Large Scale Clustering, Systematics and Non-gaussianities

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Ashley Ross, Hee-Jong Seo, Antonio Cuesta, Martin White, David Schlegel, Shun Saito, Will Percival, Nikhil Padmanabhan et al.

and

Sloan Digital Sky Survey III Collaboration
The 3D power-spectrum

ghost inflation, curvaton models, etc

matter-radiation equality

standard inflation

Dalal, Dore, Huterer, Shirokov 2008
Angular Power-spectrum

\[ C_{gg}^l = \langle \delta_g \delta_g \rangle \]

Slosar, Hirata, Seljak, SH, Padmanabhan 2008
Xia, Baccigalupi, Mattarese, Verde, Viel 2011
Xia et al. 2010
The Data

Total Area: 14,555 sq deg

1.5 million LRGs: 0.4<z<0.7

Sloan Digital Sky Survey III

Ross, SH, Cuesta et al. (2011)

SH, Ross, Cuesta, Seo, White, Schlegel et al. (in prep)

note: Colors only indicates the when a certain area of the sky is surveyed.
The Data: Splitting them into redshift bins

\[ z = 0.45 - 0.5 \]

\[ z = 0.5 - 0.55 \]

\[ z = 0.55 - 0.6 \]

\[ z = 0.6 - 0.65 \]

SH, Ross, Cuesta, Seo, White, Schlegel et al. (in prep)
For each of the redshift bin, we cross-correlates the Luminous Red Galaxies with themselves, and we get the angular power-spectra of the galaxies.

We want the best measurement of the angular power-spectra possible, from the stand point of not only statistical error, but also systematic errors.

To get the best statistical errorbar, we apply “Quadratic Estimator”, which are proven to provide:

— Unbiased Minimum variance measurement of the parameters that are being estimated if the field is gaussian.

— Many people have worked on this Quadratic Estimators: Hamilton, Tegmark, Bond, Jaffe and Knox, White, Padmanabhan, Hirata, Blake, et al.
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What we expect to see

Angular Power Spectra

WMAP7 Templates

C_l

0.0001

1e-05

1e-06

1e-07

0.40<z_{photo}<0.45

0.45<z_{photo}<0.50

0.50<z_{photo}<0.55

0.55<z_{photo}<0.60

0.60<z_{photo}<0.65

0.65<z_{photo}<0.70

multipole

Lawrence Berkeley National Laboratory
Systematics

- Therefore, the systematics I am going through here are mostly for getting a clean angular power-spectrum which contains information such as the shape of matter power-spectrum, scale dependent bias that can be caused by non-gaussianities at the early Universe.

\[ C_{l}^{gg}(Data) = C_{l}^{\text{real real}} + \epsilon_{1}C_{l}^{\text{stars,stars}} + \epsilon_{2}C_{l}^{\text{sky,sky}} + \epsilon_{3}C_{l}^{\text{c,c}} + \ldots \]
Short summary:

Ross, SH, Cuesta et al. (2011)
You can’t cut to certain sky area only!
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Can we restrict ourselves to certain $l$-modes?

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Real Galaxy Power  Stars  Sky Brightness  Color Offset
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\[ C_{\ell}^{gg}(Data) = C_{\ell}^{\text{real} \, \text{real}} + \epsilon_1 C_{\ell}^{\text{stars} \, \text{stars}} + \epsilon_2 C_{\ell}^{\text{sky} \, \text{sky}} + \epsilon_3 C_{\ell}^{\text{c} \, \text{c}} + \ldots \]

Real Galaxy Power    Stars    Sky Brightness    Color Offset
Effect of stars

SH, Ross, Cuesta, Seo, White, Schlegel et al. (in prep)
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**Can we restrict ourselves to certain l-modes?**

\[
C_{i}^{gg}(Data) = C_{i}^{greal,greal} + \epsilon_1 C_{i}^{stars,stars} + \epsilon_2 C_{i}^{sky,sky} + \epsilon_3 C_{i}^{c,c} + \ldots
\]

Real Galaxy Power  Stars  Sky Brightness  Color Offset
The effect of sky brightness

run9 X sky brightness (from Ashley)
run10 X sky brightness (from Ashley)

SH, Ross, Cuesta, Seo, White, Schlegel et al. (in prep)
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Can we restrict ourselves to certain l-modes?

\[ C_{ll}^{gg}(Data) = C_{ll}^{real,real} + \epsilon_1 C_{ll}^{stars,stars} + \epsilon_2 C_{ll}^{sky,sky} + \epsilon_3 C_{ll}^{c,c} + \ldots \]

Real Galaxy Power    Stars    Sky Brightness    Color Offset
Color offsets

DR8 Color offsets in g-r

Color offsets as discussed in Schlafly et al. 2010
The effect of the color offsets

SH, Ross, Cuesta, Seo, White, Schlegel et al. (in prep)
What can we do when we can’t/ don’t want to cut to a certain l-range?
Systematics: Taking them out of the equation

\[ \delta^o_g = \delta^t_g + \sum_{i=0}^N \epsilon_i \delta^s_i \]

True galaxy overdensity

Observed galaxy overdensity

Various systematics

For example, if \( i=2 \) only:

\[
< \delta^o_g \delta^s_1 > = < \delta^t_g \delta^t_g > + \epsilon_1 < \delta^s_1 \delta^s_1 > + \epsilon_2 < \delta^s_2 \delta^s_1 >
\]

\[
< \delta^o_g \delta^s_2 > = < \delta^t_g \delta^t_g > + \epsilon_1 < \delta^s_1 \delta^s_2 > + \epsilon_2 < \delta^s_2 \delta^s_2 >
\]

\[
< \delta^o_g \delta^o_g > = < \delta^t_g \delta^t_g > + \epsilon_1^2 < \delta^s_1 \delta^s_1 > + 2\epsilon_1\epsilon_2 < \delta^s_2 \delta^s_1 > + \epsilon_2^2 < \delta^s_2 \delta^s_2 >
\]

We also need to take into account of all the covariances between systematics and across different band power

SH, Ross, Cuesta, Seo, White, Schlegel et al. (in prep)
Ross, SH, Cuesta et al. (2011)

\[ w(\theta) \times \theta \]

\[ \theta(\text{degrees}) \]

0.45 \leq z_{\text{phot}} \leq 0.5

0.5 \leq z_{\text{phot}} \leq 0.55

0.55 \leq z_{\text{phot}} \leq 0.6

0.6 \leq z_{\text{phot}} \leq 0.65

MegaZ, \ C_{\text{star}}

DR8, \ C_{\text{star}}

Ross, SH, Cuesta et al. (2011)
• **Systematics, systematics...**

• Cross-correlations with systematics can be very useful in not only detecting them, but also removing the systematics.

• Systematics can easily give spurious signals that mimic large scale power.

• The analysis shown earlier are mostly concentrated on the LRGs, but the systematics with quasars are fairly similar.
Conclusions

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$C_l^{gg} (\text{DATA})$
• For each of the redshift bin, we cross-correlates the Luminous Red Galaxies with themselves, and we get the angular power-spectra of the galaxies.

• But in order to derive cosmological constraints, we need to be able to predict the angular power-spectra given any cosmological models.

• That’s why: we need the theory:

\[
C_{l}^{gg} = \int dz \frac{H_0}{c} b^2(z) \left(\frac{dN}{dz}\right)^2 D^2(z) P\left(l + \frac{1}{2}, \chi \right)
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C^{gg}_{l}(\text{DATA}) = \int dz \frac{H_0}{c} b^2(z) \frac{dN}{dz}^2 D^2(z) P\left(\frac{l + \frac{1}{2}}{\chi}\right)
\]

Given a cosmological model, we can predict the theory, except we need two inputs: bias \( b(z) \) and redshift distribution \( \frac{dN}{dz} \).
SDSS III has been taking spectra of all of these photometric LRGs, therefore, we have an unbiased spectroscopic confirmation of the photometric redshifts for ~10% of the sample, therefore, we have very good understanding of the redshift distribution of the sample.
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We then only need to know bias, but since it only changes the overall amplitude of the angular power-spectrum.

We don’t need to worry about this for BAO.
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\[
C_{l}^{gg} \propto \frac{H_0}{c} b^2(z) \left( \frac{dN}{dz} \right)^2 D^2(z) P\left( \frac{l + \frac{1}{2}}{\chi} \right)
\]

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We don’t need to worry about this for BAO.
Overlap of the redshift bins

Ho, Ross, Seo, White, Schlegel et al. (in prep)
The Reason why BAO become so popular is that it is one of the cleanest probe of cosmology, since there are not that many systematics that can cause a shift in BAO scale (~100 Mpc).

Therefore, the systematics I am going through here are mostly for getting a clean angular power-spectrum which contains other information such as the shape of matter power-spectrum, scale dependent bias that can be caused by non-gaussianities at the early Universe.

\[
C_{l}^{gg}(\text{DATA}) = b^2 C_{l}^{\delta_m \delta_m} + C_{l}^{d,d} + C_{l}^{s,s} + C_{l}^{g(z),g(z')} + \ldots
\]

Dust Extinction: We cross-correlate the extinction map (SFD) with the galaxies to see if there is any correlations.

Stellar Contamination: We cross-correlate the stellar density maps (generated from SDSS) with the galaxies.

Color offsets: We compute cross-correlations between all of the photometric offsets (from Schlafly et al. 2010).

Galaxies from next photometric slice: We compute all the correlations between different redshift slices, and take into account of the covariances and correlations between different slices.
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- Dust Extinction
- Stellar Contamination
- Galaxies from next photometric slice

If we don’t take out the systematics, we won’t be able to trust the power-spectra until at least \( l > 40 \).
Remember? What we expect to see

![Graph showing BAO wiggles in the WMAP7 Templates]

- 

BAO wiggles
Physics of Angular Clustering

\[ b = \frac{\delta g}{\delta \rho} \]

describe how galaxies are related to cold dark matter

\[ \frac{dN}{dz} \]

describe how many galaxies are there at each dz bin

\[ D(z) \]

describe how matter grows

\[ \frac{l + \frac{1}{2}}{P\left(\frac{2}{\chi}\right)} \]

describe how matter clusters (matter powerspectrum, describes the rms fluctuations)

Galaxy angular power-spectrum

\[ C_{gg}^{l} = \int dz \frac{H_0}{c} b^2(z) \left(\frac{dN}{dz}\right)^2 D^2(z) P\left(\frac{l + \frac{1}{2}}{\chi}\right) \]
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Galaxy Angular power-spectrum contains a wealth of cosmological information ranging from

a) What is dark energy? to

b) What happened at the very early Universe? Inflation? What kind?
The effect of dust extinction

Ho, Seo, Ross, White, Schlegel et al. (in prep)