \xi(s, \mu_s) L_\ell(\mu_s). \]

no pairs with \( r_\sigma < 0.534 \, h^{-1} \text{ Mpc} \).
A 2.5% Measurement of the Growth Rate from BOSS

Model: 5 standard HOD parameters + velocity parameters
- $\gamma_{HV} \ (\propto f\sigma_8)$
- $\gamma_{IHV}$ (satellites)
- $\gamma_{cen}$ (centrals)

Joint fit to $w_p$ and “xi-hat”

Growth of structure $f_x\sigma_8 = 0.450 \pm 0.011$
2.5 x improvement over DR11 large scale analysis

but no systematic error!

Reid, Seo, Leauthaud et al. 2014
Because observed clustering of CMASS does not appear to vary with redshift:

**Single constant HOD with redshift**

“CMASS” : Constant Mass

Simple selection function
Stellar Mass Completeness of the BOSS CMASS and LOWZ samples

Leauthaud et al. 2015
arXiv:1507.04752
BOSS Selection Function

Bluer colors indicate more recent star formation

Stripe 82 Massive Galaxy Catalog (S82-MGC)

Bundy et al. in prep

Stripe 82 co-adds + Matched NIR photometry

Leauthaud et al. 2015
Stellar Mass Function at Redshifts 0.43 - 0.7

- PRIMUS
- S82-MGC
- CMASS
Mass Completeness of CMASS Sample

- Completeness depends on $M^*$ and redshift
- Notice that mean $M^*$ increases with redshift

Also for the LOWZ sample at $0.15 < z < 0.43$

Leauthaud et al. 2015
A Redshift Dependent Model for CMASS

Saito et al. in prep
A Redshift Dependent Model for CMASS

In collaboration with Shun Saito, Andrew Hearin, Jeremy Tinker, Martin White, Beth Reid

★ Account for BOSS selection function (stellar mass, color)

★ Model built from N-body simulations directly via abundance matching

★ Model: for simplicity, begin with assumption that galaxy color in high mass halos is a stochastic process

(More sophisticated model = see Shun’s talk this afternoon)

\[ \text{stellar mass} \leftrightarrow V_{\text{peak}} \]

assume color is un-correlated with other halo properties at fixed \( M^* \)
I Gpc$^3$ N-body Simulation
Redshift

I Gpc$^3$ N-body Simulation

**Step 1:** Determine Mass Function and abundance match ($V_{\text{peak}}$)
Step 1: Determine Mass Function and abundance match ($V_{\text{peak}}$)
Step 2: Redshift dependence of stellar-mass completeness
stellar mass completeness measured for CMASS
stellar mass incompleteness measured for CMASS
stellar mass incompleteness measured for CMASS
Results: fits to $\Phi(M_*)$ and $w_p(r)$

Galaxy Number Density $\Phi(M_*)$

Projected Correlation Function $w_p(r)$
Results: Halo Occupation

\begin{figure}
\centering
\includegraphics[width=\textwidth]{halo_occupation_graphs}
\caption{Halo Occupation curves for different redshifts: low z (13.3%), med z (17.7%), high z (3.41%).}
\end{figure}
Results: Halo Occupation

[Graphs showing the occupation number density as a function of host halo mass for different redshift bins: low z (13.3%), med z (17.7%), high z (3.41%).]
Results: Halo Occupation

Mean halo mass (stellar mass) for the CMASS sample increases with $z$ (factor of 3.5 for $M_{\text{halo}}$).
BUT ...
A Fundamental Discrepancy

Redshift dependance of multipoles is constant with redshift (Reid et al. 2014)

Mean halo mass (stellar mass) for the CMASS sample increases with $z$

Observable consequences for both clustering and lensing
Evidence from Weak Lensing

Mean halo mass increases with $z$.

$\Delta \Sigma$ [ $M_\theta$ pc$^{-2}$ ]

model prediction

$z = 0.445$
$z = 0.485$
$z = 0.525$
$z = 0.565$
$z = 0.605$
$z = 0.645$
$z = 0.685$

Mean halo mass increases with $z$. Evidence from Weak Lensing model prediction
Evidence from Weak Lensing
Model: galaxy color in high mass halos is a stochastic process.

stellar mass $\leftrightarrow V_{\text{peak}}$

assume color is un-correlated with other halo properties at fixed $M^*$
Summary and Conclusions

- 2d redshift space clustering from BOSS and lensing from surveys such as HSC and DES = tiny error bars!
- Semi-linear scales, $R=0.8$ to $32\ h^{-1}\ Mpc$: galaxy formation + cosmology
- Stellar mass completeness for BOSS (Leauthaud et al. 2015)
- Galaxy-halo connection for massive galaxies at $z=0.57$?
  - color in high mass halos is not a stochastic process at fixed stellar mass
- Velocity dispersions of satellites - check assumptions in previous papers on $\sigma_{\text{FOG}}$
- How robust are constraints on $f\sigma_8$?