Large Scale Structure: Can we deliver what we promised?

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LSSTC and LSST-DESC
Large Scale Structure Working Group Chair

Presenting results also from work within Planck and SDSS3-BOSS collaboration

Snowmass meeting,
July 30th, 2013
What do we want to do with BOSS/eBOSS/DESI/LSST large scale structure data?
Main Science goals

- **Dark Energy:** Constraining the *expansion rate of the Universe* via *Baryon Acoustic Oscillations*

- **Ultimate test of non-gaussianities of the Universe?** After Planck, large scale surveys is our best chance in probing $f_{nl} \sim 1$ level non-gaussianities, we can do this with LSST!

- **Total Neutrino masses:** When combined with WMAP9, SDSS3 imaging data gives already a very stringent constraint of 0.26eV (95% CL)

- **Dark Matter:** We can probe *modified gravity* with *redshift space distortions*, and by combining with lensing, we can understand the bias of our tracers as a function of scale and redshift.
What are Baryon Acoustic Oscillations (BAO) anyway?

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These fluctuations of 1 part in $10^5$ gravitationally grow into...

Universe at 300,000 years old (CMB)

This sound wave can be used as a “standard ruler”
Dark energy changes this apparent ruler size

Courtesy slide from David Schlegel
and animation from Daniel Eisenstein
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These ~unity fluctuations today

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Clustering in 3D

Ghost Inflation/ Curvaton inflation

Standard Inflation

matter-radiation equality

BAO

bias ~ 2.5

bias ~ 1.5

$P(k) \propto (H/H_0)^3$
So we can do BAO in spectroscopic data like BOSS and SDSS!
AND we can do BAO in imaging data also (not only spectroscopic!)

\[ \Delta \chi^2 = 4.73 \]
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Padmanabhan et al. 2006
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Padmanabhan et al. 2006

$\alpha_{\text{wg}} = 1.066 \pm 0.048$

S. Ho, Cuesta, Seo, Ross, DePutter et al. (2012)
Seo, S.Ho, White et al. (2012)
AND we can do **BAO** in imaging data also (not only spectroscopic!)

This is what we expect if we have 4 times more volume, and in LSST, we have a lot more than 4 times volume in SDSS
So how do we do this Large Scale Structure measurement?
Observations:
flux(x,y,band/wavelength), observational systematics(x,y,band/wavelength): psf, sky, dust, airmass and respective errors

Basic Reduction pipeline

Extracted object, observational systematics properties

LSS systematics removal, statistics estimation

Large Scale Structure (BAO, full clustering measurements)

Theory, Beyond Linear Model Predictions

Simulations (possibly with DM simulations + HOD), Covariance Matrix

Cosmology (cosmological parameters, formation and evolution of galaxies, quasars...)

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The First Challenge

- Make the measurement
- Create the sample, and the selection function properly
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The samples you can gleam from the sky is not a fair sample of the Universe, but rather a real Universe convolved with all the lovely observational systematics.
Short summary:

Ross, SH, Cuesta et al. (2011)
Partial answers to The First Challenge

- Setting systematic weights for each galaxy, so that the effects of observational systematics are minimized (Ross, SH et al. 2011, Ross et al. 2012)

- Projecting out systematics by using systematic templates (Pullen & Hirata 2012, Slosar et al. 2013, Huterer et al. 2013)

- Cross-correlating observed densities with systematics to remove the effects of systematics on the over-densities (Myers et al. 2008, SH, Cuesta et al. 2012)

- Cross-correlating multiple redshift slices to detect unknown observational systematics (Agarwal, SH et al. 2013)
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Yes, the theory of large scale structure is non-trivial:

The Second Challenge:
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Observation:
redshift space galaxy correlation function
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What we can confidently predict:
real space dark matter correlation function
Solid lines: Linear Theory
Points: N-body simulations

Carlson, Reid and White 2012
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The Third Grand challenge

- In order to generate reliable covariance matrix of our measurements, the easy and dumbest thing to do is to simulate the whole observation many many times and see what is the variance across the simulations.
- But this can be very expensive for a large scale observation.
- Can we do better?
The Third Grand challenge

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- But this can be very expensive for a large scale observation such as LSST.

- The second and third challenge can in principle be solved by increased ability to generate synthetic Universes.
Generating Synthetic Universes

The generation of synthetic Universe usually separated into two steps:

- Creating Density field
  - Transformation of gaussian field (Coles 1992),
  - Perturbation theory like solution: PINNOCHIO (Monaco et al. 2002), 2LPT code (Scoccimaro & Sheth 2002), COLA (Tassev & Zaldarriaga 2013))

- Painting galaxies onto the density field
  - Semi-Analytical models (White 1978)
Other newer alternatives: Use Machine Learning to evolve the density field?

White: 2LPT
Blue: N-body
Very preliminary test: let’s compare the halos statistics
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If we can pass through all the challenges...
and there are more I didn’t mention...
for example: photo-z determination, bias modeling, potential BAO fitting systematics ...
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Robust Cosmological Constraints from LSS

WMAP7+HST+SN+DR8

SH, Cuesta, Seo, Ross, DePutter et al. (2012)

f_NL, local

SH, Myers, Slosar et al. (in prep)

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Cosmological Constraints from the overall shape

New preliminary constraints (3-sigma)
Constraints on early Universe via primordial non-gaussianities

Luminous Galaxies
Phot LRG (0.4)
Spec LRG
ISW
Quasars
QSO (b=1/D)
QSO alt $\chi^2$
QSO merger
Combined
Comb. merger
Comb. + W5 bi.
Merg. + W5 bi.

\[ \int N_{L,local} \]

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Imagine these being approximately 5-10 times better!

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