Large-Scale Structure: Next Frontier for Tests of Inflation

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Using publicly available NG maps by Elsner & Wandelt
Constraints from Planck

<table>
<thead>
<tr>
<th></th>
<th>ISW-lensing subtracted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KSW</td>
</tr>
<tr>
<td><strong>SMICA</strong></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>2.7 ± 5.8</td>
</tr>
<tr>
<td>Equilateral</td>
<td>-42 ± 75</td>
</tr>
<tr>
<td>Orthogonal</td>
<td>-25 ± 39</td>
</tr>
<tr>
<td><strong>NILC</strong></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>4.5 ± 5.8</td>
</tr>
<tr>
<td>Equilateral</td>
<td>-48 ± 76</td>
</tr>
<tr>
<td>Orthogonal</td>
<td>-53 ± 40</td>
</tr>
<tr>
<td><strong>SEVEM</strong></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>3.4 ± 5.9</td>
</tr>
<tr>
<td>Equilateral</td>
<td>-36 ± 76</td>
</tr>
<tr>
<td>Orthogonal</td>
<td>-14 ± 40</td>
</tr>
<tr>
<td><strong>C–R</strong></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>6.4 ± 6.0</td>
</tr>
<tr>
<td>Equilateral</td>
<td>-62 ± 79</td>
</tr>
<tr>
<td>Orthogonal</td>
<td>-57 ± 42</td>
</tr>
</tbody>
</table>
Constraints from Planck: modal expansion

\[ B(k_1, k_2, k_3) = \sum_{p,r,s} \alpha_{prs} q_p(k_1)q_r(k_2)q_s(k_3) \]
Current upper bound on NG is \(~1000\) times smaller than this:
<table>
<thead>
<tr>
<th></th>
<th>CMB</th>
<th>LSS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>dimension</strong></td>
<td>2D</td>
<td>3D</td>
</tr>
<tr>
<td><strong># modes</strong></td>
<td>$\propto l_{\text{max}}^2$</td>
<td>$\propto k_{\text{max}}^3$</td>
</tr>
<tr>
<td><strong>systematics &amp; selection func.</strong></td>
<td>relatively clean</td>
<td>relatively messy</td>
</tr>
<tr>
<td><strong>temporal evol.</strong></td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td><strong>can slice in</strong></td>
<td>$\lambda$ only</td>
<td>$\lambda, z, M, \text{bias...}$</td>
</tr>
</tbody>
</table>
Harvard-Cfa survey (1980s)
Dark Energy Survey (2013)
Dark Energy Survey (2013)

DESI (~2017)
Dark Energy Survey (2013)

DESI (~2017)

LSST (~2020)
Dark Energy Survey (2013)

DESI (~2017)

Euclid and WFIRST (~2025)

LSST (~2020)
Dark Energy Survey (2013)

21cm mapping

Euclid and WFIRST (~2025)

DESI (~2017)

LSST (~2020)
# of articles with “Non-Gaussian” in the title on the ADS data base

Produced by Emiliano Sefusatti
Large-Scale Structure in Three Easy Steps:
Step 1:  
Produce theory predictions  
(including from simulations)
Simulations with non-Gaussianity ($f_{NL}$)

- Same initial conditions, different $f_{NL}$
- Slice through a box in a simulation $N_{\text{part}}=512^3$, $L=800$ Mpc/h

- Under-dense region evolution decrease with $f_{NL}$
- Over-dense region evolution increase with $f_{NL}$

$\begin{align*}
 f_{NL} &= -5000 \\
 f_{NL} &= -500 \\
 f_{NL} &= 0 \\
 f_{NL} &= +500 \\
 f_{NL} &= +5000
\end{align*}$
...and now with baryons!

Zhao, Li, Shandera & Jeong, arXiv:1307.5051
Step 2:
Use multiple LSS probes in dataset
FIG. 11. Complete set of the two-point functions we use. The top row shows the CMB-galaxy correlation functions, while the remaining panels are the galaxy-galaxy correlations. Error bars are from 10,000 Monte Carlos, whose means are the red dashed lines, and the blue line is the standard \( \Omega_{\Lambda} \)CDM cosmology from WMAP7, with constant biases (not a fit to these data).

Address systematic concerns using the methods outlined in Refs. [53, 56]. However, we do not expect these issues to be correlated with other samples, and should be able to trust correlations between the quasars and other data sets. In particular, the quasars have a large overlap in redshift with the NVSS data. Potential SDSS systematics, such as airmass and seeing, are survey-specific and should thus have no correlation with NVSS data. In addition, we find no correlation with NVSS data and potential systematics (Galactic extinction, stellar density, synchrotron emission) that trace the structure of the Galaxy. Further, we trust correlations between the quasars and the LRGs, as the LRG sample has already proven to be robust to systematic fluctuations. Thus, while we do not consider the quasar ACF as a reliable probe of PNG, we will exploit the external correlations between the quasars and the other data sets. Also in this case, this includes the cross-correlation with the CMB, which for the same reasons should be relatively free from contamination, as also confirmed by its frequency independence shown in G12.

IV. MODELING THE DATA

A. Data Considered

We have discussed six different large-scale structure data sets, which yield six auto-correlations, fifteen cross-correlations and six correlations with the WMAP CMB temperature. Our final data set is shown in Fig. 11, including the galaxy-CMB cross-correlations and the Giannantonio et al. 2013 Using LSS (and CMB) tracers - correlation functions
From Fig. 3 it is clear that the CCF for the 2MASS quasar ACF alone.

Final constraints:

- LRG - CMB
- NVSS - CMB
- LRG - NVSS
- NVSS - HEAO
- NVSS - QSO
- LRG - LRG
- NVSS - NVSS
- QSO - QSO

Conservative
Fair
Fair + NVSS ACF
Naive
Covariance of weak lensing probes

<table>
<thead>
<tr>
<th>( \phi(S/N) )</th>
<th>( \omega(\theta) )</th>
<th>( \gamma_t(\theta) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear peaks</td>
<td>Shear 2-pt</td>
<td>Shear field</td>
</tr>
</tbody>
</table>

S. Marian, Smith et al. 2013

results from numerical simulations
Step 3: Control the Systematic Errors
Systematic errors

- Already a limiting factor in measurements
- Will definitely be limiting factor with Stage-IV quality data
- Quantity of interest: \((\text{true sys.} - \text{estimated sys.})\) difference
- **Self-calibration**: measuring systematics internally from survey
Example I: photometric redshift errors

\[ Z_{\text{phot}} - Z_{\text{spec}} \text{ from “training set”} \]

- \[ \sigma_{68} = 0.077 \]
- \[ \sigma = 0.128 \]

Requirements

- 50% error degradation

C. Cunha

Ma, Hu & Huterer 2006
Example II: LSS calibration errors

- dominate on large angular scales
- can be measured, removed using same or other data

Leistedt et al 2013
see also Ho et al 2012; Huterer et al 2013
Conclusion:

LSS has a lot to offer; *many* handles on both physics (NG/DM/DE) and systematics

Cunha, Huterer & Doré 2010